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Are biodegradable plastics a promising solution to solve the global plastic pollution?☆

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ABSTRACT

A large amount of plastic waste has been discharged into the environment worldwide, which causes the current white pollution problem. The accumulated waste plastics in the environment can be furtherly degraded into small pieces such microplastics and nanoplastics through weathering, which will do more harm to the environment and humans than large plastics. Therefore, plastic production and disposal are needed to be considered. Biodegradable plastics (BPs) have become the focus of recent research due to their potential biodegradability and harmlessness, which would be the most effective approach to manage the issue of plastic waste environmental accumulation. However, in the long run, it is uncertain whether BPs can be a promising solution to waste disposal and global plastic pollution. Consequently, both sides of the dispute are discussed in this paper. At present, most conventional plastics can not be replaced by theses BPs. Biodegradation of BPs needs certain environmental conditions, which are not always reliable in the environment. Additionally, changes in human behavioral awareness will also affect the development and application of BPs. BPs should not be considered as a technical solution, thus excusing our environmental responsibility, because littering does not change with the promotion of an effective technology. As such, the conclusion is that BPs may be a part of the solution. The effectiveness in providing environmentally solutions for plastic waste management depends on the combination of affordable waste classification technologies and investment in organic waste treatment facilities. Therefore, there is still a long way to go to solve the global plastic pollution through BPs.

1. Introduction

Plastics have been widely used in production and life since the day they were invented due to their remarkable properties in durability, lightness, stability and low cost. Global plastic production has reached 348 million tons in 2017 (PlasticsEurope, 2018). Problematically, the durability and toughness of plastics have two sides. These properties can not only improve the performance of plastic, but also in turn pose a serious threat to the environment, making plastic resistant to natural degradation. This resistance has become a great challenge in the waste management process, especially in the area of sustainable waste management. A large amount of plastic waste has been discharged into the environment worldwide, which causes the current white pollution problem (Dauvergne, 2018). White pollution is a kind of image appellation for the environmental pollution phenomenon of waste plastics. It refers to the pollution of ecological environment and landscape caused by the use of plastic products such as packaging bags, agricultural mulch film, disposable tableware, plastic bottles etc. made of polystyrene (PE), polypropylene (PP), polyvinyl chloride (PVC) and other high molecular compounds, which are discarded as solid waste. According to statistics, 280 million tons of plastic waste were produced in 192 coastal countries and regions in 2011, and about 8 million tons of the waste flowed into oceans (Jambeck et al., 2015). The accumulated plastics in the environment can be decomposed into small fragments, gradually forming microplastics or even nanoplastics (Shen et al., 2019a; Shen et al., 2019b). The negative impacts of plastics on society have become increasingly significant, such as causing direct landscape problems and posing potential environmental risks to living organisms and humans, especially those deliberately formulated plastics with inexpensive

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and almost indestructible properties. How can we deal with these materials? Plastic waste disposal and its environmental risks are serious problems to be considered. There are several ways to manage plastic wastes: recycling, incineration, sanitary landfill and others. Plastic packing is one of the most problematic types of plastic waste because it is usually designed for single use and ubiquitous in garbage and extremely difficult to be recycled (PlasticsEurope, 2016). The flexible increasing use and multi-layer packing poses challenges to collection, separation and recycling. Although some plastics can be recycled, there are many steps involved, requiring separate collection, long-distance transportation, processing and remanufacturing. The high cost of these steps, the low commercial value of recycled plastics and the low cost of raw materials limit the plastic recycles. Additionally, when plastic waste is burned, the greenhouse gases (CO_2) and other irritant gases (HCl) will be released. Harmful chemicals contained in plastic wastes that can be released into the environment during plastic waste disposal. Currently, some measures have been taken to address the problem of plastic waste, including “plastic limit”, “plastic prohibition”, and improving the treatment efficiency of plastic waste. However, these methods are only effective to some extent, because the scale of plastic production is much higher than the reduction by these treatment methods, and many people still need to be educated about responsible waste treatment methods. With the increasing global plastic production, people are increasingly aware of the environmental problems of plastic waste.

