

Biotechnology for the mitigation of plastic waste from the oceans

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Abstract. In contemporary times, the term “plastic” represents a family of polymers that are synthetically developed and have the property of being deformed without breaking. Since the beginning of its manufacturing at industrial levels, the amount of the world’s plastic production has already risen over 20,000%. Most of the produced plastic ends up having the sea as the end destination and it is known that there are toxic compounds associated with its decomposition that can cause serious problems to the ecosystem and to marine fauna. Biotechnology, as an area of study that integrates several areas of science, is committing to develop methods that may be useful in reversing the impacts that improper disposal of plastic can cause in the environment. The development of biodegradable materials and faster degradation tests with selected microorganisms have been the most effective biotechnological techniques, although they do not yet have a major impact on existing pollution mitigation. This paper will discuss the current accumulation of plastic in the oceans, as well as some of the biotechnological alternatives adopted to reverse the amount of plastic material discarded annually which ends up in the sea.

Keywords: Biotechnology; Pollution; Plastic waste; Mitigation; Oceans.

Resumo. *Biotecnologia para a mitigação de resíduos plásticos dos oceanos.* Nos tempos contemporâneos, o termo “plástico” representa uma família de polímeros que são sinteticamente desenvolvidos e têm a propriedade de serem deformados sem quebrar. Desde o início de sua fabricação em níveis industriais, os números da produção de plásticos pelo mundo já subiram mais de 20.000%. Boa parte dos plásticos produzidos acabam tendo o mar como destino final e sabe-se que existem compostos tóxicos associados à sua decomposição que podem causar sérios problemas ao ecossistema e seus indivíduos. A biotecnologia,

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como ciência que integra diversas áreas das ciências, tem se proposto a desenvolver métodos que possam ser úteis na reversão dos impactos que o descarte indevido de plástico pode causar no meio ambiente. Desenvolvimento de materiais biodegradáveis e testes de degradação mais rápidos com auxílio de microrganismos selecionados têm sido as técnicas biotecnológicas mais eficazes, apesar de ainda não apresentarem grande impacto na mitigação da poluição já existente. Esse trabalho propõe-se a discutir o atual acúmulo de plástico nos oceanos, bem como algumas das alternativas biotecnológicas adotadas para reverter a quantidade de materiais plásticos anualmente descartada nos mares.

Palavras-chave: Biotecnologia; Poluição; Resíduos plásticos; Mitigação; Oceanos.

Introduction

The environmental impacts caused by human waste are visually perceptible in large urban centers and population clusters. The lack of proper redirection to municipal solid waste, or even the lack of treatment of materials from selective collection, can have serious consequences to the environment, fauna, flora and humankind. The influence that the human species has on the terrestrial system, whether due to accumulated litter or other physical and chemical changes, is so representative that it comes to resemble other natural geophysical processes, indicating the possible arrival of the "anthropocene" as suggested by some authors (Steffen et al., 2011).

Among all the materials that are synthesized and discarded by humanity and that do not degrade easily in the environment, plastic is considered one of the most abundant and harmful. It is estimated that, by 2015, 8.3 billion tonnes of these materials were produced worldwide, generating losses and changes in many ecosystems because of their toxicity (Geyer et al., 2017).

Of all the plastic ever produced, it is evaluated that 10% had oceans as the final destination (Laglbauer et al., 2014). This fact is of great relevance, as it is known that there are compounds related to the degradation of plastics in the seas that are toxic to marine fauna. These degraded plastics may contain a toxic chemical charge at risk of being transmitted through the food pyramid (Jambeck et al., 2015).

Some measures have been used to reduce the amount of plastic that is discarded in the oceans, since effective technology is not currently available to reverse the pollution that is already widespread. Biotechnology is an area of science that is developing models of action to achieve this goal, creating materials that are more easily degraded and using microorganisms that have the ability to accelerate the process of degradation of some types of plastic.

There is a growing awareness of the consequences of plastic materials improper disposal, especially its negative effects on maintaining the balance of marine ecosystems. This paper aims to discuss how some biotechnological measures can be useful to reduce the amount of plastic discarded annually in the oceans.

