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THE POTENTIAL USE OF BACTERIA FOR THE BIODEGRADATION OF PLASTIC WASTES

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ABSTRACT

In this paper, the study focuses on the analysis of [1] the potentiality of plastic-eating bacteria as a leading solution to the severe problem of waste management that results in Global Warming by which plastics are one of the most significant contributors, and [2] its types, species, and effectiveness on different kinds of polymers.

Petrochemical-based plastics, also known as just conventional plastics, are composed of long-chain molecules called polymers. Polymers are primarily non-biodegradable, meaning they cannot be broken down naturally. Their chemical structure is highly complex and does not resemble any of the natural organic compounds that microbes evolved to break down, providing them far greater resistance to natural breakdown. By then, the mass production of plastics for specific industrial applications branched out, which has a radically dominant usage, including providing protection, safety, and increased usability.

Researchers have discovered that certain microorganisms have the properties and characteristics of being biodegradable. This study focuses on identifying and characterizing enzymes and metabolic pathways used by these microorganisms to degrade plastic, which could be used to improve the efficiency of plastic degradation on a larger scale and to develop new biotechnology applications.

Evaluating the effectiveness and feasibility of using plastic-eating bacteria for biodegradation to establish the optimal environments for bacterial growth and plastic decomposition, as well as the limitations and challenges. This research can be carried out through laboratory experiments and field studies in which the development and activity of these bacteria are monitored and evaluated under dynamic parameters. Furthermore, the investigation is recommended to analyze this approach's economic sustainability and scalability, including the cost of developing and utilizing these microorganisms and the potential for growing international commercialization.

INTRODUCTION

Amid the progressive industrial revolution, synthetic plastics manufacturing was plumped up for a broader-scale production used for industrial applications in the 1950s, paving its way to unimaginable mass production. There are several distinctive properties of plastics, such as low cost (Balakrishnan & Sreekala, 2017), lightweight (Francis et al., 2017), flexibility, durability (Callister,2016), strength, user-friendly design, and fabrication capabilities (Balakrishnan & Sreekala, 2017), leading them to become conventionally utilized over other materials in many fields and become ubiquitous in modern society. Worldwide plastic production has hovered around 30 million metric tons (Mr.McGuire, 1967) since its inception. In 2016, global production had drastically transcended tenfold to 335 million metric tons. However, if current trends precede, the annual production will likely surpass 12 billion metric tons by 2050.

Petrochemical-based plastics, also known as conventional plastics, are composed of long-chain molecules known as polymers that are 'mostly' non-biodegradable, meaning they cannot be broken down naturally. Generally, their chemical structure is exceedingly complex and does not resemble any of the natural organic compounds that microbes evolved to break down, providing them far more resistance to natural breakdown processes, including weathering, UV radiation, and oxidation. The biodegradation rate of petrochemical-based plastics is substantially influenced by external factors such as

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plastic-type, environmental conditions, and biodegradation rate (Signh & Sharma, 2008). Although plastics have become a necessity, their massive production volume has outgrown most artificial materials and has been under environmental scrutiny.

In 2019, the packaging industry surged 40% of the industrial sector, which is radically dominant in terms of utilization, including providing protection, safety, and greater usability. On the other hand, 16% contributes towards building and construction, illustrating that the fundamental properties of plastic are compatible with construction materials. Using certain traditional processes, such as landfilling and incineration, may result in similar environmental degradation, and they may also be far more expensive to handle (Krueger et al., 2015; Song et al., 1998). Furthermore, current trends toward the production of biodegradable plastic have resulted in a reduction in environmental contamination caused by plastic discharged into the environment. (Ioakeimidis et al., 2016; Shimao, 2001)

