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Potential Solution to the Plastic Plague

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ABSTRACT

In the past 117 years since the first plastic was created, the advancements leading up to today were very significant and beneficial for humanity, however, at the expense of our environment. Two probable solutions to plastic pollution are discussed in this paper: microorganisms and nanoparticles (NPs). Microorganisms essentially use three steps to degrade plastic, first they attach to the polymer, then use it as the carbon source, finally degrading the polymer. Aerobic and anaerobic biodegradation are two different types of methods that microorganisms use; this leads to a difference in products when polymers are degraded. Aerobic biodegradation generally has products like carbon dioxide (CO_2) and water (H_2O), while anaerobic has a very large variety of different compounds. Three bacteria were found to be the most efficient, *Bacillus subtilis* ATCC 21332, *Comamonas acidovorans* TB-35, and *Gloeophyllum trabeum*. Between the two methods of plastic degradation, microorganisms are natural with less potentially harmful byproducts during the process of biodegradation. However, microorganisms are slower to degrade compared to NPs, as they use living bacteria. NPs use different coatings to enhance their process of plastic degradation, helping with the process of chemical reactions to degrade the polymer. Titania Nanoparticles (TiO2 NPs) and Silver Nanoparticles (Ag NPs) were found to be among the most efficient with 68% to 200 hours and 64.5% to 840 hours, respectively. NPs is a better solution to invest in than microorganisms as it is faster and more efficient, with more research the harmful byproducts may be mitigated.

Introduction

Plastic pollution has always been at the forefront of problems ever since its creation; however, it is just now in the 21st century that many have realized just how prevalent the problem of plastic truly is. Although plastic has helped human civilization tremendously, the current and lasting effects of plastic cannot be ignored. Various health concerns regarding micro/nano plastic cause problems such as thyroid dysfunction, obesity, diabetes, and reproductive impairment (Ofondu et al., 2021). Including the health concerns of plastic, the act of recycling plastic "truthfully" has not been entirely helpful to decrease the amount of plastic waste. Ray and others further discuss that in the U.S. what plastic that was supposed to be recycled ended up being dumped illegally into the environment. The rest of the plastic being shipped off somewhere that did not actually get recycled, only to be burnt or left on the landfill sites (Ofondu et al., 2021). The two most important actions to help control plastic waste in the world would be to understand the health concerns for the environment and reach a solution to recycling or mitigating the plastic the world produces.

Although a permanent way to get rid of plastic is not yet available, there have been many other experiments to, at the very least, research and shorten the time for plastic degradation. Such an example is the presence of microorganisms, according to a 2021 study from Nara Institute of Science and Technology in Japan, *Penicillium simplicissimum* YK, a fungus, was used for the biodegradation of polyethylene. It was found that polyethylene with a molecular weight higher than 100,000 was degraded by the fungus to a lower molecular weight with the use of hot nitric for the only carbon source. As proved in the study, microorganisms can degrade plastic to a certain length given the time, although the efficiency still needs to be studied further. In a similar study also from Japan, the Kyoto Institute of Technology in 2016, Shosuke Yoshida and his team isolated a bacterium, *Ideonella sakaiensis*. They discovered the bacterium being capable of using the PET (polyethylene terephthalate) as its energy and carbon source. The two enzymes discovered were responsible for breaking down PETs and converting them into energy for the bacterium. As depicted in the study it is possible to further develop enhanced methods for biodegrading PETs based on the bacturim discovered. In a study that took place at the University of Messina in Italy, researchers investigated the potential of Antarctic marine bacteria, *Arthrobacter, Pseudoalteromonas, and Psychrobacter* in degrading PCBs (polychlorinated biphenyls). They found that certain cold-adapted bacteria from Antarctic seawater could partially degrade polyethylene at low temperatures (Michaud et al., 2007). The results of the study suggest that these microorganisms have adapted to the extreme cold and possess the metabolic capability to break down plastic, making them have potential for bacteria that can break down the plastic in our environments. It can be considered that microorganisms are one of the most promising solutions shown thus far.

In the United States of America, a study was conducted at Reed College in Oregon to find if a certain bacteria can be used to reduce the number of PETs. According to their study in the *ASM Journals* Roberts and his team used two different bacteria species, *Pseudomonas and Bacillus*. It was concluded that these two bacteria strains grew synergistically in the presence of PET; effectively using the PET into its own parts and fuel; it was also noted that the byproducts of the PET waste could be used into useful materials for environmental stability (Roberts et al., 2020).

According to the study conducted by Brandon and others in the state of California, the mealworms (*Tenebrio* and *molitor*) possess the ability to degrade polyethylene within their gut. The process involves enzymes produced by gut bacteria that break down these plastics into smaller molecules, which are then used by the mealworm for food or to break it down even further (Brandon et al., 2018). The research can enable the potential biological solution to plastic pollution, utilizing insects and their associated microbes to degrade common plastic types.

