Chapter

The Beneficial Roles of *Pseudomonas* in Medicine, Industries, and Environment: A Review

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Abstract

This chapter intends to consider *Pseudomonas* versatility as regards the beneficial uses of *Pseudomonas* for production of primary metabolites including enzymes. This chapter will consider the use of *Pseudomonas* for production of secondary metabolites from various pathways which are equally useful in the industries and in medicine. *Pseudomonas* pigments and its usefulness in bioelectricity, medicine, etc. will equally be considered in this chapter. The authors are to integrate knowledge in versatility of *Pseudomonas* for use as agents of microbial production of biosurfactants for environmental cleanup, restoration, and remediation.

Keywords: pigments, enzymes, bioelectrochemical, bioremediation, medicine, industries

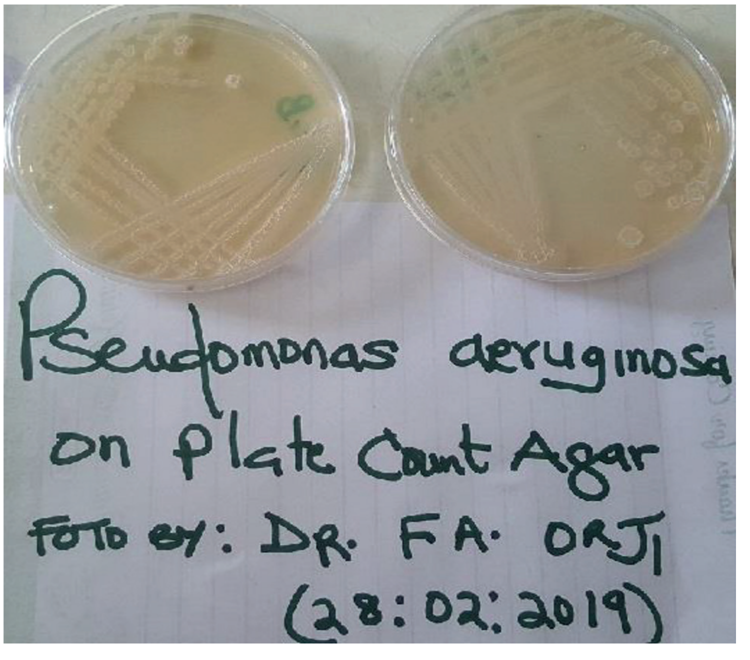
1. Introduction

Pseudomonas happens to be one of the most studied genera of prokaryotes (bacteria) and was first identified by Migula in 1894 at the end of the nineteenth century and described as Gram-negative, polar-flagellated, and rod-shaped bacteria. Thereafter the time of identification, the description of *Pseudomonas* has broadened; new methods have been developed to enhance the comprehensive study of the morphology and physiology of *Pseudomonas*. It is worthy to mention that the morphological features of these bacteria are common to several bacteria genera and are of little value in the positive identification of members of the genus (*Pseudomonas*). There are advanced nucleic acid-based methods that easily differentiate these bacteria from other similar genera, thus revealing the taxonomic relationships among various bacterial species including the genera *Pseudomonas*.

Pseudomonas is known to occupy a wide range of niches due to metabolic and physiological array. Their diversity enables *Pseudomonas* to adjust to exigent environmental conditions and withstand unfavorable conditions caused as a result of living and nonliving factors like oxygen, moisture, high and low temperature, etc.

The diversity of *Pseudomonas* determines wide research interest in this genus (*Pseudomonas*). *Pseudomonas aeruginosa* is ubiquitous in the environment (soil and water) and flourishes in individual with weakened or compromised immune system. The increasing resistance to multiple antibiotics makes these bacteria (*Pseudomonas aeruginosa*) virtually intractable once it colonizes the human host, and devastating effects can manifest.

Other species of *Pseudomonas aeruginosa* have the ability to degrade a large number of compounds that are recalcitrant to other bacterial species, thus producing secondary metabolites and biopolymers, making these strains useful in medicine, industries, and environment [1].