General description of plastic waste

By 2000 BC, ancient civilizations had already used substances extracted from plants to make household utensils, such as figurines and beads (Utracki, 1995; Hosler et al., 1999; Mulder et al., 2001; Crawford et al., 2017). Since then, human needs have been

changing as the lifestyles of different societies have evolved. Researchers around the world began to look for substances that would provide certain needs that the more primitive compounds, such as rubber, did not supply. The objective was to develop something that presented ease of modeling, high mechanical and thermal resistance, and impermeability, among other characteristics (Mulder and Koot, 2001).

One of the first polymers artificially synthesized was the nitrocellulose registered by the French researcher Henri Braconnot, in 1833 (Utracki, 1995). This was only the first of many other types of plastic that have been developed over the decades. The 19th century, for example, was marked by the exponential increase in patent applications due to the various types of plastic that were being synthesized worldwide (Freinkel, 2011).

In contemporary times, the term "plastic" represents a family of polymers that are synthetically developed and have the property of being deformed without breaking or fragmenting (UNEP, 2016; Bombelli et al., 2017). A polymer is a long molecule that has atoms connected by primary covalent bonds throughout its molecule. They are obtained by a process called polymerization, whereby monomeric molecules (small units) chemically interact forming (polymer) chains (Kinloch, 1995).

The period between the two World Wars was marked by the development of different models of polymers thanks to the race for the creation of more resistant, lighter, cheaper and easier to manufacture instruments. During that time, a lot of the plastics currently used were developed, such as nylon, teflon, silicones and certain types of polystyrene (Brydson, 1999; Crawford et al., 2017). But it was only after World War II, exactly in the 1950s, that plastics began to be produced on industrial scales. This was mainly due to the growing demand for manufactured products and packaging to keep or protect food and goods in general (Freinkel, 2011; Bakir et al., 2012; UNEP, 2016).

There are approximately 50 types of basic polymers included in 60 thousand plastic formulations (Shashoua, 2008). In spite of its diversity, plastics can be segmented into two large groups: "thermoplastics", which correspond to thermosetting plastics that can be easily shaped, and "thermosets", which are those that do not change stiffness with temperature. Among those, the most common types of thermoplastics are polyethylene (PE), polyethylene terephthalate (PET), polypropylene (PP), polyvinyl chloride (PVC) and polystyrene (PS). Common examples of thermosetting plastics include resins, polyurethane (PUR) and epoxy coatings (UNEP, 2016). Table 1 characterizes the most common types of plastics according to their classification and common forms of use (Plastics Europe, 2016).

Table 1. Characterization of the most abundant types of plastics.

Thermoplastics				Thermocouples		
PE	PET	PP	PVC	PS	PUR	Epoxy
Toys, (PE-HD, PE-MD), milk bottles, bottles of shampoo, tubes, household utensils (PE-HD) etc.	Bottles for water, soft drinks, juices, cleaning products etc.	Food packaging, candy and snack wraps, hinged covers, microwave-proof containers, tubes, automotive parts, banknotes etc.	Window frames, floor and wall covering, pipes, insulation of cables, garden hoses, inflatable pools etc.	Frames for glasses, plastic cups, trays of eggs (PS), packaging, insulation of buildings (PS-E) etc.	Insulation of buildings, cushions and mattresses, insulation foams for refrigerators etc.	Resins that harden when in contact with a catalyst.

Source: Adapted from Crawford and Quinn (2017). Legend: PE - Polyethylene, PET - Polyethylene terephthalate, PP - Polypropylene, PVC - Polyvinyl chloride, PS - Polystyrene, PUR - polyurethane.

Currently, the vast majority of plastic is made of hydrocarbon molecules - carbon packages and hydrogen derived from the refining of fossil fuels such as oil and natural gas (Freinkel, 2011). However, they can also be totally or partially produced from plant biomass, such as corn, sugar cane and cellulose. It is worth noting that the properties of the material are the same, since they are artificially synthesized polymers (Pathak et al., 2014; UNEP, 2016).