Given the escalating issue of plastic pollution and its severe environmental impact, it is important to explore and use the potential of plastic-degrading bacteria. Identifying and utilizing these microorganisms can significantly reduce plastic waste and help its adverse effects on the environment. By using these bacteria to develop future strategies for the management of plastic waste, we can accelerate the degradation process. Additionally exploring the use of NPs (nanoparticles) along with comparing them to the efficiency of microorganisms to determine a direction of investment allows better study of new methods for managing pollution.

Methodology

The primary purpose and goal of this study was to determine if microorganisms or plastic eating bacteria and NPs could be a viable solution to lower the amount of plastic waste output by humans. The type of research conducted was a second literature review based on numerous primary sources and informational articles accessed via ScienceDirect, google scholar, and other web pages that included peer reviewed scientific papers. A qualitative method of analysis was used in this research paper to understand the effect of plastic pollution and the use of fungi/microorganisms and NPs can be a major solution to solve one of the world's biggest problems. The steps taken to carry out this method of analysis were the use of analyzing many different research papers to determine which bacteria and how much plastic is being eaten; what NPs were used and how much plastic was degraded. Then, there were conclusions made regarding the practical use of these microorganisms or NPs on a global scale, including the consideration of waste or byproducts these bacteria and NPs produce. Further, research was also conducted to determine if the costs to continue developing the fungi/NPs was practical on said global scale, including the impact and effects if such a development were to happen. No physical tools or materials were used in this research paper, instead many different contemporary literatures were utilized to obtain modern data. Research bias was mitigated by using different journals and articles all over the world, such as international, national, regional etc. to ensure varying perspectives.

Current Problems of Plastic on the Environment and Human Health

Plastic pollution has become a significant environmental and health concern in the 21st century. The proliferation of plastic waste has led to various adverse effects on ecosystems and human health. The major issue is the persistence of plastic in the environment, which can last for hundreds to thousands of years due to its resistance to degradation. The following section information will be about marine and animal life when affected with the presence of microplastics and the effect of plastic on different aspects of human organs, lungs, blood, and placenta.

Currently, microplastics (MP) are generally very difficult to analyze due to their small nature, however much of the marine life that consumes very little amount for food like amphipods, barnacles, and lugworms can consume these microplastics. Mussels ingest microscopic amounts of food, as such the very small number of plastic particles present in their environment make their way to the mussels' diet, making it the ideal subject to test the effects of microplastics. When injected, the microplastics travel from the gut and into the circulatory system, after 48 days the microplastics are still present. The outcome was prolonged microplastic in the mussels' gut, as the laboratory only monitored the plastic for 48 days with a single digestion, in real world scenarios, mussels and other marine life will be exposed to microplastic over a lifetime. As a result, microplastics accumulate in the tissues of the mussels, raising concerns about potential impacts on marine life and food safety for humans consuming seafood. Consequently, the prolonged microplastic in any marine life can lead to cellular damage, once these microplastics get through to the circulatory system, the connective tissues of the animal's major organs will be heavily damaged (Browne et al., 2008). As we know that much of our consumption includes seafood, knowing that our marine life could potentially have harmful microplastics is important. However, it is also imperative to discuss how land animals, the other foods of human consumption are affected because of the growing number of microplastics. Since we need to examine if microplastics are truly present in the animals, samples of manure and feed were collected from 19 different farms and 3 different species, 50g of manure was collected total. 115 microplastics from manure and 18 from the feed were discovered after much analysis (Wu et al., 2021). As a result, all these microplastics in the manure and feed prove the issues with plastic in the environment, as such we can say that the microplastics are in the digestive systems of these animals. Previously we knew microplastics can travel from the gut to the circulatory system and stay inside the tissue of marine life (Browne et al., 2008) it is not unreasonable to say the food, in this case the animals with microplastics, can end up inside our bodies. Moreover not only could the immune system of the animals be harmed, but because of the identified microplastics in the manure and being used as fertilizer, the soil as well may be affected. Consequently, the contaminated soil also affects our crops and the humans that consume said crop. A visual representation of the cycle can be viewed in figure 1, showing how plastic waste ends up as microplastics and becomes a part of our diet.