2. Beneficial roles of *Pseudomonas* species in medicine

Pseudomonas aeruginosa produces a wide range of compounds with bacteriostatic or bactericide activity, which are vital in the control of multiple drug-resistant (MDR) bacteria [2]. These compounds result from secondary metabolism and are referred to as secondary metabolites from various pathways including the polyketide and shikimic-chorismic acid pathways [3]. Studies have shown substances with antibacterial or antifungal activity secreted in the secondary metabolism of microorganisms could be applied in the management of human, animal, and plant diseases [4–6].

Pseudomonas aeruginosa strains produce compounds with antimicrobial properties, which include a group of peptides called pyocins and other heterocyclic compounds such as quinolines, phenylpyrroles, and phenazines [7]. These heterocyclic compounds eliminate microorganisms via DNA damage to cell depolarization in aiding the colonization of *Pseudomonas aeruginosa* [8].

Recent research has shown strain of *Pseudomonas aeruginosa* secreting an organometallic compound with inhibitory activity against MDR bacteria, including carbapenemase-producing *Klebsiella pneumoniae* and methicillin-resistant *Staphylococcus aureus* [9, 10]. Additionally, the same strain produced a phenazine-1-carboxylic acid (in low quantity) showing antifungal potential against *Botrytis cinerea* [11, 12].

2.1 Hydroxytyrosol from *Pseudomonas* for management of cardiovascular disease

Hydroxytyrosol, a phenylethanoid, is a molecule that has attracted high interests from the pharmaceutical industry due to its antimicrobial, anti-inflammatory, neuroprotection, antitumor, and chemomodulation effects and its role against cardiovascular diseases and metabolic syndrome. Interest in this molecule has led to a wide research on its biological activities, its valuable effects in humans, and how to synthetize new molecules from hydroxytyrosol. *Pseudomonas aeruginosa* has been reported to produce high yield of hydroxytyrosol by tyrosol into hydroxytyrosol via the immobilization of *Pseudomonas aeruginosa* resting cells in calcium alginate beads. The bioconversion yield reached 86% in the availability of 5 g L^{-1} of tyrosol when cells immobilized in alginate beads were carried out in single batches [13].

In addition, *Pseudomonas aeruginosa* strain 1001 produces an esterase (EstA) that has the ability to hydrolyse the racemic methyl ester of β-acetylthioisobutyrate to produce the (D)-enantiomer, which serves as a precursor of captopril. Captopril is an important drug in the management of congestive heart failure, hypertension, and diabetic nephropathy. This is achieved via the inhibition of angiotensin-converting enzyme [14].

3. Beneficial roles of *Pseudomonas* species in the industries

Pseudomonas aeruginosa has beneficial uses in various industrial and commercial sectors around the globe. These include waste degradation, oil refineries, textile products, agriculture, pulp and paper, mining, and explosive industries. They can also be used in commercial and household drain cleaners and degreasers, septic tank additives, general cleaning products, and odor control products.

Strains of *Pseudomonas aeruginosa* have been identified to play a vital role in the industries in the production of various compounds such as:

- Vanillin
- Rhamnolipids
- Protease
- Lipase
- Biopigments etc.

3.1 Vanillin synthesized by *Pseudomonas aeruginosa* for industrial application

It is one of the most important components of natural flavors; vanillin is broadly used in food, cosmetic, and pharmaceutical industries. Recent research reports the production of vanillin through microbial transformation using isoeugenol as a precursor by a novel strain of *Pseudomonas aeruginosa* ISPC2 isolated from the soil [15].

3.2 Rhamnolipids of *Pseudomonas aeruginosa* for industrial applications

Rhamnolipids are a class of glycolipid produced by *Pseudomonas aeruginosa*, among other organisms. They have a glycosyl head group, in this case a rhamnose moiety, and a 3-(hydroxyalkanoyloxy)alkanoic acid (HAA) fatty acid tail, such as