Production

The global plastic industry experienced an increase from the beginning of its industrial production to the present day. In its early days, plastic productivity was around 5 million tonnes in the early 1950s (Shashoua, 2008). In the 2000s, this figure was already approaching 100 million tonnes; by 2009, it was around 250 million tonnes; up to the current levels exceeding 380 million tonnes per year. It is estimated that 8.3 billion tonnes of these synthetic polymers had already been produced by the year 2015 (Nuelle et al., 2014; Geyer et al., 2017).

These values become much more striking when we analyze that, in the period of 65 years (1950-2015), the annual global production of plastic increased by approximately 20,000% (Hirai et al., 2011; Plastics Europe, 2015). Shashoua (2008) suggests that this exponential growth was due to the diffusion of plastic packaging, such as bags and coatings for products. The only two moments when there was a drop in the exponential growth curve of plastics production were due to the oil crises, in 1973, and the financial crisis, in 2007 (Crawford and Quinn, 2017).

Data from 2014 points out that 65% of the world's plastics manufacturing was concentrated in three global regions: China, Europe and North America (accounting for 26%, 20% and 19%, respectively). In Europe, five countries account for 63.9% of the continent's demand for plastics, Germany (24.9%), Italy (14.3%), France (9.6%), the United Kingdom (7.7%) and Spain (7.4%). Latin America currently produces 5% of all the plastic in the world and Brazil accounts for almost half of this production. A growing value that, in 1999, was 3.4 million tons per year in Brazil (Ichida, 2009; ABIPLAST, 2015).

The packaging industry continues to be the largest consumer of polyethylene (PE) and polypropylene (PP), which together account for 92% of the world's demand, compared to other types of plastic (Bombelli et al., 2017, Crawford and Quinn, 2017). Polyethylenes are the most versatile and are of great relevance in the global packaging market because they are usually translucent, hard and waxy solids that are not affected by a wide variety of chemicals, allowing great strength and versatility (Rosato et al., 1999). Every year, more than one trillion plastic bags made of polyethylene are used worldwide (Bombelli et al., 2017).

These values could be explained by the growing global trend of replacing reusable containers with disposables, which currently accounts for 33% of all the projected plastics in the world annually (Arthur et al., 2009; Geyer et al., 2017).

It is expected that in the coming years the production of synthetically polymerized materials will not stabilize or decrease, but will rise exponentially above the averages of previous years (EMF, 2016). The global population is also expected to rise to about 10 billion by the year 2100, also representing an overall increase in consumption and production (Bendell, 2015). This data represents an increase of more than 50% over the current values. By 2050, an additional 33 billion tonnes of plastic is expected to be produced and overall annual production is expected to be between 850 million and 1.124 billion tonnes (Shen et al., 2009; Rochman et al., 2013; EMF, 2016).

Discarded waste

Of all the municipal waste produced in the world, 16% are compound plastic (Muenmee et al., 2015). Inevitably, much of this waste disposed of in the terrestrial environment ends up in the aquatic environment. The current estimates are that 15%-40% of all plastic discarded directly in municipal solid waste is dumped into the ocean, which is equivalent to 6.4 million tons per year (Waller et al., 2017). These solids are agglomerated forming blocks in the sea, and it usually occurs when the plastic materials are transported by wind or via rivers and urban waterways ending up in the ocean. A large number of undeveloped and developing countries use open pit dumps due to the low cost associated with the practice (Muenmee et al., 2015).

According to research, of all the plastic ever produced, it is estimated that 10% had the oceans as the final destination (Laglbauer et al., 2014). This is of concern because, according to an assessment by the United Nations Joint Expert Group on the Scientific Aspects of Marine Pollution (GESAMP), 80% of the waste in the marine environment originates from land, while only 20% was a result of activities at sea, indicating a precarious worldwide control of municipal solid waste disposal. In addition, it is estimated that in 2010 alone, an amount between 4.8 to 12.7 million tons of plastic waste entered the ocean. By 2025, this value will increase to about 32 million tons per year (Jambeck et al., 2015).

Geyer (2017) made a more frightening projection on plastic production and disposal by the middle of this century. If this production and global waste management trends continue to exhibit similar growth curves to current levels, mankind will have disposed of 12 billion tonnes of plastic in landfills or the environment, the majority of which will be incinerated and only 9% will be recycled (Geyer et al., 2017). No data was presented on the disposal of these materials in the oceans in the year 2017.