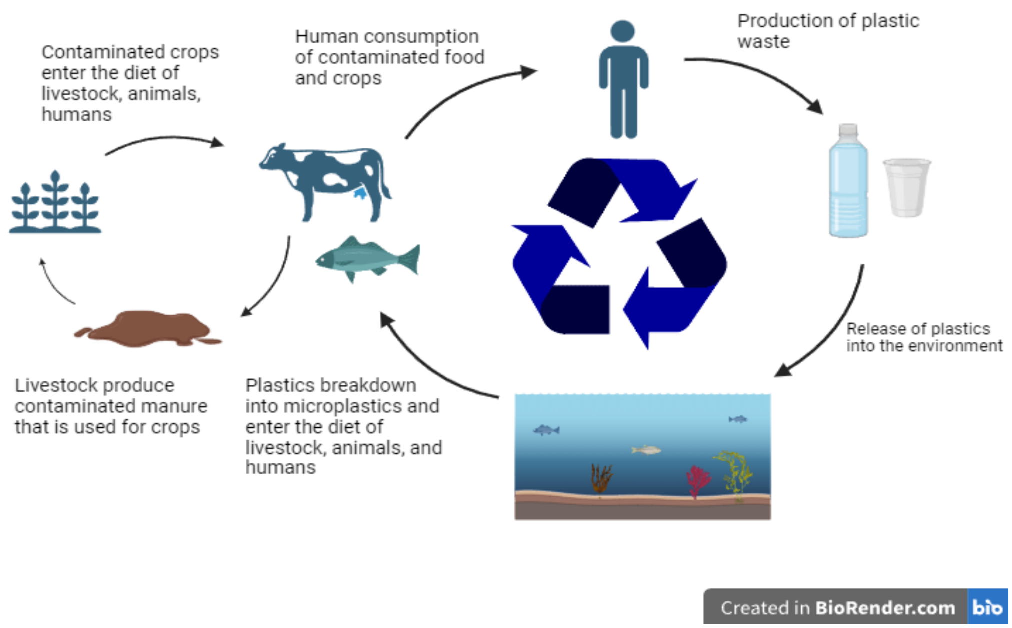

Figure 1. Graphical Representation: This graphic was created in bio render showcasing the cycle of plastics from production to environment and ending up in our diet. First as humans produce plastic it gets into our environments as previously discussed, within those environments the plastics breakdown and turn into microplastics. Microplastics then end up in the diet of various livestock and animals, finally ending up in humans, which causes many kinds of health problems. Additionally, the microplastics in the manure that the livestock produce also contaminates the crops, which again becomes a part of the diet for humans and animals alike. Source: Sangha, 2024

The effect of microplastics on human health is just as important as the effect on the environment. According to a different study the research examined the presence of microplastics in human lung tissue, confirming that these particles can be inhaled and accumulate in the lungs. The research identified several types of microplastics in lung tissue, some including Polypropylene, polyethylene, polyamide, polyurethane etc. These microplastics were found in a variety of shapes, including fibers and fragments. As a result the presence of these particles in the presence of microplastics in the lung tissue could contribute to respiratory conditions such as chronic inflammation, fibrosis, or even exacerbate conditions like asthma and chronic obstructive pulmonary disease (COPD) although more decisive research over a longer period of time is needed, the presence of microplastics in the lungs itself is enough to determine that abnormal effects are bound to happen (Lourenço et al., 2021).

Another aspect to focus on human health including the lungs is the blood, after blood samples were collected from 22 healthy volunteers and were analyzed. The study identified four high-production-volume polymers: polyethylene terephthalate (PET), polyethylene (PE), polymers of styrene (including polystyrene and others), and polymethyl methacrylate (PMMA). Polypropylene (PP) was also analyzed but was mostly below quantifiable limits. Those microplastics were found to have a mean sum concentration of quantifiable plastic particles in blood was found to be 1.6 µg/ml in other words, 1.6 plastic particles were in every ml of blood, a very significant amount. As such, it demonstrated that plastic particles could enter the human bloodstream, indicating bioavailability and potential health implication, raising concerns about the exposure and health risks associated with plastic particle pollution, due to the plastics in the blood there may be potentially affects of immune regulation and other diseases (Leslie et al., 2022).

The placenta is a very important organ for the fetus during pregnancy since it provides oxygen and nutrients to the developing baby. After analyzing six human placentas obtained from women with normal pregnancies and identifying/characterizing microplastic fragments smaller than 5 µm it was found twelve microplastic particles were found across the placentas of four out of the six women studied. Specifically, three particles were identified as polypropylene, a common thermoplastic polymer used in various applications such as packaging and textiles. These microplastics in the placenta could carry harmful chemicals known as endocrine disruptors, which pose potential risks to human health and the fetus. The health effects of microplastics on both maternal and fetal health are quite adverse. Microplastics can act as carriers for toxic chemicals and persistent organic pollutants, potentially disrupting the hormonal balance and affecting developmental processes in the fetus (Ragusa et al., 2021).