Nowadays, the development of biodegradable plastics (BPs) from renewable biomass has become a topic of great interest. BPs are usually made from renewable raw materials such as lignin, cellulose, starch and bioethanol. At present, biodegradable and commercially available natural polymers on the market mainly include polylactic acid (PLA), polyhydroxyalkanoate (PHA), polyhydroxybutyrate (PHB), polyhydroxybutyrate valerate (PHBV) and polyhydroxybutyrate (PHV). BPs can be biodegraded without any harmful effects caused by their persistence (Haider et al., 2019).

Today, BPs have been successfully applied in some industrial and environmental protection programs. Although some BPs have shown excellent physicochemical, mechanical and degradable properties in many industrial applications, it is well known that BPs are currently not a substitute for conventional plastics (Rujnićsokele and Pilipović, 2017). In the view growth of BPs, there is an impact of knowledge gap to seek attention in this area. Consequently, there is still a question whether BPs can be a promising solution to solve the waste disposal problem and global plastic pollution in the long run. Herein, the both sides of the dispute about BPs are discussed in this paper. The application of BPs and the challenge of solving environmental plastic pollution, and some perspectives are also raised.

2. What are BPs?

Degradable plastic refers to a kind of plastic whose properties can meet the use requirements and remain unchanged during the storage period, but can be degrade into environmentally sound substances under natural environment conditions after use. BPs are a new type of plastics that can be biodegraded and disappeared in the natural environment (HYPEPicó and Barceló, 2019). Its degradation principle is that it can be decomposed by microbes (bacteria, fungi, algae, etc.) existing in the nature to materials (CO_2, H_2O, CH_4 and biomass), which can be integrated into the natural ecosystem without ecotoxic effect or residual by-products. The ideal BP is a kind of polymer material, which has excellent performance and can be slowly biodegraded, and finally it exists in nature as a part of carbon cycle. According to the degree and nature of biodegradation, BPs can be divided into two types: completely biodegradable plastics and destructive biodegradable plastics. The first type is fully degradable, which is made of natural polymers such as starch, cellulose and chitin or agricultural and sideline products through microbial fermentation or synthesis into degradable polymers (Iannotti et al., 2018). According to the source of new materials, BPs can be roughly divided into three categories: microbial synthetic plastics, natural polymer plastics and synthetic biodegradable plastics. Microbial synthetic plastics are a kind of polyester with aliphatic structure and ester group as the main chain (such as PHB), which is produced by special microbes with sugar and organic acid as raw materials through fermentation and synthesis (Belal and Farid, 2016). The natural polymer plastics are some polymers existing in nature, among which the most representative is all starch plastics. Starch is a polysaccharide produced by plants to store energy. Starch based BP is thermoplastic starch (TPS), which is a material made by heating and mixing starch with plasticizer. Starch based biosynthetic plastics are more excellent degradable materials based on starch (Gere and Czigany, 2019). The second type is destructive biodegradable plastics, which are not completely degraded (Picó and Barceló, 2019). It is that a natural polymer such as starch is combined with a synthetic polymer to achieve the purpose of destroying the structure of the copolymer by biodegradation of natural components, such as oxo-biodegradable polymers (Thomas et al., 2012). Through the addition of additives, the molecular chain in the polymer will be destroyed, which will lead to its biodegradability (Napper and Thompson, 2019). The combination of natural ingredients and synthetic ingredients includes blending in molten or solution state, copolymerization of monomers in mixed dispersion system, etc. The difference between the two is that the natural component in the former is added into the formed ordinary plastics as an additive, and does not establish a chemical bond with the polymer structure of the plastics; the latter is connected into the chain by chemical bond as a monomer of the plastics.

Due to its good biodegradability, BPs are mainly used as soft and hard food packing materials. Packing is the largest application filed of BPs at present (European Bioplastics, 2019). The best-selling products are garbage bags, soft packaging, rigid packaging and disposable ceramics. In the future, the main market of BPs is plastic packing film, agricultural film, disposable plastic bag and disposable plastic tableware. Compared with conventional oil-based plastic materials, the cost of BPs is slightly higher (Rujnićsokele and Pilipović, 2017), but people are willing to choose new BPs with higher price to protect the ecological environment. Therefore, the BP industry has a huge development prospect and broad application market.