According to the Manual of Integrated Management of Solid Waste, produced by the Special Secretariat for Urban Development of the Presidency of the Republic of Brazil (Brasil, 2001), plastics accounted for 3% of the gravimetric composition of municipal waste in Brazil. Generally, in Brazil, produced wastes are allocated to landfills, controlled landfills and open dumps. In Brazil, only 58.4% of the waste has an adequate destination (ABRELPE, 2015).

Problems for the ecosystem

Plastic materials are already fully diffused at high concentrations in all oceans, including more remote areas such as the deep waters of Antarctica (Waller et al., 2017). These products are detected in different sizes, being more common in the form of *microplastics*: small fragments of degraded plastics that have a diameter of 300µm to 5mm (less than this size are considered *nanoplastics* and larger as *macroplastics*) (Halle et al., 2017). It is suggested that there are currently 15 to 51 trillion of these particles in the seas, which could be equivalent to 93 to 236 thousand tons (macroplastics were not taken into account) (UNEP, 2016).

Both macros and microplastics negatively interfere in the maintenance of marine life. Packing bands, synthetic ropes and lines, or driftnets can cause animal entanglements. Micrometric pieces of plastics can be ingested with great ease by most marine animals (Derraik, 2002). According to a 2012 report produced by the UN Convention on Biological Diversity, more than 600 species of animals (including microorganisms, birds and even whales) have been documented in scientific publications for having suffered some physical injury caused by the ingestion of plastic (GEF, 2012; Wilcox et al., 2015).

There are no healthy levels for the ingestion of plastic and its effects on various organisms are extremely harmful. When ingested, plastic can cause physical damage to the digestive system, compromise digestive efficiency and release toxic chemicals into the body (Ryan, 1987).

The transmission of these toxic compounds also occurs through feeding. The adsorption of persistent organic pollutants into the plastic and their transfer to the tissues and organs through ingestion affects not only marine megafauna as well as lower trophic level organisms and their predators, but it may also affect humans (Eriksen et al., 2014).

In the case of seabirds that have ingested large amounts of plastic, the consumption of food may end up being reduced, resulting in the inability to deposit fat and, consequently, to decrease its motor activities (Derraik, 2002). To make matters even worse, researchers say that several species of seabirds are in population decline due to several factors, including the ingestion of plastic present in coastal regions of reproduction (Croxall et al., 2012). Projections also state that by 2050, plastics will be found in the digestive tract of 99% of all species of seabirds and that 95% of these will have ingested some type of plastic (Wilcox et al., 2015).

Reversing the situation

After several decades of plastic production growth, mankind has reached a plateau where it has become virtually impossible to stabilize or decrease the amount of plastic produced every year. It is through the undue disposal of urban solid waste, along with the precariousness that many cities and countries treat their garbage, that many plastic debris end up in the watersheds and consequently in the sea.

Plastic debris has the capacity to freely travel long distances due to its low density and easy flotation. This characteristic causes these polymers to circulate freely and spread throughout the seas, even when there are no nearby population clusters. Reversing this framework is a massive challenge.

In some areas, environmental protection mechanisms act on local preservation, but they do not have widespread effects. The truth is, in practice, there are no readily available technologies that are effective in collecting and cleaning marine debris from large areas.

A contribution of global scope measurements is necessary. The combination of factors such as (i) the reduction of waste production volumes; (ii) the collection of waste already generated and guarantee of appropriate redirection; (iii) and establishing effective measures in material disposal management may be the beginning of a more effective methodology for reversing the alarming numbers involved in plastic production.

Analysis and discussion

Biotechnology, according to the Organization for Economic Co-Operation and Development (OECD), an institution formed by 35 countries, can be defined as "the application of science and technology to living organisms, as well as its components, products and models, to modify living or non-living materials for the production of knowledge, goods and services", that is, a science that uses different scientific fields to stimulate technological processes (biochemistry, microbiology, chemistry) supported by plant, animal and microbiological structures. This science plays a crucial role in maintaining life and preserving ecosystems in general (OECD, 2005).