Contributors of Plastic Pollution

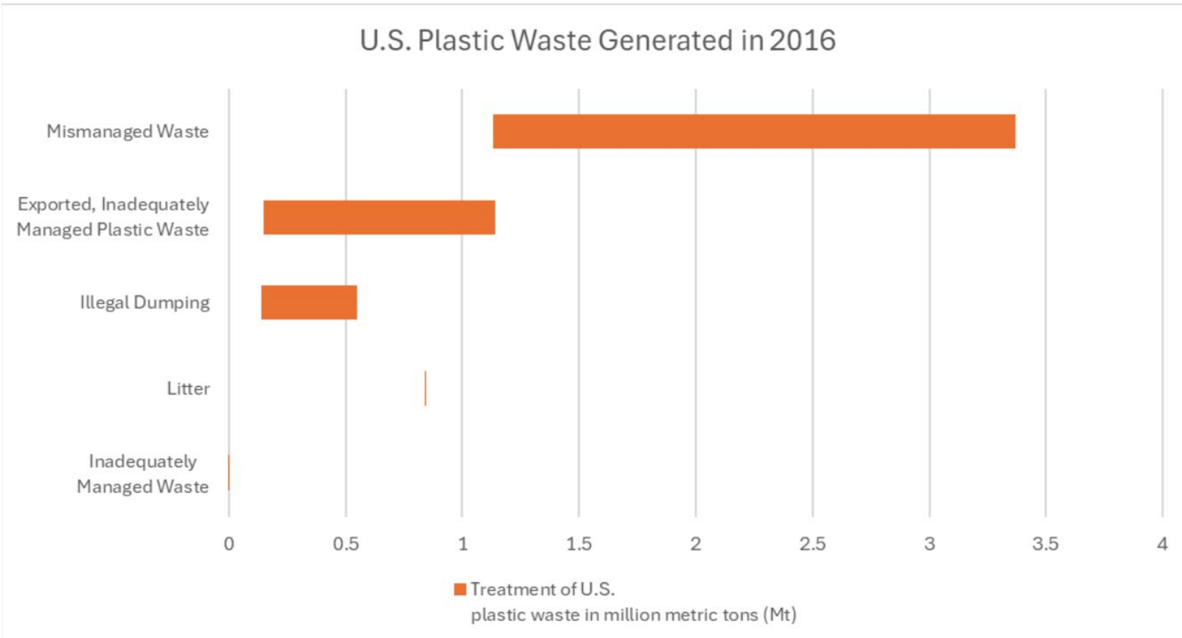

Figure 2. U.S. Plastic Waste Generated in 2016: This graphic was created in Microsoft Excel using information from a study that was conducted to determine the amount of plastic waste that countries produce, in a visual or graphical format. As seen through the stacked bar chart, mismanaged waste ranged from (1.13–2.24), this is the total amount of waste from the rest of the categories. The other types of waste are as follows; exported, inadequately managed plastic waste (0.15-0.99); illegal dumping (0.14–0.41); litter (0.84); inadequately managed waste (0). Exported waste is the plastic waste that was collected in the United States for recycling and mismanaged in the countries where it was exported to. Regular mismanaged waste, however, is waste from the lack of infrastructure in the domestic country. Source: Law et al., 2020

The causes of plastic pollution are incredibly important to take note of, if we cannot stop the cause the pollution will keep happening, leading to the negative effects on the environment and human health, as talked about before. This study employed systematic monitoring techniques to assess the abundance and distribution of plastic debris in marine environments. Researchers conducted field surveys and analyzed data collected over several years. They utilized standardized protocols to quantify plastic debris and investigate its sources. By correctly identifying and analyzing data the results show the major causes that lead to plastic pollution including inadequate recycling practices where insufficient infrastructure and low public awareness contribute to ineffective recycling of plastic waste. Leading to a large portion of plastic not being recycled and instead entering the environment. Poor management throughout the lifecycle of plastic waste, including collection, sorting, and recycling processes contribute majorly to the pollution of plastic. Illegal disposal of plastic waste in natural environments, including oceans and rivers, and overflowing landfills where plastic waste is deposited allows plastic waste to contaminate surrounding environments. Urban areas contribute to plastic pollution through runoff from streets and storm drains. Also discarded fishing gear (ghost nets) and plastic waste from maritime shipping contribute to marine plastic pollution (Ryan et al., 2009). California has a large population, an arid climate, short periods of rain, and long dry seasons, making it the ideal place to determine the amount of plastic pollution that ends up inside the marine environment. Although this study only researched the plastic from the runoff after a large rainstorm, the premise is still the same, there are many contributors to plastic pollution and much of it ends up in our environments. Samples were collected from before and after extensive rainfall (9cm) all at 5 different stations, from 200m to 5km offshore. It was found that the plastic from after rainfall was much higher than before it, the density (count of plastic pieces per meter^3) was 3 times as much before the rainfall. The difference in the amount of plastic that ended up in the marine environment happened at the different stations where the samples were collected. From 0.355 to over 4.750 mm of plastic had the largest difference in the amount of all stations except the furthest one (5km) the percentage of the debris from 1.000 - 4.749mm had the largest difference from before and after the storm (Moore, 2008). As such highlighting the runoff of plastic just from rainfall promotes such a massive difference of the plastic transferred from the city to the oceans. The runoff of plastic is also one of just many other methods mentioned previously that shows just how important it is to realize the many different contributions to the pollution of plastic.

Microorganisms in Plastic Degradation

The contributors of plastic pollution are important to eliminate or at the very least limit the amount, however just because we can slow down the pollution of plastic degradation does not mean that our environment is currently clean. As such it is important to find solutions to remove the current plastic; one of those probable solutions may be with microorganisms. Currently microorganisms are organisms that are primarily seen through microscopic methods, like bacteria, viruses, or fungi. There are many different types of plastic, some are biodegradable, while others are synthetic, meaning they do not degrade naturally in the environment as quickly and persist for a very long period. Firstly, before determining if microorganisms are a viable solution to breaking down plastic, it is important to realize what biodegradation is and the different types. Essentially biodegradation is the change of the structure in materials, in this case plastic, by utilizing a physical or chemical change, however this change happens in the environment naturally in the sense that microorganisms degrade them instead of humans (Alshehrei, 2017).