3. Can BPs solve the problem of plastic environmental accumulation?

With the rapid development of petrochemical industry, plastics have gradually penetrated into every aspect of daily life, followed by the problem of “white pollution” which can not be ignored. These most incorruptible waste plastics not only do harm to human health, but also to the ecological environment (Shen et al., 2019b; Shen et al., 2019c). At present, the common treatment methods for waste plastics are incineration, landfill and recycling. As we all know, incineration and landfill are the most negative treatment methods, which cause great pollution to the environment such as release of stimulate gas and leakage of leachate, and are very undesirable. Recycling is another relatively good way, however, actually, only a small percentage of “recyclable” plastic wastes are recycled into the original products, even the most easily recycled plastics (Ellen MacArthur Foundation, 2016). Challenges lie in the use of colorants, additives and fillers in the plastic production process, pollution from consumer use, and loss of production during recycling. Low-grade plastic waste, such as multi-layer plastic packing and plastic film, is particularly difficult to separate and dispose. The plastic can only be recycled about 2–3 times before its quality drops to the point where it can no longer be used (Sedaghat, 2018). Each cycle of the recycling process shortens the length of the polymer chain, thus causing mass loss and requiring further material treatment. As such, the best way to deal with waste plastics is to make them decompose into harmless CO_2 and H_2O in natural state to return to nature.

Plastic is a kind of high molecular compound which is polymerized by monomers. The long chain of carbon molecule in its structure is very firm and not easy to break, which is the main reason why conventional oil-based plastics are difficult to decompose. The principle of BPs is to reduce the difficulty of breaking the long chain of carbon molecule, so that it is easy to decompose from polymer into small pieces, and then further degrade into CO_2, H_2O, and biomass. Unfortunately, however, there are still questions whether BPs can be a promising solution to solve the waste disposal problem and global plastic pollution. Accordingly, three scientific evidences are discussed here.

Firstly, it is well known that BPs are currently not a substitute for most conventional plastics. At present, only PP and PE are the most common petroleum based plastics in the world (Geyer et al., 2017). Global plastic production has reached 335 million tons in 2016 and 348 million tons in 2017 and is growing (PlasticsEurope, 2018). BPs only accounted for 0.5% of about 335 million tons of the annual plastic production, and are expected to increase to about 2.62 million tons in 2023 (European Bioplastics, 2019). Although the production of BPs is still increasing, it is no more than a drop in the bucker to solve the global problem of plastic environmental accumulation. The key reason is cost. Plastic is too cheap, the production process is too mature, and the use is too large in the world. According to the analysis, the price of BPs produced by the current process is about several times (3–10 times) that of conventional PP and PE (Luyt and Malik, 2019). Moreover, some BPs are not as good as conventional plastics (Shahlari and Lee, 2012). For example, PHB has better barrier properties than PP, which makes PHB superior to commercial plastics in the packaging of oxygen-sensitive products such as food and beverages. However, its application is still limited due to its low plasticity and impact strength, which results in many difficulties in polymer processing. The above two factors greatly limit the popularization and application of BPs and hinder the substitution of BPs for petroleum based plastics.