Several researchers have discovered various microorganisms with biodegradable characteristics in plastic. Considering their growth settings, certain bacteria are specialized to destroy chemically and structurally matched polymers. Through vast breakthroughs, several species of plastic-eating microbes that are superficially effective in breaking down non-biodegradable plastics, such as the genus Pseudomonas putida (Nikel & De Lorenzo, 2018), can degrade polyethylene (PE), Stenotrophomonas panacihumi (Jeon & Kim, 2016) can degrade polypropylene (PP), Pseudomonas otitidis, Acanthopleuribacter pedis, Bacillus cereus (Anwar et al., 2016) can degrade polyvinyl chloride (PVC), Rhodococcus ruber (Mor & Sivan, 2008) polystyrene (PS), and Thermobifida fusca (Müller et al., 2005), Thermobifida halotolerans (Ribitsch et al., 2012), Thermomonospora curvata (Wei et al., 2014), Saccharomonospora viridis (Kawai et al., 2014), Comamonas testosterone F6 (Gong et al., 2018), Streptomyces species (Farzi et al., 2019), Nocardia species (Sharon & Sharon, 2012), and Ideonella sakaiensis 201-F6 (Yoshida et al., 2016) polyethylene terephthalate (PET), the most widely used in large-scale. Through the biodegradation process, the plastic-eating bacteria release enzymes called plasticizers. These enzymes can break down the plastic polymer's chemical bonds and then convert them into smaller molecules, which can be utilized as their source of energy and nutrients.

This research on plastic-eating bacteria has primarily focused on identifying and characterizing enzymes and metabolic pathways used by these microorganisms to degrade plastic, which could be used to improve the efficiency of plastic degradation on a larger scale and to develop new biotechnology applications, such as bioremediation and bioplastic production. Given the circumstances of plastic pollution, bioremediation must be scaled up for industrial and environmental purposes, vastly clearing up large-scale contaminated regions. Additionally, this diminishes the fabrication of virgin plastics, which may be recycled to manufacture new plastic products.

The most well-known and widely studied plastic-eating bacteria is a strain of Ideonella sakaiensis, which has been proven to be superior at breaking down PET plastics, which are the most largely unusable, at temperatures between 30 degrees and 50 degrees Celsius and a range of pH levels. This robustly can keep up as its enzyme, named PETase, was found to break down PET up to 20 times faster than a naturally occurring enzyme found in bacteria.

Scaling up its utilization tends to be challenging, such as limited availability, slow degradation rate, and scalability. These are promisingly a magical silver bullet solution, optimizing its role in mitigating plastic solution way more efficiently.

OBJECTIVES

The main focus of this paper is projected to be the investigation of the potentiality of plastic-eating bacteria as a solution to the problem of waste management. Moreover, the primary purpose of this paper is solely to pursue these objectives:

1.) Define and give a detailed overview of a plastic-eating bacteria.
2.) To differentiate and highlight the degrading mechanisms among various microorganisms capable of decomposing petrochemical-based polymers.
3.) Substantiate the use of plastic-eating bacteria as a potential solution to the serious problem in waste management.

METHODOLOGIES

In this study, the researchers used a systematic literature review approach to investigate research questions. The approach involves identifying, evaluating, selecting, and combining relevant research evidence and arguments related to the research questions. The systematic aspect of this method refers to the fact that a consistent design is followed and the process is clearly communicated. In essence, a systematic literature review is a study of existing research, using the same methods as those used in primary research studies.

Google Scholar, a well-known search engine, was the main resource used in this analysis to find pertinent research. The reason the researchers selected it is that it has reliable and pertinent educational research repositories. The initial search results yielded more than 100 potentially relevant papers using at least two combinations of the chosen keywords, with the keywords being "Plastic eating bacteria," "biodegradation," ”synthetic plastics,” and "plastic pollution." The dataset was constructed by applying predefined criteria to find studies on the bacterial biological degradation of synthetic petroleum-based polymers. The articles employ a comprehensive approach, including an updated list of all previously identified bacteria assumed to degrade synthetic plastics, determining and defining the best methods for assessing biodegradation, critically evaluating previous studies, and proposing future research directions on polymer biodegradation to support better development of biodegradation technologies.

RESULTS AND DISCUSSION

In 1988, the first introductory concept of degrading microbial bacteria was first reported in a scientific study, which found that a strain of bacteria called Pseudomonas aeruginosa can degrade polyethylene, a prevalent type of plastic. As the years have progressed, multiple other strains of bacteria have been thoroughly found to have the ability to depolymerize synthetic plastics.