Different Types of Biodegradations

Currently there are two different types of biodegradations, aerobic and anaerobic biodegradation. The key main difference between the two types lies in the presence of oxygen. It is also important to note that an electron acceptor is a chemical entity that accepts electrons transferred to it from another compound during a chemical reaction (Priyanka & Archana, 2011).

Aerobic biodegradation requires oxygen to act as the electron acceptor for the microorganisms, as such aerobic bacteria thrive in oxygen-rich environments. The final products are typically carbon dioxide (CO_2) and water (H_2O), also the process is generally more complete, often leading to full mineralization of organic compounds.

Anaerobic biodegradation occurs in the absence of oxygen and uses different electron acceptors such as nitrate, sulfate, iron, manganese, or carbon dioxide. Anaerobic bacteria that can survive and function without oxygen. The final products vary greatly as mentioned previously, anaerobic bacteria can use different electrons acceptors and thus lead to different final products, also this process can be less complete, resulting in the accumulation of partially degraded organic compounds (Priyanka & Archana, 2011).

Advantages and Disadvantages of Aerobic and Anaerobic Biodegradation

There are differences with aerobic and anaerobic biodegradation, along with these differences come with the strengths and weaknesses of the two types. There are differences in energy consumption and how they are captured, in aerobic bacteria during the chemical reaction of degradation, energy is released in the form of heat and cannot be captured, contrary to the releasing of energy of aerobic bacteria, anaerobic biodegradation is released in the form of methane gas, which can be captured (Bátori et al., 2018). There is not one singular straightforward method to biodegradation as such in different circumstances different methods need to be utilized to achieve the desired results, for example in places such as landfills where oxygen is not as abundant, anaerobic bacteria works the best, and in places such as water treatment facility where oxygen is indeed abundant aerobic bacteria is the best method to utilize. For these reasons it is imperative to recognise the situation, circumstances, and context to effectively use each method of biodegradation.

Different Microorganisms Mechanisms, Case Studies, Examples, and Usefulness

There are many different studies that use a wide variety of microorganisms, as such it is difficult to find the "best" bacteria since many of the studies are under different contexts, situations, and requirements. However, there is still a way to at least help determine what bacterias should be further invested into, it is also important to note as discussed previously the presence of oxygen greatly determines what type of bacteria will be used (Priyanka & Archana, 2011). One of the ways to determine a bacterium that degrades plastic well is the difference in weight of the polymer that was degraded in perspective of the time it took and the type of plastic. There are 3 steps that to biodegradation they are attaching the microorganism to the polymer, using the polymer as its carbon source and then finally degrading it (Zeenat et al., 2021).

Bacterial strain	Average weight loss (mg)	Visible degradation
Control – abiotic	0.0 ± 0.1	No
Control – autoclaved biomass	0.4 ± 0.1	No
Acinetobacter sp. ATCC 31012	1.2 ± 0.1	No
Aeromonas sp. ATCC 55641	1.4 ± 0.1	No
Bacillus sp. ATCC 19385	0.8 ± 0.3	No
Bacillus subtilis ATCC 6051	1.4 ± 0.3	Yes
Bacillus subtilis ATCC 21332	2.0 ± 0.1	Yes
Corynebacteria sp. ATCC 21744	0.9 ± 0.1	No
Corynbacteria hydrocarbooxydans ATCC 21767	0.8 ± 0.1	No
Delftia acidovorans soil isolate	1.2 ± 0.2	No
Escheria coli	0.5 ± 0.1	No
Pseudomonas sp. 273	0.6 ± 0.3	No
Pseudomonas aeruginosa PA01	1.5 ± 0.2	No
Pseudomonas fluorescens ATCC 13525	1.3 ± 0.1	No
Pseudomonas oleovorans ATCC 29347	0.5 ± 0.1	No
Pseudomonas putida ATCC 12633	1.0 ± 0.2	No
Rhodococcus sp. ATCC 29671	0.6 ± 0.2	No
Rhodococcus erythropolis ATCC 4277	0.6 ± 0.1	No
Rhodococcus rhodochrous ATCC 13808	0.6 ± 0.2	No
Streptomyces clavulegirus ATCC 27064	0.9 ± 0.1	No
Sphingobium herbicidovorans ATCC 70029	0.9 ± 0.1	No

Yeast/fungal strain	Average weight loss (mg)	Visible degradation
Control – abiotic	0.0 ± 0.1	No
Aspergillus niger ATCC 16888	0.8 ± 0.2	Yes
Candida bombicola ATCC 22214	1.0 ± 0.0	No
Candida cylindracea ATCC 14830	0.7 ± 0.3	No
Candida tropicalis ATCC 15114	0.8 ± 0.1	No
Paecilomyces lilacinus ATCC 200182	1.9 ± 0.1	Yes
Penicillium pinophilum ATCC 9644	0.5 ± 0.1	Yes
Phanerochaete chrysosporium ATCC 24725	0.4 ± 0.1	No
Rhodolutra rubra ATCC 9449	0.7 ± 0.1	No
Trametes versicolor ATCC 12679	0.6 ± 0.1	No
Yarrowia lipolytica ATCC 20390	0.8 ± 0.1	No