Secondly, the production of BPs seems to be much easier than their treatment. Degrading a polymer, especially conventional plastics, requires more energy and exertions, which may also occur on BPs. Biodegradability is related to the chemical properties of polymers and the environmental conditions. Biodegradation is the processing of using living organisms (bacteria, fungi, etc.) to degrade BPs into oligomers, monomers or CO_2 and H_2O, and eventually entering the ecosphere. The biodegradation mechanism of BPs is illustrated in Fig. 1. Biodegradation usually involves three phases: biodeterioration, biofragmentation, and bioassimilation (Emadian et al., 2017). BPs have long chain, high molecular weight and complex chemical structure, which means that they can neither be ingested by microorganisms nor further degraded via cell membranes. In biodeterioration, living organisms aggregate on the surface or inside of environmental BPs to form biofilms (microbial colonization), and the properties of BPs would be changed due to the continuous growth and reproduction of microorganisms. In biofragmentation, BPs are gradually converted into oligomers and monomers in the presence of depolymerase produced by microorganisms. Finally, these substances are assimilated by microorganisms to provide carbon and energy sources and then converted into CO_2, H_2O and other materials. When these metabolites are released back into the environment, the whole biodegradation process of BPs is completed. However, biodegradation of BPs needs certain environmental conditions, which is controlled by oxygen content, ambient temperature, pH, water content, polymer characteristics, etc. (Fig. 1). A fact is that BPs can be biodegraded but the degradation process needs specific conditions that are not always reliable under the natural conditions (Nazareth et al., 2019). For example, the slow degradation of BPs in marine environment has been noted (Morohoshi et al., 2018; Sashiwa et al., 2018), and the non-degradability of BPs has also been observed ins some cases

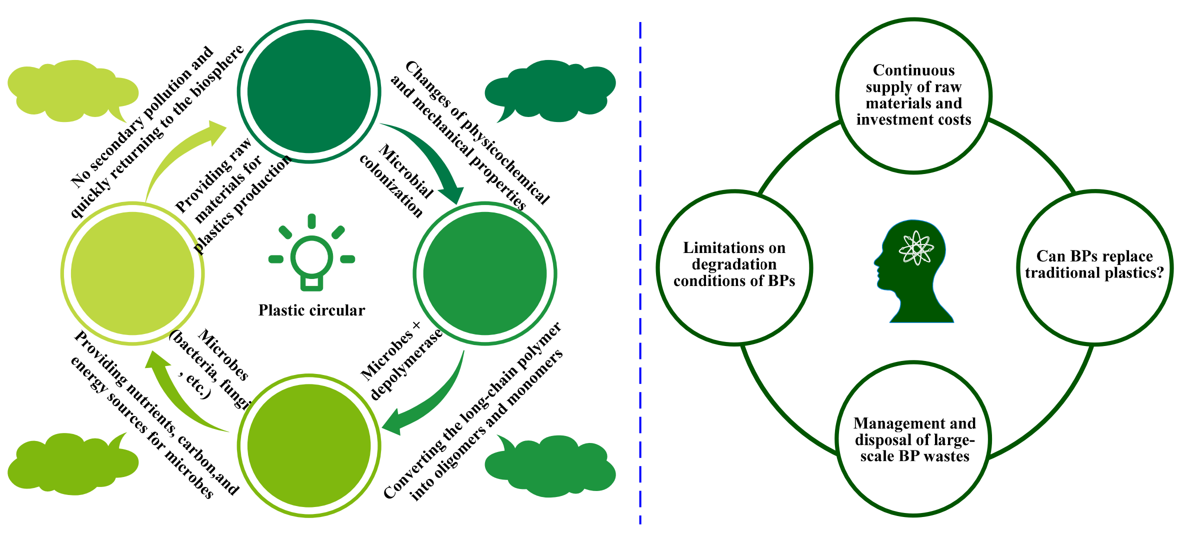

Fig. 1. Biodegradation process of biodegradable plastics (BPs) and influencing factors. The biodegradation processes of BPs are controlled by many factors: microbes, degradation conditions and BPs themselves. These conditions may not be always feasible in field conditions. Supply of raw materials, investment and operational costs, and effective management of BP wastes can also directly or indirectly affect the wide application of BPs.

