Land-Based Plastic Pollution and Biocontrol in Developing Countries: Issues, Challenges and Directions

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Abstract

The increasing accumulation of plastic wastes in the environment has been a threat globally with the developing countries bearing the brunt more. In this review, causes, sources and ecological consequences of land-based plastic pollution in developing countries are highlighted with a view to suggesting green solution to the problem of plastic or polymer pollution in terrestrial environment. Besides, the emerging biocontrol measure and its life-cycle analyses are emphasized along with the opportunities arisen from the green method. Thus, the study concluded that biocontrol method is a feasible, cost effective and eco-friendly method for the biomanagement of plastic pollution in developing countries.

Keywords: *biocontrol, developing countries, land-based, plastic pollution, soil environment*

1.0 INTRODUCTION

The soil environment is an ecosystem exposed to pollution constantly because it is a natural sink for most pollutants released from natural sources and man-made activities. In assessing pollution effects, land pollution by polymeric or plastic wastes has been rated as one of the challenging environmental issues of the millennium. Plastics are polymeric products consisting of wide range of synthetic or semi-synthetic organic and inorganic compounds. Plastics are majorly manufactured from petrochemicals with polymeric outputs of polyethylene (PE), polycaprolactone (PCL), polyurethane (PUR), polyhydroxy butyrate (PHB), polyhydroxyalkanoate (PHA), polyvinyl chloride (PVC), polyethylene terephthalate (PET), polybutylene succinate (PBS), polylactic acid or polylactide (PLA), polypropylene(PP), and polystyrene (PS) used for diverse applications (Yoshida *et al*., 2016).

Due to their extensive industrial and domestic applications, there is an ever-increasing trend towards the production and consumption of plastics. However, a wide spectrum of these polymers is non-biodegradable with few exceptions. The long-term accumulation of non-biodegradable polymers in the soil led to a decrease in soil fertility in addition to many other ecological and health crises. According to Temoor *et al*. (2018), the broad use of plastics, lack of proper waste management strategies, and casual community behavior towards the proper disposal of plastic wastes are factors responsible for increase in the risk of plastic pollution in the environment. Apart from the fact that microplastics are released in soil environment after prolong resident time of plastics wastes in soils, most (90%) of the plastics come directly from land-based sources (Jambeck *et al*., 2015). Annually, between 4 and 12 million metric tons of plastics that are mismanaged on land enter the oceans. According to Jambeck *et al*. (2018), this amount is released by occupants of land within 50 km from the coast. In addition, plastic wastes spill into marine environment continually as 76% of the 50 largest uncontrolled dumpsites found around the world are located on coastlands. This is because across the globe, about two billion people live without waste collection facilities while 3 billion use poor solid wastes management methods and uncontrolled waste disposal sites around their environment (Barnes *et al*., 2009). However, according to Geyer *et al.* (2017) without waste management and infrastructural improvements; the cumulative quantity of 12 metric tons of plastic wastes (13.2 billion US tons) will enter landfills or the environment by 2050. Similarly, if current production and poor waste management trends continue, 90% of plastic wastes will enter the ocean by the year 2050. In Africa and other developing nations, increasing trend in per capita consumption, urbanization, and population growth combined with a lack of sufficient infrastructure to manage the increased waste generation aggravate the issues of plastic waste management (Jambeck *et al*., 2018). Many researchers claimed that developing countries of the world are responsible for plastic pollution as the highest rates of population growth and urbanization occurred in major coastlines of developing nations (Jambeck *et al*., 2015). Moreover, large amount of plastic wastes was reported in Africa's coastline areas. By 2060, an estimated 49 million more people in low elevation coastal flood plains will be found along coastline areas with more plastic wastes generation and its attendant negative impacts (Lebreton and Andrady, 2019). According to Jambeck *et al*. (2018), Algeria, Angola, Egypt, Ghana, Kenya, Libya, Morocco, Nigeria, South Africa, Sudan, and Tunisia are developing countries with high tendencies to generate more plastic wastes in recent years because they have prominent coastlines areas. Therefore, there is urgent need to address the issues of plastic pollution to ensure sustainable environment. Diverse methods such as recycling, incineration, and chemical methods have been suggested to alleviate the debacle of plastic pollution in the environment. Besides, these methods produce several secondary impacts with negative consequences in the environment. However, the use of biocontrol or biological control has been suggested as a reliable and cost-effective means of harnessing plastic wastes. In developed countries many researches have been conducted specifically on the use of microbes and engineered microbes for the biodegradation of recalcitrant polymeric wastes in terrestrial environment (Pyriyanka *et al*., 2011). Bacteria and fungi species such as *Pleurotus species* have been suggested as biological agents that could be engineered for the biodegradation of plastic wastes in lands (Sudhakar *et al.*, 2012).