Figure 3. Fungal and Bacteria Strains: The two tables represent which yeast and bacteria had visible degradation and the average weight loss of the plastic in milligrams in a more readable format. As seen through table 2, Bacterial Strain, *Bacillus subtilis* ATCC 6051 and *Bacillus subtilis* ATCC 21332 were the only bacteria with visible degradation and the highest average weight loss. As seen through table 1, Yeast/Fungal Strain, *Paecilomyces lilacinus* and *Penicillium pinophilum* both had visible amounts of degradation, however *Aspergillus niger* was not mentioned because of the lower amounts of weight loss compared to the other two fungi. Source: Tan et al., 2008

The two following bacteria strains are aerobic, as stated previously oxygen is needed for degradation to work. *B. subtilis* ATCC 6051 and *B. subtilis* ATCC 21332 exhibited the most degradation of polymer films out of many other bacteria during the 21 day span at 30°C. ATCC 6051 had an average weight loss of 1.4+/-0.3 mg and ATCC 21332 was 2.0+/-0.1 mg. With the same treatments to yeast/fungi *P. lilacinus* (weight loss 1.9+/-0.1 mg) and *P. pinophilum* (0.5+/-0.1 mg) (Tan et al., 2008). We cannot determine if the previously stated bacteria are efficient as such comparing them to a different bacteria would be the best choice, *Comamonas acidovorans* TB-35 uses polyester polyurethane (PUR) as its carbon source, although the type of bacteria (aerobic/ anaerobic) is not specifically stated, the final products discovered were diethylene glycol and adipic acid, as such we can conclude that *C. acidovorans* TB-35 is an anaerobic bacteria. The amount of diethylene glycol produced was 0.5 mg and 1.2mg of PUR was degraded after a 24 h incubation period at 45°C (Akutsu et al., 1998). Another study done with marine bacteria included the use of nylon 6 and 66 as the polymer for the carbon source of bacterias *Bacillus cereus, Bacillus sphericus, Vibrio furnisii, and Brevundimonas vesiculari*. It was observed that *B. cereus* degraded the both nylons the best over a 3 month period the molecular weight of said nylons decreased by 42% and 31% respectively, the weight also decreased by 7% and 2%. This was done at 35°C submerged underwater with a mineral salt medium of 7.5 pH. Although it was not explicitly stated, the final product was a variety of different compounds, not water or carbon dioxide, as such it is reasonable to conclude that the bacteria were all anaerobic (Sudhakara et al., 2007). It is also important to note that weight loss might have been caused by the degradation of additional chemical additives. A different study utilized polymer polystyrene sulfonate (PSS) as the sole carbon source with a *Gloeophyllum trabeum* strain as the bacteria or biodegrader. The products of the bacteria were not listed as such it is indeterminable to decide whether the bacteria is aerobic or anaerobic, however this is the most efficient out of the previous bacteria and their studies listed at almost 50% of the PSS molecular weight being degraded after 20 days (Krueger et al., 2015). Again there may have been additional chemical additives that assisted with the degradation.

Microorganism /Fungi	Weight loss (mg)	Percentage Degradation (%)	Time Taken (Hours)	Polymer	Source
***B. subtilis* ATCC 6051**	1.4+/-0.3	N/A	504	Polymer Films	(Tan et al., 2008)
***B. subtilis* ATCC 21332**	2.0+/-0.1	N/A	504	Polymer Films	(Tan et al., 2008)
P. lilacinus	1.9+/-0.1	N/A	504	Polymer Films	(Tan et al., 2008)
P. pinophilum	0.5+/-0.1	N/A	504	Polymer Films	(Tan et al., 2008)
***C. acidovorans* TB-35**	1.2	N/A	24	Polyester Polyurethane (PUR)	(Akutsu et al., 1998)
B. cereus	N/A	42	2191	Nylon 6	(Sudhakara et al., 2007)
B. cereus	N/A	31	2191	Nylon 66	(Sudhakara et al., 2007)
Gloeophyllum trabeum	N/A	50	480	Polymer Polystyrene Sulfonate (PSS)	(Krueger et al., 2015)

Figure 4. Microorganism/Fungi: The table represents the different microorganisms that each study used, the percentage degradation of the plastic, the amount of weight loss, the amount of time that it took to degrade, the type of polymer that was used, and the corresponding source for each study.
Source: Sangha, 2024

Microorganisms being a solution for commercial use is still quite far, however many studies using different bacterias, polymers, and conditions have been verified. Although the scale is still quite small with only being milligrams amount of plastic, the different studies shown prove that biodegradation is still quite a possible solution, considering how Krueger and his team have researched a bacteria with an almost 50% degradation of the respective polymer is definitely a step in the right direction. The microorganisms may not seem useful right now but as we see the different studies over the years more research came out a larger percentage of degradation of plastic is being studied and although we cannot make direct comparative analysis as each study uses different conditions and restrictions (i.g temperature, polymer, location etc.) in a general sense we can assume that the different bacteria discovered will have higher biodegradation percentages. This is especially true when looking at the study with Tan and his team, by using different bacteria under the same conditions they were able to find out the best one at degrading the polymer films. As such the different bacteria need to be under the same conditions to figure out the best degradation possible, it is also important to note that the conditions where the bacteria is used will vary from each location.