(Napper and Thompson, 2019). Consequently, these factors in the biodegradation process must be considered. The time of biodegradation controlled by polymer characteristics is critical for determining the applicability of BPs to end-of-life management technologies or their possible fate in the environment. If the biodegradation rate is not significantly different from that of conventional plastics of the same kind even in the presence of microorganisms and key enzymes, limited biodegradability ill not benefit the environment or the management of BP wastes. Biodegradation depends on the complexity, the chemical structure and the crystallinity of the polymers. BPs with functional groups (−COO−, −OH, and −COOH) and with flexible active sites have higher degradation rates because these active groups can bind to enzyme sites much faster than those on rigid BPs. Shorter polymer chains lead to faster degradation, and complex chemical structures (e.g., PHB) require additional enzymes or complex coenzymes (Narancic and O'Connor, 2019). Ambient temperature and pH will affect the biodegradation rate because surface cracking of BPs caused by temperature and pH changes will accelerate the degradation. The presence of plastic additives in BPs may also interfere with the biodegradation process. Additionally, large-scale disposal of BPs must be also considered. The production and consumption of large quantities of BPs mean that a promising solution for large-scale treatment is needed. Large-scale plastic waste is usually disposed of by landfill, incineration, biological treatment (composting and anaerobic digestion), and recycling. Currently, industrial composting is the main concern in the management of end-of-life of BPs (Narancic and O'Connor, 2019). Before composting, BPs suitable for composting should be collected and separated through separate collection schemes and transported to industrial composting facilities.

Thirdly, change of human behavioral awareness is important. The solution to the problem of global plastic pollution needs a change in human behavioral awareness combined with viable promising approaches, and the latter will be largely ineffective without the former. We should not consider BPs as a technical solution, thereby excusing our environmental responsibility, because littering does not change with the promotion of an effective technology. There are several possibilities for unmanaged plastics, including littering, open dumping and open burning, which are more prevalent in rural areas or where waste management infrastructure is less developed. BPs must be managed by society rather than being randomly released into the environment. In addition, the use of greenwashing practices affects the purchase of so-called biodegradable products by buyers who believe in sustainability or environmental privilege, and may cause people to improperly discard these materials into the environment (Nazareth et al., 2019). To some extent, these strategies can also have a positive impact on purchase decisions, which is very unfavorable to the global public policies to control plastic pollution (Choice, 2010). Given the technologies currently available to identify polymers, products claiming to be biodegradable should be strictly controlled and such strategies should be adopted before such environmental damage leads to a loss of consumer confidence. Accordingly, BPs cannot provide an approach for society to continue to throw rubbish because it is also a kind of environmental pollution that BPs are thrown at random and piled up in the environment, but provide a new waste management option for human beings. The accumulation of plastic waste on the earth is still a problem and the management of plastic pollution requires global efforts.

4. What are the potential risks of using BPs to the environment?

BP is also a kind of plastic, which inevitably has a potential impact on the environment during its application. When BPs are disposed in an uncontrolled manner, there are two fates in the environment: accumulate and break up. Like conventional plastics (PE and PP), BPs can also fragment into microplastics and nanoplastics. Recently, scientists have begun to study the impacts of biodegradable microplastics (BMPs) with the gradual understanding of BPs. Shruti and Kutralam-Muniasamy (2019) thoroughly discussed the potential effects of BMPs on the environment. The potential effects of limited types of BMPs on aquatic organisms have been characterized. Studies performed by Green et al. (2015) and Green et al. (2016) have demonstrated the adverse effects of BMPs (PLA) on diversity and benthic community growth richness. Similar results of respiratory rate of *Arenicola marina* L. in sandy sediment have also proved by the high concentration stress and the increase of respiratory rate caused by PLA in flat oyster and the high dose response of PLA in sandy sediments (Green, 2016). Straub et al. (2017) studied the adsorption and function of BMPs (PHB) and polymethylmethacrylate microplastics (PMMA) in the freshwater amphipod *Gammarus fossarum*. The results showed that both microplastic treatments different particle sizes (32−250 μm) significantly affected the assimilation efficiency of amphipod *Gammarus fossarum* and reduced the increase of wet weight. González-Pleiter et al. (2019) studied the potential ecotoxicological effects of secondary PHB nanoplastics (25−100 $mg \cdot L^{-1}$, 200 nm) on three representative aquatic organisms (*Daphnia magna*, *Anabaena sp.* and *Chlamydomonas reinhardtii*). The results showed that secondary PHB nanoplastics induced a significant decline in cell growth changes in related physiological parameters in all three aquatic organisms. The authors also pointed out that the PHB nanoplastics released as a consequence of abiotic degradation of PHB microplastics were detrimental for the tested aquatic organisms. The above studies have shown that biological exposure to conventional and biodegradable microplastics and nanoplastics also shows similar ecotoxicological effects to test organisms. Consequently, induced changes can indicate that BPs are not completely safe to the environment.