Biotechnology instruments can be used to minimize future damage caused by increasing concentrations of discarded plastics. There are two biotechnological factors that can positively influence projections for the production and disposal of plastics in the world:

- (i) Elaboration of biodegradable plastics, i.e., plastics that have a natural degradation time lower than other plastics and do not present a harmful effect on the environment, biota, soil stability, and do not emit large concentrations of methane gas and do not contaminate groundwater;

(ii) Development of efficient techniques to reduce the time necessary for the degradation of non-biodegradable plastics through biotic degradation by living controlled organisms.

Biodegradable plastics

Crawford et al. (2017) suggested that for a biodegradable plastic to be considered, it should be susceptible to deterioration by biological organisms, namely the carbon present in the plastic composition must be the power source for the organism. For this process to occur, two steps are imperative:

- i. The *degradation* occurs through factors such as oxygen, heat, moisture, light, UV or enzymatic action so that the bonds between carbon are broken, resulting in fragmentation of the plastic into smaller units;
- ii. Soon thereafter, *biodegradation* occurs. In this step, the carbonic units are already in a size small enough to pass through the cell walls of microorganisms. Then, they can be converted into biomass.

Importantly, biodegradable plastics are not necessarily bioplastics, synthetic polymers that are entirely or partially composed of renewable biomass resources (plants such as corn, tapioca, potato, and algae, for example) (Rosato et al. 1999; GEF, 2012; Pathak, 2014). This is because the biodegradation property does not depend on the source of the raw material, but on its chemical structure, that is, a particular type of plastic from fossil fuels may be more biodegradable than another type manufactured in its totality by vegetal biomass (Pathak, 2014; Crawford et al., 2017).

Among the main types of biodegradable plastics, we can cite three (see Table 2).

Table 2. Schematic representation of the main biodegradable plastics.

Polyhydroxybutyrate (PHB)	Polycaprolactone (PCL)	Poly(lactic acid) (PLA)
Produced by the bacterium <i>Alcaligenes eutrophus</i> . Resistant to hydrolytic degradation and resistance to UV light. Confection of shampoo bottles, cups, jerseys, disposable shavers, sutures (non-toxic degradative capacity) (Brydson, 1999; Crawford et al., 2017).	Hydrophobic, good solubility, low melting point (between 59 and 64 °C) and acceptability by the human body: potential in the field of medicine. Development of implantable structures or even sutures that require longer residence in the body, due to its ability to biodegrade more slowly in the human body (Crawford et al., 2017; Woodruff, 2010).	The bioplastics from corn starch. Mechanical, thermal, barrier and processability properties: elaboration of degradable sutures, drug-releasing microparticles, nanoparticles and porous scaffolds for cellular applications. Plastic bottles: complete biodegradation lasts around 2 weeks in case of disposal in a sewage treatment plant and approximately 2 months in case of disposal in soil or aquatic environments (Crawford et al., 2017; Hamad, 2015)

Polyhydroxybutyrate (PHB). With its production boosted mainly by the oil crisis in 1973, when the price of oil rose more than 300%, polyhydroxybutyrate (PHB) is one of the most popular thermo-bioplastics currently belonging to the class of polyesters. It is produced by biochemical methods through the bacterium *Alcaligenes eutrophus*. These

have the ability to accumulate carbohydrate (usually glucose) in the form of polyesters, such as energy storage. After the whole fermentative process, 80% of the bacterial body mass is of polyester, which is able to be purified. It is randomly composed of hydroxybutyrate and hydroxyvalerate throughout the chain.

This material has the ability to withstand hydrolytic degradation, since it has no chemical affinity with water, unlike other biodegradable plastics. Another relevant feature is its high resistance to UV light. Its application in the market goes from the manufacture of shampoo bottles, cups, t-shirts, disposable shavers, to being used in the human body in sutures, precisely because of its non-toxic degradative capacity, occurring naturally, without the need for removal (Brydson, 1999, Crawford et al., 2017).

Polycaprolactone (PCL). PCL is another type of biodegradable polymer with great relevance in the biomedical industry. Due to its hydrophobicity, good solubility, low melting point (between 59 °C and 64 °C) and exceptional acceptability by the human body, stimulating several researches on its potential application in the field of medicine. Due to its low melting point, it is not suitable for high temperature applications. However, it can be mixed with other plastics to improve impact resistance. Research has shown that this material can be used for the development of implantable structures or even sutures that require a longer permanence in the body, due to its ability to biodegrade more slowly in the human body (Crawford et al., 2010).