Side Effects and Byproducts of Microorganisms in Plastic Degradation

There is not a lot of research based on the side effects of the microorganisms in the aspect of plastic degradation, however what we can know is the byproducts, which are what microorganisms produce when using polymers as the sole carbon source for energy. In the study of Akutsu and his team while researching the degradation of polyester polyurethane (PUR) the bacteria, *Comamonas acidovorans* had produced diethylene glycol and adipic acid as byproducts (Akutsu et al., 1998). Another study that had bacteria form byproducts was with Sudhakara and his team discovered the byproducts NHCHO, CH3, CONH2, CHO and COOH from the four different bacteria that were used (Sudhakara et al., 2007). Although there are no known side effects of bacteria as of yet, many of the byproducts that the bacteria produce have already been documented, and some byproducts may also be useful as materials.

NPs in Plastic Degradation Mechanisms

When classifying materials or compounds as NPs, specific criteria must be met. NPs are defined as materials with at least one dimension that falls within the nanoscale, and typically below 100 nanometers, being in these conditions may be accepted as a nanoparticle. There are four major dimensions of NPs, the first one Zero-Dimensional (0D) NPs are the simplest form of nanomaterial where all dimensions (length, width, and height) are confined within the nanoscale; they also exhibit unique optical and electronic properties. One-Dimensional (1D) NPs are one dimension of material that extends beyond the nanoscale; Carbon nanotubes and nanowires are typical examples. Their extended structure allows for unique mechanical and electrical properties, such as ballistic conduction, where electrical resistivity remains unchanged regardless of the length of the material. Two-Dimensional (2D) NPs, unlike 1D where one dimension extends the nanoscale, 2D has two dimensions within the nanoscale. Examples include graphene and thin films. The layered structure of these materials leads to remarkable electrical, thermal, and mechanical properties, making them suitable for applications such as flexible electronics and high-strength composites. Although Three-Dimensional (3D) NPs may have a larger overall size than the other three, they are still composed of nanoscale building blocks. Nanostructured materials, nanocomposites, and nanoporous materials fall into this category. These materials exhibit unique mechanical and thermal properties due to their nanoscale constituents, which influence the overall behavior of the material (Dolez, 2015).

NPs can have either organic or inorganic matrices, and they are often utilized with coatings to enhance their properties or reduce toxicity. For instance, organic NPs like dendrimers and lipid-based NPs are widely used in medicine due to their biocompatibility and ability to degrade within the body, minimizing toxicity. In contrast, inorganic NPs, such as quantum dots, have superior optical and electronic properties but may pose toxicity risks due to their persistence in the body. To mitigate these risks different coatings are applied, although there are still challenges regarding their long term safety (Dolez, 2015).

Different NPs, Case Studies, Examples, and Usefulness

Nanoparticle	Percentage Degradation (%)	Time Taken (Hours)	Density of Polymers	Source
Silver Nanoparticle (Ag)	64.5	840	Low	(Jayaprakash & Palempalli, 2018)
Silver Nanoparticle (Ag)	44.4	840	High	(Jayaprakash & Palempalli, 2018)
Titania Nanoparticle (TiO2)	68	200	Low	(Thomas & Sandhyarani, 2013)
Gold Nanoparticle (Au)	51	24	Low	(Pol & Thiyagarajan, 2009)

Figure 5. Nanoparticle Comparison: The table represents the different NPs that each study used, the percentage degradation of the plastic, the amount of time that it took to degrade, the density of the plastic that was used, and the corresponding source for each study.
Source: Sangha, 2024

Like microorganisms, another solution to potentially eliminate plastic pollution is through the use of NPs. There are many different types of NPs each with its own properties and purpose, Ag or silver NPs were used in a recent study to measure the degradation of two different types of plastic (High and low density plastic). As previously stated with microorganisms, the way to measure the usefulness of these NPs is the amount of weight or percentage the plastic was degraded. For this study polyethylene plastic bags with both types of density were used, the high and low density plastic films, in separate groups, were immersed in 100ml of water with the Ag NPs and left for 5 weeks. It was discovered that the low density plastic was degraded 64.5% of the original weight and 44.4% for the high density plastic. The products of the high and low density polymers included alcohols, alkanes, alkenes, ketones and many others (Jayaprakash & Palempalli, 2018). The products of the degraded polymers could be used as material for many different compounds and the important conclusion to this study was the success of the Ag NPs as it did degrade 64% and 44% of the high/low density films, respectively. In another study different NPs were used, titania NPs (TiO_2). The low-density polyethylene was degraded using those NPs in the presence of UV radiation. Similarly to the previous study, the polyethylene was dissolved and mixed with the TiO_2 NPs and degraded under the solar radiation from 9 am to 4pm. The degradation achieved 68% of the original weight within 200 hours over the course of a month, and the products produced were in formation of hydroperoxides (Thomas & Sandhyarani, 2013). Similar to the UV radiation mentioned in the previous study, the gold (Au) NPs combined with multi-walled carbon nanotubes (MWCNTs) degraded about 51% of the low density polyethylene films in 24 hours, under the sun radiation. The products seem like they were water vapor, CO_2, and other molecules with 2–5 carbon atoms (Pol & Thiyagarajan, 2009). The capability of the NPs are proven to potentially be worth the investment for future advancement, as many of the different NPs have high degradation percentages, by having more advancement into this sector of research it may be possible to make the degradation even higher. Although it is important to note the products of the NPs and intensively research where they could be used.