On the verge of vast progressive breakthroughs, several factors implicate the exponential evolution of plastic-eating bacteria. First, one of the factors is natural selection. This has been a critical process by which it firmly supports the bacteria's environmental adaptation, affecting their longevity and high spontaneous reproduction rates under such harsh environments. The objective of driven variation is to extract the microorganisms' potential to the utmost degree, acting as the best filter to select the most advantageous traits. Furthermore, protein engineering modifications of enzymes tend to modify bacteria's genetic code to make proteins with newly enhanced functionalities, enhancing the stability, specificity, or activity of these enzymes and making it more straightforward for the bacteria to disintegrate plastic. This biocatalyst intends to promote in a much more structured and sustainable way without using hazardous chemicals or producing unwanted byproducts. This thrivingly increases bacterial evolution rather than natural evolution since the alterations made to the bacterium's genetic sequence are more thoroughly and precisely controlled, providing the bacteria with more excellent, efficient, and effective plastic breakdown capabilities. Additionally, the environment exasperates selection pressure. Amidst worsening environmental degradation, technological application for the constructive development of a new diverse selection of strains of plastic-eating bacteria serves as a band-aid solution for large-scale bioremediation by becoming increasingly well-adapted to degrading plastic and leveraging it as a food source.

Different biodegradation processes have been classified based on how plastic polymers are addressed systematically. This process is frequently a mix of enzymes generated by bacteria and general mechanisms. Adsorption is a method through which bacteria attach to the surface of the plastic and form a biofilm. This is a crucial phase in plastic biodegradation because it allows bacteria to carry out their metabolic activities and break down the plastic. A biofilm is a complex community of bacteria protected from environmental stresses by a protective matrix of extracellular polymeric substances (EPS). Furthermore, monomer utilization facilitates the breakdown of plastic waste into much smaller units of biodegradable polymers such as monomers. Bacteria can transform plastic into biomass and metabolic products by breaking it down into its constituent monomers, providing a sustainable waste management alternative. It may also be utilized as a feedstock for manufacturing new plastic, filling the loop in the plastic cycle.

PET may be biodegraded by some bacterial isolates, including Pseudomonas fluorescens and Sphingomonas, by breaking down its monomers into simple molecules. PET plastic biodegradation usually begins with bacteria creating enzymes that break down the plastic into smaller fragments, allowing the bacteria to access and consume the plastic more effectively. PE (Polyethylene) and PP (polypropylene) are also commonly biodegraded by bacteria but slightly slower than PET biodegradation. These plastics are made up of shorter monomer chains and are more resistant to degradation than PET. Certain bacteria species, such as Alcaligenes faecalis and Comamonas testosteroni, can biodegrade PE and PP.

Most petro-plastics cannot be degraded by certain species of plastic-eating bacteria, although some studies have found that almost all synthetic plastics can be microbiologically degraded. For instance, polyvinyl chloride is highly resistant to degradation, which can be degraded by Pseudomonas otitidis, Acanthopleuribacter pedic and Bacillus cereus (Anwar et al., 2016). However, further adaptive study and development are needed to optimally enhance the pace and amount of gradual deterioration.

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Ideonella sakaiensis bacteria have the potential to substantially reduce plastic waste pollution since they can absorb polyethylene terephthalate (PET), the significant component of plastic, in just six weeks. This hydrolyzes PET using two enzymes and a significant chemical intermediary to produce the essential building blocks for development. These bacteria can produce safety secretions from PET, which they also require for metabolism. Nevertheless, these bacteria have a limited range of environments. The DNA of Ideonella sakaiensis may be changed using genetic engineering techniques to add genes from Azotobacter sp., allowing them to grow in habitats such as soil and water where there is typically much plastic debris. Since it removes the location-based barrier on Ideonella sakaiensis, this combination is predicted to optimize the bacteria's potential. Consequently, it is feasible to sufficiently deal with the problem of plastic waste without damaging the environment, bringing sustainability to both nature and human life.

Through the analysis of genomic data obtained directly from an environmental sample, metagenomics enables the study of all microorganisms, regardless of whether they can be cultured. It explicitly shows the study of microbes in their natural habitat, which includes the intricate microbial communities in which they often dwell. It enables species identification and knowledge extraction regarding the functioning of microbial communities in their natural setting. After metagenomics, DNA has been cloned and expressed in a heterologous host, and function-based screenings can be used to find novel proteins of industrial interest encoded by the genes of previously inaccessible microbes.

It is best to conduct a metagenomic study of the microbial population involved in plastic biodegradation to determine the composition of the microbial community and predict the capability of in-site biodegradation advancements in sequencing technology and bioinformatics analysis has helped to accelerate metagenome screening. It enhances the identification of the broad microbial population and allows the mining of polymer degradation genes or enzymes. The discovery of new plastic-degrading enzymes increasingly relies on a culture-independent technique, such as metagenomics.