3-hydroxydecanoic acid [16–20]. Presently, rhamnolipids produced by *Pseudomonas aeruginosa* are the most essential class of biosurfactants, since the US Environmental Protection Agency has permitted their use in food products and other industrials applications. Rhamnolipids have been exploited by food industry particularly in increasing of food shelf life, considering to their high antimicrobial activity and physicochemical properties and also for emulsion stabilization, extends shelf life and inhibits hemophilic spores in Ultra-high temperature processing (UHT) soy-milk In combination with niacin [21]. A combination of niacin with rhamnolipids in salad extends its shelf life and inhibits the growth of mold. The shelf life in cottage cheese has been extended through the inhibition of mold and bacterial growth, especially Gram-positive and spore-forming bacteria. This has been achieved using a mixture of natamycin, nisin, and rhamnolipids. Consequently, these molecules and their mixtures are used to either eradicate food contamination directly, as food additive, or indirectly, as detergent formulation for cleaning surfaces that come in contact with the foods. Some other applications of rhamnolipids in the food industry especially in baking and confectioneries include promoting their dough or batter stability, volume and shape, structure, dough texture, width of the cut, and microbiological conservation [22]. In addition, they have been used to improve the properties of butter cream, nondairy cream filling for croissants, decoration cream and Danish pastries, and other fresh or frozen fine confectionery products [23]. Important food flavors are also synthesized from rhamnose which are gotten from rhamnolipids [24].

Furthermore, beyond the roles of rhamnolipids as agents that reduce surface and interfacial tension, they also have several other functions in food where they promote texture and shelf life of starch-containing products; regulate the agglomeration of fat globules; stabilize aerated systems; modify rheological properties of wheat dough; improve stability, consistency, and texture of oils and fat-based products; and inhibit separation. They aid in the general mixing of ingredients and can also retard the growth of molds and some bacteria in food. In ice cream and bakery formulations, rhamnolipids are also used to control consistency, retard staling, solubilize flavor oils, stabilize fats, and reduce spattering [25]. It has been demonstrated that rhamnolipids can be explored to control the attachment and to disrupt biofilms of individual and mixed cultures of the food-borne pathogens [26].

3.3 Industrial application of proteases from *Pseudomonas aeruginosa*

Pseudomonas aeruginosa is known to produce enzyme (proteases) with enzyme commission number (EC 3.4.21-24 and 3.4.99; peptidyl 3.4.21-24 and 3.4.99; peptidyl peptide hydrolases) which are applicable in industries that break down amino acids through the addition of water across peptide bonds and catalyze peptide synthesis in organic solvents and in solvents with low water content.

Proteolytic enzymes are largely found in all living organisms and are necessary for the growth of cells and cell differentiation [27]. *Pseudomonas aeruginosa discharges* extracellular protease making use of maltose as a major carbon source for the production, which has a maximum protease activity at pH 9.5, temperature of 37°C, and incubation time of 48 h [28].

3.4 Lipase from *Pseudomonas aeruginosa* for industrial applications

Lipases are glycerol ester hydrolases (EC 3.1.1.3) that hydrolyze ester linkages of glycerides at water-oil interface. Recent research shows that *Pseudomonas aeruginosa* are one of the best producers of lipase enzyme which have shown great potential with regard to their application in different sectors and industries [29]. The importance of microbial lipase production has increased in the last decades. Owing to their molecular structure and catalytic properties, these enzymes have specific biotechnological applications in various industrial sectors such as in cosmetology, environmental waste management, and foods, and specifically with regard to lipase, it acts as catalyst for synthesis of esters and for transesterification of the oil for the production of biodiesel [30].

3.5 Biopigments from *Pseudomonas aeruginosa* for industrial applications

The production of pigments by *Pseudomonas aeruginosa* strains as an area of research has been advanced over the years by different scholars. The various types of pigments produced by *Pseudomonas aeruginosa* are largely classed under the chemical name of phenazines. Phenazine compounds are of good biotechnological value. Apart from their possible uses as biopigments and coloring agents, they also function chemically as effective redox agents and can possess antimicrobial potentials. In current research, these redox-active agents have been heavily assessed for their potentials in acting as mediator compounds in bioelectrochemical applications. These bioelectrochemical applications can be channeled into the direct generation of electrical energy via instant electron harvesting from the cell surface of bacteria, as well as in the bioelectrochemically assisted remediation of harmful pesticides and chemicals and the potentials in the bioelectrochemically assisted fermentative production of certain commodity chemicals like butanol, ethanol, acetate, hydrogen gas, hydrogen peroxide, distilled water, and so on [31].