In addition, BMPs can also act as vectors for microorganisms and chemical pollutants. Some studies have evidenced that microplastics are important vectors of microorganisms (Frere et al., 2018; Shen et al., 2019c) and chemical pollutants (Hartmann et al., 2017; Koelmans et al., 2016; Pittura et al., 2018; Ziccardi et al., 2016). Due to the similar characteristics of particle size, good fluidity and good stability, BMPs also have a strong adsorption and enrichment tread for chemical pollutants and microorganisms. Recently, Zuo et al. (2019) investigated the adsorption and desorption of poly(butylene adipate co-terephtalate) (PBAT, 2338 ± 486 μm), PS (250 μm) and PE (2628 ± 623 μm) for traditional organic pollutants (phenanthrene). The results showed that the adsorption and desorption capacity of PBAT BMPs was significantly higher than that of PS and PE microplastics. The authors further reported that BMPs were a strong vector of phenanthrene compared with the conventional microplastics.

Unfortunately, however, it is too early to assert the threat state (with or without threat) of BMPs due to the lack of data in this respect. Few studies have found the effect of BMPs on very limited aquatic organisms. The potential effects of BMPs have not been performed in many cases, and it is unclear for a series of animals used as human food. As such, it is difficult to determine the more specific threat that BMPs may pose to the health of organisms, ecosystems and humans. The coecological effect of BMPs on ecosystem should be a concern issue in the future. It is necessary to evaluate and integrate the effect on human food safety and health by testing the potential effects of BMPs on different organisms and ecosystems.

5. What is the function of BPs in solving plastic pollution?

Although the current level of substitution is very low, BPs can replace most of the conventional plastics currently in use and consumption. Shen et al. (2009) investigated the potential technology substitution of BPs for conventional oil based plastics. The authors reported that the largest substitution rate could reach up 94%, of which 31% were BPs and 63% were biobased plastics but not biodegradable plastics. However, the actual level of production and substitution is still far from the theoretical maximum. Because of economic factors, difficulties in rapid scale and the availability of BP raw materials, and slow adoption of new BPs in the plastic industry, this potential may not be exploited in the short and medium term. Although BPs are still in the development stage, and the market is not fully formed as a whole, it has shown the substitution effect on conventional plastics in some fields.

a) Disposable plastic products

There are a large number of disposable plastic products in daily life, such as plastic bags, garbage bags, disposal plastic lunch boxes and tableware, product packing bags. This kind of these products is widely distributed in our daily life, with a large amount of consumption, but as the same time, they produce a series of problems such as white pollution. For BPs, disposable plastic products are the most potential application areas in the future strategy of realizing low-carbon economy and sustainable development of industry. BPs used for disposable products need to have a faster degradation speed, and their mechanical properties should be able to meet the strength requirements of daily use.

b) Agricultural application (biodegradable plastic mulch film)

At present, most of the mulch film used in production is a kind of high molecular hydrocarbon transparent film, which is made of PP blow molding. Conventional high polymer plastics have good strength, and it will take hundreds of years for the residual film to become harmless material to the soil. The residual plastic film in the soil has a bad effect on the arable and aeration of the soil, and even leads to the decreases of crop yield. The harm of plastic mulch film pollution is mainly manifested in the following aspects: (1) reducing the level of soil fertility; (2) affecting the fertilizer efficiency; and (3) making the crop malnutrition. The treatment of residual mulch film is mainly driven by administrative forces, mechanical recovery and manual pickup. Unfortunately, however, no matter mechanical or manual, the accumulation of residual mulch film cannot completely remove for a long time, and the cost of recovery of residual mulch film is also gradually rising. The most feasible way to solve the problem of residual film is to use agricultural degradable mulch films. On the one hand, the degradable film has the same effect as the conventional film (PBAT vs PP), and at the same time solves the inevitable residual film pollution caused by the conventional film. On the other hand, large-scale promotion of degradable mulch film can play a role in resolving traditional excess capacity.