Recently, diverse metabolic capabilities of microorganisms and their interactions with plastics in temperate ecosystems have been revealed (Urbanek *et al*., 2017). Contrarily, the knowledge explored in the areas of biocontrol of plastic wastes is scanty in most developing countries. Thus, the essence of reviewing the biocontrol of land-based plastic pollution in developing countries as an environmentally-friendly, green alternative and cost-effective method. Notwithstanding, to achieve successful biodegradation processes, scientists have supported that petroleum based nonbiodegradable plastics be replaced with bioplastic resources in order to increase the biodegradability of plastic wastes (Guo *et al*., 2012; Gajendiran *et al*., 2016; Europlastic, 2018; www.bioplasticresearch.com., 2019). The incorporation of biogenic natural capitals such as fibers into plastic to produce bioplastics has diverse advantages such as enhancement of biocontrol of plastic wastes and reduction in the amount of petrochemicals used for plastics production. The reduction in the amount of petrochemicals will safe petrochemicals for other uses as the price of crude oil increases indiscriminately. Moreover, the replacement of petroleum-based plastics with bio-based polymers will save energy; as production of petroplastics consumes 65% more energy with up to 30 to 80% higher greenhouse gases emitted (Ahvenainen, 2003).

2.0 CAUSES OF LAND-BASED PLASTIC POLLUTION IN DEVELOPING COUNTRIES

The pollution of the soil environment by plastics is of great concern across the globe because plastics are recalcitrant in nature (European Commission, 2013). The worldwide production of plastics from land was approximately 322 million tons in 2015 (Mangaraj *et al*., 2018). According to Lebreton *et al*. (2018), 5.25 trillion plastic debris in which the majority comes from land may float on the oceans as the largest percentage accumulated in the North Hemisphere. Human activities that are land-based are the major sources of plastic pollution in the environment (Hammer *et al*., 2012). In another vein, plastic debris from land may also be transferred into the marine ecosystem through wind action, animal movements among other factors. Besides, poor waste management procedures on land, accidental or incidental releases as well as population pressures are examples of causes of land pollution by plastics. Approximately 275 million metric tons (MT) of plastic wastes were generated on land by people in 192 coastal countries in 2010, with 4.8 to 12.7 million MT entering the ocean from land (Jambeck *et al*., 2015). Moreover, studies have shown that the primary pathway for plastic wastes on land includes human movement and behaviour such as littering or dropping of items (Dada and Awotoye, 2013), vehicular transport along roads in villages, towns and cities among others. In the research demonstrated by Lebreton and Andrady (2019), 91% of municipal plastic wastes (MPW) generated on land are transported via watersheds larger than 100 km^2. At the high peak of rainfall in the month of August, September and October, the peak of plastic inputs from land into the ocean were reported in the marine environment of Africa and North America with their River outflow locations stacked with massive plastic wastes emanating from land.

3.0 ENVIRONMENTAL IMPACTS OF LAND-BASED PLASTIC POLLUTION

There has been growing public concern over environmental deterioration associated with the disposal of conventional plastics such as air pollution while burning plastics. Carbon monoxide, chlorine, hydrochloric acid, dioxin, furans, amines, nitrides, styrene, benzene, 1, 3-butadiene, and acetaldehyde are examples of obnoxious gasses released into the environment during the combustion process (Kirwan, 2003). Plastics do not biodegrade and can remain in place for centuries, until they are burned or used as recycling products. According to EU (2017), by 2050, the world's oceans could contain more plastic than fish (by weight) from land; and that plastics production will account for a greatly increased share of global oil use and greenhouse gasses (GHG) emissions. Besides, the current system of plastics production is mainly linear rather than circular, with heavy reliance on non-renewable fossil feedstock. It also has low levels of re-use and recycling, and suffers from high levels of leakage into the environment with attending ecological crisis.