Phenazine pigments are naturally occurring heterocyclic compounds with varied chemical formula and pigmentations and are secreted mostly by *Pseudomonas* species. A good number of different structurally related phenazine compounds have being identified so far, totaling over 100. However, prominent among these phenazine pigments include chemical and color variants such as pyocyanin, pyoverdin, pyorubin, and pyomelanin. Most times, these pigments are produced by *Pseudomonas aeruginosa*; however a number of other *Pseudomonas* species produce similar chemical variants of these pigments [32]. A well-studied pigment for industrial application is pyocyanin. Pyocyanin with the chemical formula N-methyl-1-hydroxyphenazine is the pigment responsible for characteristic blue-green coloration of some *Pseudomonas* spp. It is a major molecule responsible for quorum sensing signaling for *Pseudomonas.* In Pharmacology, there are possible effects that pyocyanin can have on prokaryotic cells; such effects are linked to antimicrobiosis, and there is a related similarity in the chemical structure of flavins and flavoproteins as well as flavins adenine mono-/dinucleotide and isoalloxazine and flavin compounds in general. The bioactivity of the pigment situates it a worthy candidate as a biocontrol agent of other microbes. In light of this, various antimicrobial studies expounding on the bioactivity of pyocyanin-secretory strains of *P. aeruginosa* have been conducted.

Research exploits have traced microbial antagonistic activities of pyocyanin to be due to its redox activity in terms of univalent oxidoreductive ability as well as its ability to generate reactive oxygen species (ROS) and radicals of superoxide. This biomechanism is basically broad spectrum; however, extensive research has been embarked upon to enhance modes of delivery using nanotechnology and other important techniques, thus boosting its value for application [33]. In addition, the ROS generated by pyocyanin can be targeted against tumor cells, these cells are susceptible to pyocyanin-generated ROS as it basically interferes with some inherent intracellular eukaryotic cell functions like the activities of topoisomerase I and II.

An extensive industrial application of the electrochemical values of pyocyanin has also found applications in biosensor design and production. Pyocyanin is utilized as a redox compound for transporting electrons extracellularly between cells/test enzyme molecules and the material used as electrode. The application of such biosensor can be tailored for agriculture, environmental studies, and medical diagnostics.

In the textile industry, there is potential for the applications of phenazine pigments as textile colorants. This can be a way of reducing cost and increasing awareness on the sustainable use of natural products in industrial processes.

4. Contributions of *Pseudomonas aeruginosa* in the environment

A vast variety of synthetic chemicals have gained entrance into the ecosystem as a consequence of industrial activities, agricultural applications, and domestic usage which results to pollution in the environment. Furthermore, it is important to state that environmental pollution takes place when pollutants contaminate the surroundings, bringing about changes which adversely affect our normal lifestyles. This results in the incorporation of unwanted substances in the soil and water bodies due to anthropogenic activities. These pollutants are a result of oil spillage, herbicides, and pesticides. The use of herbicides and pesticides in soil ecosystem leads to the absorption of the nitrogen compounds into the soil. In response to this, nutrients might be available in the soil but not available to the plants.

4.1 Biodegradation of xenobiotics by various strains of *Pseudomonas aeruginosa*

Pesticides are organic compounds manufactured and used for the control of pests. They have great impact on human health and have active ingredient for the management and control of plant pests, insects and vermin [34]. An organochlorinated cyclodiene pesticide generally known as endosulfan (6,7,8,9,10,10-hexachloro-1,5,5a,6,9,9a-hexahydro-6,9-methano-2,4,3-benzodioxathiepine 3-oxide), currently in use around the globe for pest control in food and nonfood crops, has been classified under the category of persistent organic pollutant (POP). The solubility of endosulfan in water is significantly low, but it persists in the soil and water environment for more than 3 to 6 months. Endosulfan is pervasive and environmentally persistent; as a result the presence of endosulfan residues can be traced in surface water, groundwater, atmosphere, and water bodies. When these pesticides are released in the environment, they become pollutants, with ecological effects that require remediation. The consistent use and release of large quantities of pesticides either from accidental spills, direct application in agriculture, residues from cleaning of containers, faulty equipment, or inefficient methods used in the application of the products have led to huge environmental pollution and other attendant issues. Some of such issues include but not limited to changes in the nature of soils, groundwater, inland and coastal waters, and air [35, 36]. Biodegradation of toxic waste offers a promising strategy by which such chemicals may be detoxified [37] (**Figure 1**).