Furthermore, there are underlying pre-treatment strategies for raising the surface area poised to be destroyed by enhancing the catalytic activity of plastic-eating bacteria. The first is shredding, which refers to small fragments of shredded plastic particles. It allows bacteria to disintegrate in a single location, which makes it simpler to decompose. Second, the ultrasonic treatment utilizes high-frequency sound waves to break the plastic into smaller fragments, allowing the bacteria's enzyme to destroy it over a greater surface area. It induces mechanical stress in the solution, which disrupts the structure of the plastic and improves the mixing and mass transfer of the bacteria and plastic, hence accelerating the breakdown rate. Third, chemical treatment can weaken plastic bonds, exposing and emulsifying the plastic in an acid. Ultimately, heat treatment acts as a critical instrument in maximizing the breakdown of plastics, but heat treatment settings must be closely regulated to inhibit any detrimental effects on bacteria. These pre-treatment techniques broaden and scale up the effectiveness of biodegradation, making it a far more viable solution to waste management.

Several potential applications need to be applied in industry and environmental management. In the industrial aspect, additives can be added to the plastic during manufacturing to improve its properties, such as making it more durable and flame-resistant. However, some additives can also make the plastic more resistant to degradation by bacteria.

On the other hand, some additives can boost the degradation of plastic-eating bacteria. For instance, the addition of nutrients such as nitrogen and phosphorus can provide the bacteria with the energy and building blocks they need. Also, adding surfactants, compounds that reduce the surface tension of liquids can increase the efficiency of plastic degradation. Yet, additives' impact is complex and depends on the plastic, bacteria, and additives' specific properties.

Given the worsening and deteriorating plastic pollution, bioremediation on a large scale is viewed as one of the environmental measures. It is a natural and sustainable technique that relies on microorganisms' biological activity. Compared to alternatives, more energy-intensive processes, such as mechanical and chemical treatments, make it more ecologically friendly. It also degrades plastic trash into smaller, biodegradable components, minimizing its environmental effect and assisting in the cleanup of contaminated areas. Furthermore, when compared to alternative waste management and environmental remediation techniques, it might be a cost-effective solution. Eventually, it may be integrated with other treatments, such as heat and chemical treatment, to increase process efficiency and degradation.

Plastic pollution is one of today's most pressing environmental problems, and its influence escalates daily. It is critical to address the growing plastic pollution problem to offset its detrimental impacts and ensure a cleaner, healthier, and more sustainable future. This necessitates a multifaceted strategy that entails lowering plastic production and usage, improving waste management methods, and investing in alternative material research and development. Besides, increasing public awareness of the problem and promoting individual actions such as limiting plastic usage and adequately disposing of plastic waste will help lessen the impact of plastic pollution and safeguard the environment for future generations.

CONCLUSION

This research intended to broadly emphasize the all-inclusive importance of plastic-eating bacteria, destabilizing the different prevalences of synthetic plastic pollution. The general mechanisms of plastic-eating bacteria involve the depolymerization of plastic polymers into smaller biodegradable components. Different plastic-eating bacteria are specifically designated into specific types of plastics since not all types of plastic can be degraded by bacteria, as some plastics have biochemical and structural characteristics resistant to degradation. This unequivocally unveils their diversity for the potential for biotechnology to play a role in addressing the plastic waste problem through natural selection. The adoption of metagenomics, which is bound to delve into an analysis of both culturable and unculturable microorganisms, will contribute to finding bacteria and biocatalysts with the potential for plastic biodegradation.

Through propagation in the production of innovative plastic polymers with enhanced biodegradability, the design of microbial cell factories with better breakdown efficiency under different conditions, and the modification of enzymes through protein engineering. Furthermore, the vast implementation of such pre-treatment techniques and additives that affect the microbial breakdown of synthetic polymers is essential since it tends to provide the energy and building blocks they need and increase the surface area of the plastic, making it more accessible for the bacteria to degrade. A further thorough study in this sector is anticipated to eventually evolve into viable bioremediation that can be established on a vast scale, given the unending capacity of bacteria and their continuing versatility in a dynamic environment. Thus, more study is needed to evaluate a wide range of suitable alternatives capable of degrading non-biodegradable plastics.

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