c) High-end market

The application of BPs in high-end market includes medical supplies, drug release materials, 3D printing materials, etc. PLA, PHA, polycaprolactone (PCL) and other BPs have good biocompatibility, which can be controlled by molecular design synthesis, so they have development potential in high-end market. PLA is one of the most commonly used 3D printing wires. Compared with other used 3D printing materials such as acrylonitrile butadiene styrene, PLA has many advantages: it not only has rich colors and good transparency, but also can achieve higher printing speed and better printing; moreover it is environmentally friendly. Because of good biocompatibility, PHAs are widely used in medical fields, such as medical suture, repair device, orthopedic needle, guided tissue repair, articular cartilage repair stent, etc. PCL has good thermoplasticity and molding processability, which can be made into fibers, flakes, sheets, etc. Due to their special properties, BPs will play more irreplaceable role in the high-end filed, and have broad development spaces.

6. What are the opportunities and challenges of using BPs?

BPs are of great significance for global environmental protection. The emergence of BPs is an inevitable requirement for the sustainable development of the environment in the 21st century. Therefore, it is common goal for all countries in the world to strengthen the research on BPs and promote the product development of BPs. The challenge comes from promoting this alternative potential. There are four important factors: technical aspects, financial, management and consumers (Fig. 2).

Firstly, the development of technology plays a big role in the acceptance rate of BPs. In the existing technology, there are methods to improve the thermal stability and mechanical strength of BPs by compounding with inorganic materials. It will also cause the increase of degradation products and the decrease of degradation rate. The biodegradation performance of BPs is realized by degradation of macromolecules into micromolecules by environmental microorganisms, and this degradation process is very slow, especially the resin molecular materials. It is difficult to recycle the waste plastics, and whether the degradation products will not pollute the environment remains to be studied. Additionally, large-scale disposal of BPs must be also considered. Improvements to the compost infrastructure, including compost classification and BP recycle, will allow for the treatment of BPs in compost facilities (Andrade et al., 2016). Therefore, waste management and public behavioral awareness are the important factors in solving the problem of plastic accumulation in the environment, but they are not fundamental. The progress of technology and the development of new materials are also considered in the future.

Secondly, financial measures greatly inhibit the development of BPs. Compared with conventional plastics, the material price for producing BPs is relatively high, and the technical process is complex, so the final product price is far high than that of conventional plastics. Cost has always been an important indicator of whether a product can be applied to the market on a large scale. Therefore, the price of agricultural raw materials should be monitored to ensure that they are competitive with fossil fuels, so as to promote the transfer of conventional materials to biodegradable materials. Moreover, new equipment and synthesis process should be optimized to reduce the production cost of BPs. Improve the function of synthesis BP materials, such as cellulose, starch and shell, and widen the use of materials, which is also an important measure to reduce costs.

Thirdly, the BP industry lacks a favorable management system. There are three ways to manage plastic wastes: recycling, incineration, and sanitary landfill. Due to the chaotic collection system of conventional plastic and BP, the disposal of plastic wastes has become difficult. BPs can be burned like conventional plastic, and the energy of BPs is similar to that of conventional plastics (Dilkes-Hoffman et al., 2019). However, in terms of landfill, conventional plastics and BPs are quite different. Conventional plastics are difficult to decompose in landfill. During degradation of BPs in landfill, methane, a higher global warming potential gas than CO_2, can be produced. Industrial composting and anaerobic digestion