Soil microorganisms including *Pseudomonas* that are repeatedly exposed to pesticide may develop new capabilities to degrade such chemicals. Research studies have revealed that microbial degradation process to detoxify pesticide contaminations can be used effectively to overcome the pollution problems [38].

Pseudomonas aeruginosa play a vital role in the biodegradation and bioremediation of these toxic compounds found in soil and water by utilizing the pesticides as its carbon source and energy. Therefore *Pseudomonas aeruginosa* hold a lot of promises in the biodegradation of chemicals of environmental concerns into innocuous substances. In developed and developing countries, strains of *Pseudomonas*

Figure 1.
Pesticide transport pathways to surface and groundwater in agricultural landscapes (www.agro.basf.com).

aeruginosa have been extensively employed in ex situ remediation. Herbicides and pesticides impacted soil which constitutes hazards if allowed to circulate in the food web and chain.

4.2 The use of *Pseudomonas aeruginosa* in the biodegradation and bioremediation of petroleum hydrocarbons

Crude oil spills into marine (offshore) bodies or soil (onshore) environments are very toxic and dangerous to the ecosystem and could be detrimental to the well-being of life forms, air, water, and soil processes and could as well increase the potential of fire hazards [39]. Onshore spill of crude oil affects living forms in the habitat, reduces agricultural productivity, and pollutes groundwater and sources of potable water and living biota in flowing water bodies, among others [40]. Eliminating or limiting these adverse effects from crude oil spillage situations implies total prevention of the spillage where possible and amending the soil via the procedure known as bioremediation [41]. Some known methods used in remediating crude oil-polluted soils include physical separation, chemical degradation, photodegradation, and bioremediation [42]. However, bioremediation is gaining preference because of its comparative effectiveness, relatively lower costs, and eco-friendliness when compared to other techniques. Conversely, methods other than bioremediation used for oil-polluted soil remediation have shown potentials of leaving secondary metabolites, which are secondary residuals left after the primary crude oil pollutant has been removed [43]. These by-products can even exhibit higher toxicity levels than the parent crude oil pollutant. Fortunately, bioremediation technique usage detoxifies contaminants in crude oil and effectively removes pollutant by destroying them instead of transferring them to other medium [44].

Researchers have used plant species for bioremediation, in a process known as phytoremediation, but the deploying microorganisms as biologically mediated remediation of crude oil-polluted soil are still linked to the effectiveness of phytoremediation systems [45]. This is as result of the fact that microorganisms are still required in the rhizosphere of plants for efficient soil remediation via phytoremediation [58]. This makes the use of microorganisms for the remediation of soil polluted by crude oil spills of increasing interest to researchers and stakeholders involved in crude oil-polluted soil amendment. A good example of bacterial strains of microbes used in reported works for effective repair of crude oil-polluted soil is *Pseudomonas aeruginosa* [46]. In an attempt to degrade petroleum hydrocarbon, *Pseudomonas* will normally release biosurfactant which will reduce crude oil from high molecular weight to low molecular weight. This is to enable the bacteria to utilize the petroleum hydrocarbon [47].

4.3 Production of biosurfactants by *Pseudomonas aeruginosa*

Biosurfactants are a structurally diverse group of surface-active substances produced by microorganisms. The microorganisms that produce biosurfactants include *Pseudomonas*, *Bacillus*, *Micrococcus*, *Mycobacterium*, *Rhodococcus*, etc.

All biosurfactants are amphiphiles which consist of two parts: a polar (hydrophilic) moiety and nonpolar (hydrophobic) group [48].

The advantages of biosurfactants over chemically synthesized surfactants includes but not limited to; pH tolerance, less toxicity to the environment, biodegradability, better foaming properties, and them being able to be produced from agro-based industrial wastes [49].

Generally, biosurfactants have an ability to stabilize emulsions in various industrial applications [50] and are well-used in the food and pharmaceutical industries to achieve stability of emulsions. In addition, they have been applied in polluted water and soil during bioremediation in order to reduce interfacial tension, and it enhances the polar and nonpolar moieties to mix up.