Polylactic acid (PLA). Derived from lactic acid, polylactic acid (PLA) is one biodegradable bioplastic that is second only to polyhydroxybutyrate in terms of use. It is developed through the fermentation of products with agricultural origins, such as corn starch. This polymer has excellent mechanical, thermal, barrier and processability properties, making it ideal for the manufacture of degradable sutures, drug-releasing microparticles, nanoparticles and porous scaffolds for cellular applications. PLA, when used for the manufacture of plastic bottles, for example, is completely biodegraded in around 2 weeks when disposed of in a sewage treatment plant and approximately 2 months when disposed of in soil or aquatic environments (Crawford et al., 2017; Hamad, 2015).

Biodegradation of plastics

Currently, few reports describe the efficiency of biological degradation of plastic materials. Even scarcer, relevant groups of microorganisms are discussed in scientific literature for having biodegradable capacity on certain types of plastics, indicating a possible chance of their use in bioremediation techniques. This technology uses the ability of microorganisms or plants to accumulate and detoxify environments by degrading or removing contaminants from a particular environmental space. Although there are several other techniques for decontamination or environmental decontamination, bioremediation remains one of the cleanest and most reliable because it removes organic and inorganic pollutants, even when they are present in low concentrations. Some of the most relevant examples of organisms that can convert plastic into energy and biomass are presented below (Gaylarde, 2005; Hlihor, 2017).

***Ideonella sakaiensis*.** Recent research in Japan has succeeded in isolating a bacterium that has a significant ability to degrade polyethylene terephthalate, more commonly called PET. The strain in question not only presented the ability to biodegrade the material, but also to use it as its main source of energy and carbon, according to the authors. These cells cultured in PET are responsible for the production of enzymes with the capacity to degrade the bonds between the PET monomers, and also the consumption of mono (2-hydroxyethyl) terephthalic acid. Together, these enzymes have been able to

degrade the material into monomers that are environmentally benign, terephthalic acid and ethylene glycol (Yoshida et al., 2016).

***Brevibacillus borstelensis*.** This thermophilic bacterium has the capacity to reduce the molecular mass of polyethylene by 30%, after exposure to it for 30 days at 50 °C. Its relevance is due to the fact that it has exclusively used PE as a source of carbon and energy. The maximum biodegradation was obtained together with stimuli photo-oxidation, indicating that residues carbonyl (carbonic groups consisting of only one oxygen) coming from photooxidation contributed to biodegradation. These results are extremely relevant because they demonstrate how *B. borstelensis* can be a suitable microorganism to act in the bioremediation of areas contaminated by polyethylene, especially at higher temperatures (Hadad et al., 2005).

***Thermomonospora fusca*.** A copolyester biodegradation assay utilized the strain *Thermomonospora fusca* DSM43793 and it was possible to verify that the copolyester was degraded in mineral culture medium within days. The films with approximately 90 µm thickness were completely disintegrated in 7 days on agar plates at 55 °C. However, the final degradation of longer aromatic oligomers (which are constituent parts of these copolyesters) was not significantly achieved. Even though they have little efficiency in the biodegradation of longer chains, the authors state that the isolates “are suitable candidates for use in the study of the mechanism of degradation of copolyester and in the establishment of improved and rapid test methods for the evaluation of biodegradability” (Kleeberg et al., 1998).

Pseudomonas sp.* and *Vibrio sp. Without the presence of an additional carbon source, communities of microorganisms were isolated in polypropylene containing starch. For five weeks, these communities were incubated and the pure isotactic polypropylene was biodegraded by these communities of microorganisms even under limited oxygen conditions. In this case, anaerobic and aerobic bacteria coexisted in mixed cultures in the presence of low oxygen concentrations acting in close cooperation to degrade these polypropylene films. The certainty of this fact was due to the increase in methylene chloride concentrations from the polypropylene incubated, and, of course, the weight loss of the sample, confirming the conversion of the sample by the microorganisms. This suggests that there is a metabolic flexibility and adaptability of microorganisms that may be favorable to bioremediation of sites contaminated by isotactic polypropylene and polyethylene, two macromolecules that are supposed to be highly recalcitrant for biological metabolism (Cacciari et al., 1993).