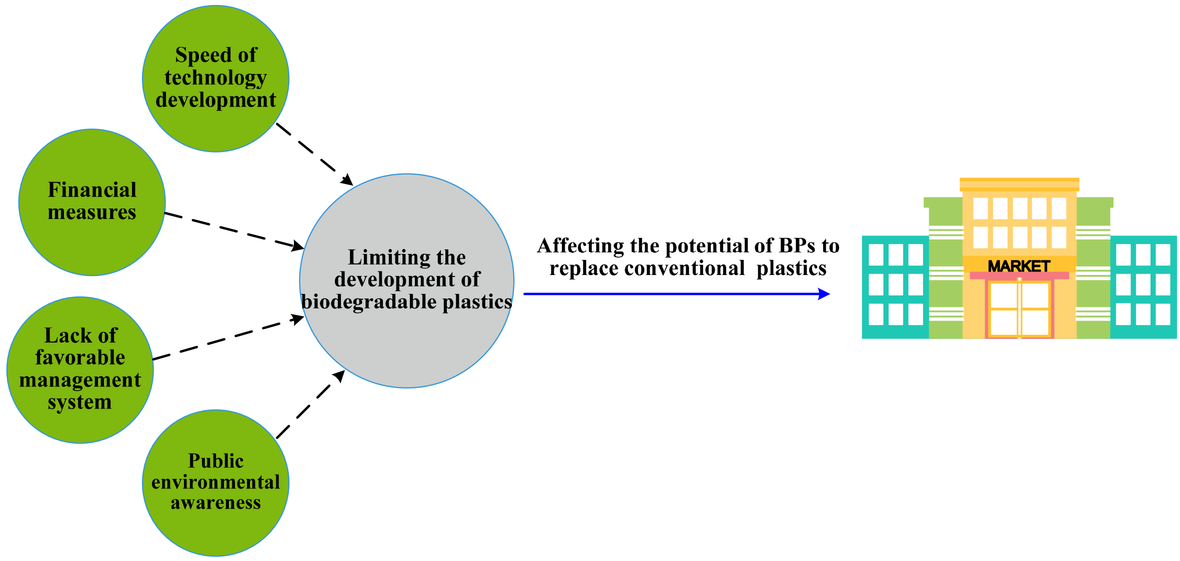

Fig. 2. Potential challenges of BPs to replace conventional plastics. There are four important factors: technical aspects, financial, management and consumers. The actual level of production and substitution is still far from the theoretical maximum. Because of economic factors, difficulties in rapid scale and the availability of BP raw materials, and slow adoption of new BPs in the plastic industry, this potential may not be exploited in the short and medium term.

are also concerns in the management of end-of-life of BPs. However, before that, BPs suitable for composting and anaerobic digestion should be collected and separated through separate collection schemes and transported to industrial composting and digestion facilities.

Finally, raising the environmental awareness of the public is also an essential part of promoting BPs. How to identify and deal with BPs is not only a major concern of the public, but also a problem to be solved. It is recommended to develop identification codes for BPs (bags, containers, and other materials) to help separate them from other recyclable materials. This needs to be combined with local education on how identify and deal with BPs. BPs may not have an adverse impact on waste management if appropriate labelling and differentiated waste collection systems are developed.

7. Conclusion

The accumulation of plastics on the planet is a severe problem in this time. The severity of this problem will exponentially increase with the increase of global plastic production and consumption. As such, measures should be taken to reduce the rate of plastic accumulation and the ecological effects caused by the inevitable accumulation. BPs can effectively protect and improve the environment, and greatly promote the development of environmental protection. However, the production of BPs seems to be much easier than their treatment. The performances of BPs are greatly questioned. There is no answer whether BPs can be a promising solution to solve the waste disposal problem and global plastic pollution. Many aspects of BPs are still in their infancy. There is no single solution to solve the problem of plastic accumulation in the environment, it is important to determine the effective combination of solutions. Just for now, BPs should be a part of the solution, albeit a very small part. The effect of BPs on plastic accumulation should not be underestimated. In addition, under the severe situation of energy conservation and emission reduction, the development of BPs is of strategic significance. Therefore, we still have a long way to go to solve the global plastic pollution until (a) all non-biodegradable plastic products can be replaced by BPs with the same or similar performance; (b) everyone in the world can dispose of BP waste according to regulations and laws and should be responsible for our environment; (c) theses collected BPs can be biodegraded on a large-scale, and the biodegradation byproducts can be returned into the ecosystem; and (d) raw materials for BPs can be continuously and inexpensively obtained from the environment.

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Appendix A. Supplementary data

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Declaration of interest

The authors have no conflict of interest to declare regarding this article.

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