Rhamnolipids are the major type of biosurfactant produced by *Pseudomonas aeruginosa* strain. Rhamnolipids are well-studied glycolipids secreted by *Pseudomonas aeruginosa* and have been found to have excellent surface activity [25] (**Figure 2**).

Incorporating rhamnolipids into remediation process enhances the solubility and elimination of these contaminants by improving oil biodegradations rates. Comparative study of biosurfactants for washing soil contaminated with crude oil was carried out where rhamnolipids showed a high degradable capacity; 80% of oil were degraded. Oil washing experiments by a combination of 10 g/l NaCl, 5.0 g/l n-butyl alcohol, and 2.0 g/l rhamnolipid provide very high oil extraction rates [52–54]. Even though rhamnolipids are the preferred enhancers for petroleum hydrocarbon soil pollutant degradation and have shown potentials to facilitate the bioremediation of soil contaminated by hydrocarbons, it has been suggested that their application must be evaluated carefully to reduce their exhibition on antimicrobial activity [55–57].

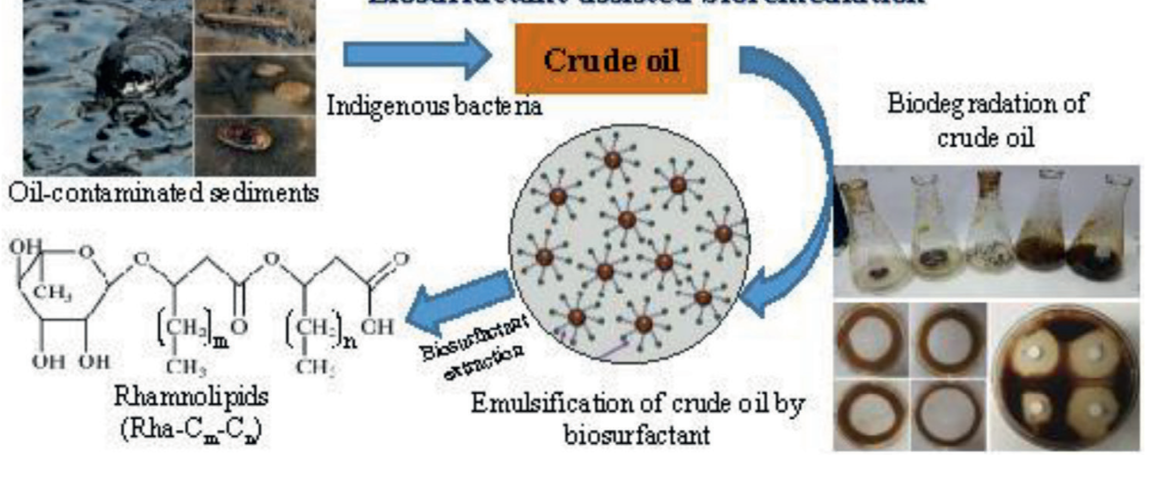


Figure 2.
Biosurfactant-assisted bioremediation of crude oil by indigenous bacteria. Isolated from Taean beach sediment [58].

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5. Conclusion

Basically, strains of *Pseudomonas aeruginosa* have been widely implicated as clinical pathogens both in humans and in veterinary cases. In addition, they have been identified to be the causative agents of wound sepsis, septicemia, and nosocomial infections.

However, this chapter took a different dimension toward the beneficial roles of *Pseudomonas aeruginosa* strains in medicine, industries, and environment. The hopes of a clean environment through biodegradation of xenobiotics and bioremediation of hydrocarbon-impacted ecosystems are high with the use of *Pseudomonas aeruginosa*. In the industries, *Pseudomonas aeruginosa* holds a lot of practical promises toward production of intermediate products including metabolites such as rhamnolipids, vanillins, lipases, biopigments, etc.

Typically, in Nigeria and other developing countries, most of these materials from *Pseudomonas aeruginosa* are imported, and this does not encourage growth and development. Thus, local production of these intermediate products from *Pseudomonas aeruginosa* is adequate to save foreign reserves and promote development.

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