Among the ecological factors that are frequently affected is the soil environment because it is one of the paramount receivers and natural sinks of waste materials including plastics. Social factor such as population pressure are known to trigger the dumping of plastic wastes in marine environment. For instance, in 2010, Sri-Lanka produced up to 1.59 MMT of plastic wastes per annum while Egypt produced 0.90 MMT of plastic wastes in the same year. However, 0.63 MMT of plastic wastes was produced annually in South Africa. Presently, in Nigeria, 450,000 MT plastic wastes are released annually from land and later end up into ocean bodies from Lagos State. This amount is half of the plastic wastes produced by other states in Nigeria. This is because Lagos state is the most populated of all the megacities and coastal states in Nigeria (Vanguard, 2018). The deliberate release of plastic wastes, when abandoned or dumped outside licensed waste collection points is a challenge to the ecosystem functioning. Incidental release through the loss of containers, poor management of plastic wastes (Barnes *et al*., 2009) are one of the channels by which plastics pollutes the land.

Moreover, sea bagging activity which may involve the packaging of plastic wastes produced on land and dumping in aquatic environment has been one of the major sources of plastics in the environment. Many household plastics wastes, cargo wiring straps, covering materials and cargo plastic residues, packaging material, plastic sheets, engine-room oil or detergent containers, and discarded plastic based medical and sanitary equipment are dumped on land indiscriminately (Hammer *et al*., 2012). Consequently, sea lives are threatened by plastic products used on land and disposed in water annually. 1n 2016, four out of the thirteen whales found beached at Germany had significant amounts of plastic wastes in their stomachs after carrying out a necropsy study on them. The plastic burden found in them included approximately 13-meter-long shrimp fishing net, a plastic car engine cover, and the remains of a plastic bucket used on land (Yale, 2016). According to Kuhn *et al*. (2015), 233 marine species, including all marine turtle species, more than one-third of seal species, 59% of whale species, 59% of seabirds, 92 species of fish and 6 species of invertebrates has been recorded to ingest plastics. Not less than 344 species including all marine turtle species, more than two-thirds of seal species, one-third of whale species, and one-quarter of seabirds had been entanglement in recent times. Moreover, in 2018, the autopsy performed on a dead pilot whale in Thailand by Thailand's Department of Marine and Coastal Resources revealed that more than 17 pounds of plastic wastes including more than 80 plastic bags were retrieved from the stomach of the Sperm whale (Yale Environment 360, 2018). Besides, sudden death, marine lives are entrapped, encircled or constricted by plastic debris. In addition, 89 species of fish and 92 species of invertebrates has also been reported incapacitated by plastic materials after been entangled (Kuhn *et al*., 2015).

Moreover, biochemical responses to plastic ingestion have also been observed in marine wild lives. Oxidative stress, metabolic disruption, reduced enzyme activity, and cellular necrosis were observed by Ogonowski *et al*. (2016) in animals that are victims of plastic ingestion.

4.0 BIOCONTROL OF PLASTIC POLLUTION IN TERRESTRIAL ENVIRONMENT

Biocontrol of plastic pollution in the terrestrial environment has been regarded as a green technology that could be employed in treating land-based pollution by plastics in developing countries. Research demonstrations also revealed that microbes are capable of degrading plastics and bioplastics under conducive biodegradation condition (Figure 1). Microorganisms such as bacteria and fungi are involved in the degradation of both natural and synthetic plastics while some microbes have gone through gene shuffling bioengineering approach to improve their inert potentials to degrade plastics (Guo *et al*., 2012). Microbes such as *Brevibacillus borstelensis, Comamonas acidovorans TB-35, Pseudomonas chlororaphis, P. aeruginosa, P. fluorescens, Rhodococcus erythropolis, R. rubber, R. rhodochrous, Staphylococcus cohnii, S. epidermidis, S. xylosus, Streptomyces badius, S. setonii, S. viridosporus, Bacillus amyloliquefaciens, B. brevis, B. cereus, B. circulans, B. circulans, B. halodenitrificans, B. mycoides, B.*

*pumilus, B. sphaericus,*and *B. thuringiensis* are examples of microbes identified to degrade recalcitrant plastics such as polyethylene (Mangaraj *et al*., 2018).