Table 3 outlines the most common types of plastics manufactured and consumed annually worldwide, along with the names of the microorganisms that have been able to convert these plastic materials into an energy source and carbon for biodegradation.

Table 3. Schematization of types of microorganisms that can degrade some of the most common types of plastic.

Microorganism	Type of degraded plastic	Main features
<i>Ideonella sakaiensis</i>	Ethylene terephthalate (PET)	It makes use of PET exclusively as a carbon source; It reduces to terephthalic acid and ethylene glycol, non-polluting monomers.
<i>Brevibacillus borstelensis</i>	Polyethylene (PE)	Ideal for warmer environments; Uses PE as the main source of carbon.
<i>Thermomonospora fusca</i>	Copolyesters	High efficiency in biodegradation of copolyester plastics.
<i>Pseudomonas</i> sp	Polypropylene (PP)	They act in cooperation, increasing the efficiency of the biodegradation process of PP.
<i>Vibrio</i> sp		

Conclusions

According to the data analyzed, there is no visible prospect for reducing the volume of plastic production in the world, since these materials have become so essential in everyday life of practically every society in the world, especially considering the increased consumption of disposable plastic utensils.

Biotechnology, as a science that aggregates several areas of knowledge in order to produce and guarantee purposes and services to humanity, emerges as a solution to this problem. Biotechnology can reverse, in some way, the problem that revolves around the amount of plastic that is discarded in the oceans every year and that causes very serious sequelae to the ecosystems and their individuals, which, in turn, degrades the dynamics of life in general.

Manufacturing bioplastics (to reduce dependence on plastics from fossil fuels) and biodegradable plastics (for sustainability) is not necessarily such an effective solution to reduce the disposal of non-biodegradable materials. In addition, the volume of its production is derisory to the most common plastics. This fact means that although there is an increase in the manufacture of biodegradable utensils, the most widespread plastics (PE, PP, PET, PVC etc.) will still be present in the daily life of the population.

It is also worth mentioning that the production of biodegradable plastics is still more costly than other types of plastics made from fossil fuels, which makes the commercialization and establishment of biodegradable plastics more difficult. There is still debate as to whether they actually degrade in natural habitats or whether they will degrade in the marine environment where the heat and pressure conditions are significantly different from those tested.

It is known that the vast majority of plastic materials are impervious to biotic degradation by bacteria, as effective enzymes capable of degrading these synthetic materials have not yet been properly developed. Accordingly, the degradation of plastics tends to occur mainly through abiotic processes in which the plastics are depolymerized to their constituent monomers. As a secondary process, microorganisms and fungi can then attack and utilize these constituent monomers as energy sources. More research is needed before determining the contribution of the use of biodegradable plastics to reduce marine

debris in order to assess the impact of these polymers in both marine environments, and waste and recycling infrastructures.

Regarding sources of bioremediation, even though the aforementioned examples have proved successful in laboratory research, it is still too early to speak of their effectiveness in large-scale bioremediation of areas contaminated by plastics. It is also important to note that no studies on possible bioremediation in contaminated or polluted marine waters by plastics have been found, limiting their use even further. Bioremediation methods are only effective for certain types of plastics and under specific conditions within laboratories, indicating their non-viability in large-scale use in environments contaminated by plastics. More studies are needed in order to adapt these technologies to natural conditions.

However, even if the contemporary biotechnological aspects do not act directly in reducing the values of production and disposal of plastic materials, it does not mean that these biotechnological means cannot have an effect in the near future, since science is constantly advancing. Biotechnology may, over the years, present viable mechanisms that will succeed in mitigating the levels of plastic that end up in the oceans. It is worth mentioning that other measures need to be established in conjunction with science, such as raising public awareness of the risks attributed to the indiscriminate use of plastic and its inappropriate disposal, and the actions of governments to ensure the proper disposal of these materials.

Conflicts of interest

The authors declare that have no conflicts of interest.

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