Comparing Microorganisms and NPs

As previously stated with both NPs and microorganisms, the best way to determine if either solution is viable is through the use of determining the percentage or the weight difference of each material/organism. There are quite a bit more studies on microorganisms than NPs with plastic degradation as such more research is needed for the NPs to effectively compare each of them. However we can still determine which solution is worth investing time and money into by comparing what we have so far. It is important to first look at the products of each solution rather than the degradation, since as we know the degradation is quite good for each solution, but the degraded products, toxicity, harmfulness, and usefulness are just as important. For microorganisms the byproducts are either carbon dioxide and water in terms of aerobic biodegradation or different compounds of anaerobic biodegradation (Priyanka & Archana, 2011). It is difficult to determine what products can be produced with the anaerobic method as many different electron acceptors may be used, however judging by the aerobic method it may not be harmful. With NPs depending on the coating and type of material used the degraded compounds may include carboxylic acids, alkenes, alkanes, alcohols, ketones and esters (Jayaprakash & Palempalli, 2018). These compounds may not be safe for humans but they could be used as materials for other compounds for future applications. The degradation of plastic with NPs and microorganisms are both different and similar. For microorganisms the results are similar with much much of the degradation being between 31% to 50% for different studies, type of microorganism, and type of polymer. NPs had around a 44% to 68% degradation of different types of polymers, of course the varying degradation percentages are dependent on the conditions, as in different NPs, polymers, and treatments. The main difference between the microorganisms and NPs is the difference of nature between them, as microorganisms are natural they will generally be safer for human use, while NPs not as much studied compared to microorganisms have a varying level of safety. It is also important to note that NPs may have more potential to degrade at a higher percentage with the different materials that could be used. The speed between the two solutions also vary quite a bit as NPs may take 5 weeks to degrade 64% of plastic while microorganisms may take 20 days, this also depends on the material and organism used during degradation. It is difficult to directly compare microorganisms and NPs with many different variables at play, however NPs may have a high potential to be a viable solution than microorganisms due to the sole reason of not many studies yet having a high degradation of plastic, as seen with 68% degradation of low density and 44% of high density plastics.

Conclusion

Solving the plastic pollution is vital for our planet to remain healthy for generations to come; if it isn't possible to completely solve the problem with plastic, just one step into the right direction can greatly influence the end result. A vast, yet thorough analysis of various microorganisms and NPs was conducted to determine the efficiency and output of plastic degradation using the two solutions. Through the analysis of each microorganism and nanoparticle it becomes evident that NPs may have a higher efficiency than microorganisms however a major drawback is that they are man made. Since the microorganisms naturally occur in the environment the side effects or by-products are not as potentially destructive as the NPs. It is difficult to determine what is the absolute best method to help plastic pollution as many different factors go into the solution that someone would want. TiO2 for example had a high degradation rate among the low density polymers at 68% but also took 200 hours to complete that degradation. While the microorganism *G. trabeum* had a 50% degradation rate at 480 hours of completion time. The rate and time may also be affected depending on temperature, location, polymer, etc. However, if we disregard the fact that by-products affect the reason for one method over the other, the analysis has proven that NPs will degrade and be more efficient than their microorganism counterparts. Each method is very situational, but further investments should go to NPs with their proven abilities so far; by researching more ways to decrease potential risk of side effects NPs will be a better solution for dealing or potentially eliminating plastic pollution. Humans can also help with the pollution by doing their part to reduce the amount of plastic that goes into the environment. Litter, poor management, public awareness, and many more factors will all help lessen the amount of NPs that will have to eliminate plastic pollution when they are eventually developed for commercial use.

Limitations

This study was a comprehensive analysis of two methods to help mitigate the pollution of plastic in the environment. Microorganisms and Nanoparticles were analyzed based on the various factors including, amount of plastic degradation, time, and what type polymer was degraded. Furthermore, the study was conducted as an analysis using a compilation of both primary and literature reviews found across Google Scholar, Science Direct, and other various credible scientific platforms. Due to this study being a compilation of literature and peer reviewed research papers on the topic of microorganisms and NPs efficiency, the analysis was based on research and experiments conducted by others rather than it being personally conducted.

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