To use the biocontrol method involving microbial degradation, the efficiency and the environmental safety of the method must be evaluated using standardized testing methods by assessing the biodegradation efficacy testing and evaluation criteria of the biocontrol method. The standardized testing methods have been developed and are regulated by organizations such as the International Standard Organization (ISO) and American standard and testing methods (ASTM). According to ASTM (2012), carbon dioxide is an end product of biodegradation and evolves over time. The extent of aerobic biodegradation in soil using a measurement of evolved carbon dioxide was the factor used to determine the biodegradability of the polymer (Dada, 2019). The test is designed as a respirometric biodegradation test method using biometer flask. The method can also be carried out in aqueous medium such as marine water. However, the ISO 17556:2003 specifies "Plastics–Determination of the ultimate aerobic biodegradability of plastic materials in soil by measuring the oxygen demand in a closed respirometer or the amount of carbon dioxide evolved" (ASTM, 2012)

This standard requires the reference material to be at least 70% biodegraded within six months. In addition, according to the criteria for the standard, carbon dioxide output from blank samples should be around 20% during both the plateau phase and at the conclusion of the test. Such CO_2 emissions from blank samples in a composting test do not have threshold values at the conclusion of the test because validation is carried out within 10 days of the test (ASTM, 2012). The criteria and the requirement above are necessary to assess the validity of any biodegradability test. Hence, deviations from these criteria shall be regarded as a null or invalid test. The standard test method is reliable and can be used to test all polymers from natural and synthetic origin, copolymers or mixtures that contain additives such as plasticizers, colorants or water-soluble polymers. Consequently, this test method is designed to achieve an ideal extent of biodegradation by providing sufficient aeration and humidity to the soil environment. Also, this test requires that the carbon dioxide output from the reference material should be more than 60% and for blank this should be 20% during both the plateau phase and at end of the test.

Researches are also ongoing on the production of materials from renewable natural capitals such as starch. In South Africa, Council for Scientific and Industrial Research (CSIR) successfully produced biopolymer from renewable natural capitals to replace plastic waste which conform to the requirement of standardized testing methods. The incorporation of natural renewable stocks or fiber into polymers resulted into the formation of biodegradable bioplastics. The mechanism of microbial degradation of bioplastics involves two stages. These stages are the primary and secondary phases which are referred to as primary biodegradation and the ultimate biodegradation (Sudhakar *et al*., 2013).

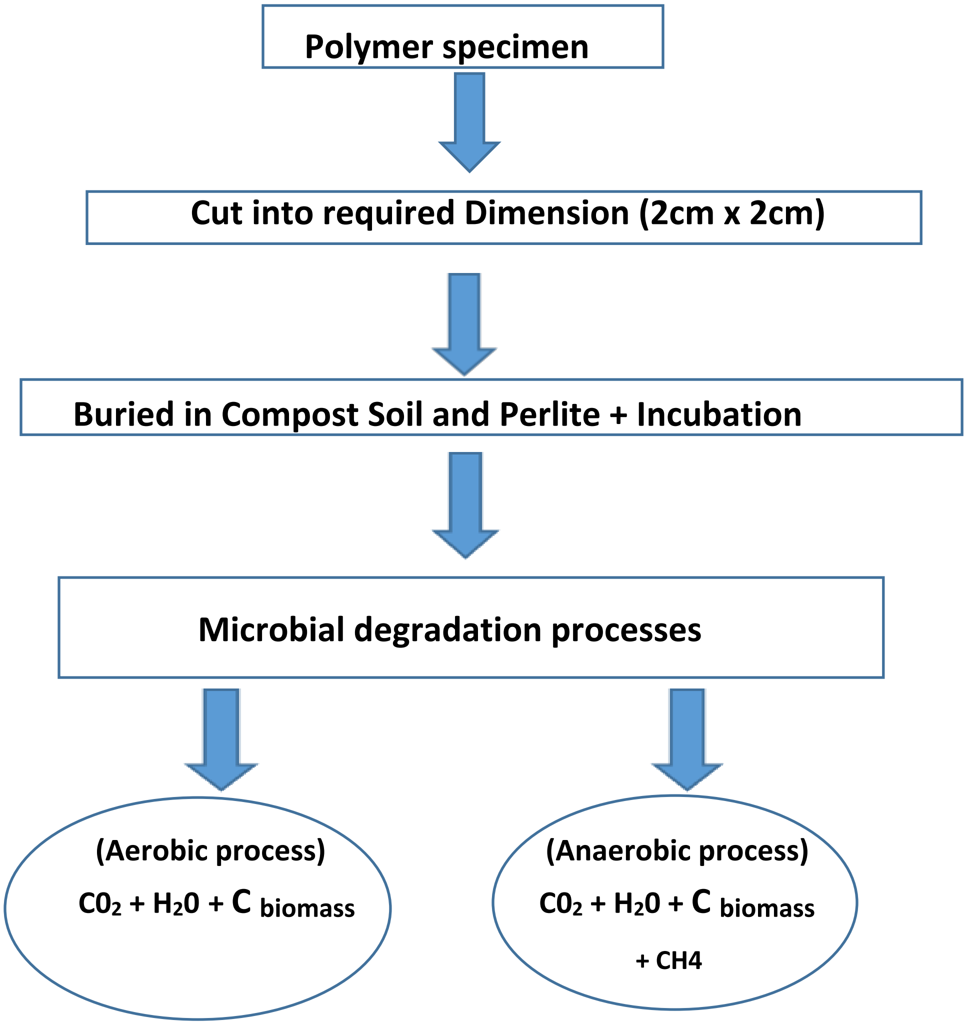

Figure 1: Biodegradation process of polymer or plastic material

At this stage, biochemical transformation of the biopolymer takes place leading to the disruption of the chain length thereby initiating the primary breakdown or biodeterioration (aging) (Maurizio *et al*., 2005). The term "aging" is used for the change in properties. It is utilized as polymer recycling, which reduces the outcome of pollution load. Polymer degradation (mineralization) forms new products during or at the end of process (Figure 2).

The main products of bioplastic degradation under anaerobic biodegradation are carbon dioxide, water and cell biomass. However, under anaerobic degradation, fatty acids, carbon dioxide, water and cell biomass are the product of the biodegradation process. Meaning that the natural biogenic polymers also are exposed to the sequential mechanisms of microbial degradation of biopolymers. Synthetic biopolymers made from starch or cellulose are biodegradable because of their biogenic origin. They degrade easily through composting. In addition to subjecting the potential biocontrol method to the standard test, life cycle analysis (LCA) of the bioplastic used is important. The LCA defines the scope of impact, the specific material flows and their impacts. The LCA also enables a better understanding of the environmental impacts of the bioplastic materials in addition with the science of industrial ecology, through the tools of biotechnology.

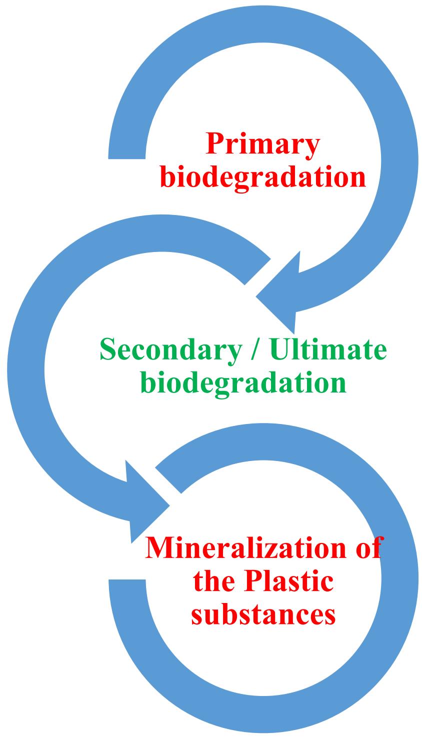

Figure 2: Major Stages in Biodegradation of plastics

4.1 The Standardized Testing Methods for Biocontrol of Plastics and Bioplastic Wastes

According to the United Nations, 3.5 billion people or half of the world's population are without access to crucial waste management services. Thus, there are significant economic and industrial interests in seeking ways of stopping plastic wastes pollution on the land; thereby fostering a more circular economy in addition with seeking environmentally friendly alternatives such as bioplastics to traditional petroleum-based plastic products (Lee *et al*., 2016). In view of these, the developed countries of the world such as the United Kingdom initiated the Commonwealth Marine Plastics Research and Innovation Framework (CMPRIF). Other environmentally sustainable groups also explore sustainable ways to clean up plastic pollution in the environment by developing environmentally friendly alternatives to plastics with improved biodegradability potentials. The production and the use of plastics with high degree of degradability such as bioplastics have been suggested as a feasible alternative. The production of bioplastics has numerous environmental benefits such as increased soil fertility, low accumulation of bulky plastic materials in the environment (which invariably will minimize injuries to wild animals), and reduction in the cost of waste management. Furthermore, biodegradable plastics can be recycled to useful metabolites (monomers and oligomers) by microorganisms and enzymes. Therefore, it is imperative to constantly work on improving the biodegradation of bioplastics for efficient management of plastic pollution in soil environment. Thus, the amount of plastics that will be released from land to other components of the environment would have reduced drastically. To achieve this, detailed knowledge about the biocontrol of land-based plastic pollution in developing countries is necessary. To use the biocontrol method involving microbial degradation, the efficiency and the environmental safety of the method must be evaluated using standardized testing methods by assessing the biodegradation efficacy testing and evaluation criteria of the biocontrol method (Sudhakar *et al*., 2018). Thorough testing and analysis are necessary both to optimize the properties of the polymers, and also to verify the true biodegradability of the polymer. The standardized testing methods have been developed and are regulated by organizations such as the International Standard Organization and American standard and testing methods (ASTM) (Annual Book of ASTM Standards, 1992; Sudhakar *et al*., 2013). According to ASTM (2012), carbon dioxide is an end product of biodegradation and evolves over time. The extent of aerobic biodegradation in soil using a measurement of evolved carbon dioxide is one of the factors used to determine the biodegradability of polymer. The test is designed as a respirometric biodegradation test method using biometer flask. The method can also be carried out in aqueous medium such as marine water.

This standard requires the reference material to be at least 70% biodegraded within six months. In addition, according to the criteria for the standard, carbon dioxide output from blank samples should be around 20% during the plateau phase and at the conclusion of the test. Such CO_2 emissions from blank samples in a composting test do not have threshold values at the conclusion of the test because validation is carried out within 10 days of the test. The criteria and the requirement above are necessary to assess the validity of any biodegradability test. Hence, deviations from these criteria shall be regarded as a null or invalid test. The standard test method is reliable and can be used to test all polymers from natural and synthetic origin, copolymers or mixtures that contain additives such as plasticizers, colorants or water-soluble polymers. Consequently, this test method is designed to achieve an ideal extent of biodegradation by providing sufficient aeration and humidity to the soil environment. Also, this test requires that the carbon dioxide output from the reference material should be more than 60% and for blank this should be 20% during both the plateau phase and at end of the test.

Biodegradation depend on both polymer structure and environmental factors. Moreover, wide scopes of tests are required to fully quantify the biodegradability of a given plastic. Globally, Standardized testing procedures have been defined by international organizations. These organizations are the International Organization for Standardization (ISO), Organization for Economic Co-operation and Development (OECD) and ASTM. The experimental procedures and designs from these organization will ensure a global uniformity in determining the biodegradability of plastics. The organizations define and regulate a number of standard test methods that are used to properly assess biodegradable polymers taking into consideration a variety of environmental factors.

Presently, in South Africa, indirect alternative method of controlling plastic wastes pollution on land is by encouraging people to use biodegradable bioplastics as alternative to plastic use. Researches are also ongoing on the production of materials from renewable natural capitals such as starch. In South Africa, Council for scientific and Industrial research (CSIR) successfully produced biopolymer from renewable natural capitals to replace plastic wastes which conform to the requirement of standardized testing methods (Department of Science and Technology, 2016). The incorporation of natural renewable stocks or fiber into polymers resulted into the formation of biodegradable bioplastics. These biodegradable bioplastics are classified into three classes such as biopolymers made from natural capitals of plant and animal origin, biopolymers produced by microbes and those synthesized from bio-derived monomers.

5.0 CONCLUSION

Land-based plastic pollution is a challenging issue across the globe. Developed countries of the world used various methods to reduce the debacle of plastic pollution. Some developed countries proposed amendments to the Basel Convention to provide countries the right to refuse unwanted or unmanageable plastic wastes in their territories as well as focus on coordinating scattered global initiatives and building up relevant international law. All these methods may be successful, however, the use of biocontrol to handle plastic wastes is a green and affordable method which can be employed by identifying potential microbes that are responsible for the biodegradation of plastic wastes. Besides, there is need to manage the environment sustainably by embracing the production of bioplastic products instead of nonbiodegradable plastics. Howbeit, more researches are to be conducted in the area of plastic wastes management through biocontrol method.

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