Valorization Of Organic Waste into Bioplastic: A Prospect Analysis for Bangladesh

Rabeya Sultana*[1], Md Musfike Meraz[2] and Md. Riad Hossain[3]

[1] Environmental Science Discipline, Khulna University, Khulna 9208, Bangladesh, e-mail: rabeya.sultana@es.ku.ac.bd

[2] Environmental Science Discipline, Khulna University, Khulna 9208, Bangladesh, e-mail: mdmusfikemeraz017@gmail.com

[3] Institute of Disaster Management, Khulna University of Engineering & Technology, Khulna 9203, Bangladesh, email: riad.hossain@idm.kuet.ac.bd

Abstract. Organic waste valorization offers a promising pathway for the creation of value-added products like bioplastics, while simultaneously mitigating the financial burdens associated with waste management. This study thoroughly examines the prospect of the production of bio-plastics from organic waste and thereby reducing the waste management burden in the context of Bangladesh. Urban areas of Bangladesh generate around 23,688 tons/day of municipal solid waste (MSW) of which 68.3-81.1% are organic and 75% of that organic fraction is food waste. By 2025, the urban population is expected to reach 78.44 million, generating 47,000 tons/day of garbage with 0.6 kg/day production rate. Studies have surfaced that the organic fraction of Municipal Solid Waste (OF-MSW) shows potential for producing polyhydroxyalkanoates (PHAs), with Enterobacter aerogenes bacteria producing 40g of PHAs from 1kg of O-MSW, alongside other byproducts, which equates to about 8236.9 kJ of energy. At a 40% efficiency rate, 18,800 metric tons of PHAs can be produced daily which results in an annual production of 6,862,000 metric tons of PHAs, which is approximately twice the anticipated plastic demand by 2050, i.e. 3,657,560 metric tons. This reduces waste and lessens dependence on non-renewable petroleum. Though bioplastic costs (2.4 - 5.5 US$/kg) are higher than petroleum-based plastics (0.13-1.2 US$/kg), large-scale production and technology advancements may lower costs by 15-19%. The projected expense for fulfilling Bangladesh's plastic demand by 2050 is estimated at US$4,750.43 million for bioplastic. Unlike conventional plastics, bioplastics cause 20-50% less environmental harm, offering a more eco-friendly alternative.

Keywords: Bioplastic, Organic waste, Health hazards, Waste management.

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1 Introduction

The introduction of the first synthetic plastic material dates back to 1862. However, it wasn't in mass use until the discovery and commercialization of polyethylene (pe) in the 1930s that made the use of plastics to surge (American Chemistry Council, 2010). Nowadays, plastic has become a ubiquitous material in modern society due to its versatile applications in various fields such as packaging, shopping, fluid containers, industrial products, and building materials. According to Colwill et al. (2012), packaging (38%) and construction (21%) were the most significant end uses of plastics, with nearly half of the total plastics consumed taking the form of pe and polypropylene. Typically, plastics are made from hydrocarbon monomers that are obtained from the cracking of crude oil and natural gas. According to Queiroz et al. (2009), the production of plastics is estimated to account for around 4%-5% of total crude oil consumption. The rise of globalization and consumerism has led to a significant burden on the planet's resources and raw materials due to a shift towards a "throw away" culture. As a result, the quantity of plastic manufactured has substantially surged from 15 to 311 million metric tons during the period of 1950 to 2014 (Rattana et al., 2019). Regrettably, this heightened level of plastic production has resulted in detrimental consequences for both land and water ecosystems, with a particular emphasis on the oceans. The accumulation of plastic waste presents a grave hazard to oceanic species and ecosystems, as it triggers bio-magnification and bio-accumulation. According to Ocean Conservancy. (2017) report, single use plastic such as food and drink plastic packaging are the most common items observed in ocean and coastal regions.

The utilization of plastic products has been found to lead to the generation of an alarmingly huge amount of waste. This waste management issue has now escalated to a global environmental concern owing to the non-biodegradable nature of plastic and its associated products. Predictions indicate that the future will encounter a significant rise in plastic use, which in turn will result in a sharp increase in the production of post-consumer plastic waste. For instance, the study by Lebreton et al. (2019), suggests that by 2025, the global urban population is expected to generate over 6 million tonnes of solid waste every day, including plastic waste. Even if only 10% of this waste is plastic, it would still amount to more than 200 million tonnes of plastic waste, which was the entire global plastic resin production in 2002 (Plastics Europe, 2014). The recycling rates remain discouragingly low, and the expected increase in single-use products only exacerbates the situation further (Lebreton et al., 2019). Although packaging products are often disposed of with their functional attributes still intact and can be easily reused or recycled, only about 9.4% of plastics are presently recycled in the United States, primarily due to issues with collection (EPA, 2016). Globally, only about 9% of plastic waste has ever been recycled with 12% being incinerated and the remaining 79% accumulating in natural ecosystems (Geyer et al., 2017; Walker et al., 2023). According to Borrelle et al. (2020), an estimated 19-23 million tonnes of plastic waste generated globally in 2016 entered aquatic ecosystems, but this number is predicted to increase to 53 million tonnes annually by 2030. Mismanaged waste located near inland waterways or coastal regions poses a significant environmental threat, as it can enter rivers and oceans, increasing the risk of local flooding and degrading air quality from open dumps.

Recent research suggests that people from asia and africa will likely bear a disproportionate burden of plastic waste on the environment in the future (Lebreton et al., 2019; United Nations, 2015). The popularity of plastic products in Bangladesh dates back to the post-independence era. From early 1982, polythene bags became widely available to people of all classes in Bangladesh and within five years, they became a significant threat to the natural environment of the country (Halden, 2010; van Leeuwen, 2013). Although recycling is the most cost-effective and environment-friendly solution to the problem of plastic waste, recycling practices in Bangladesh are still in their infancy. Furthermore, people in Bangladesh find it more convenient to dispose of in open areas (Mourshed et al., 2017). According to Dawson (2019), with the rapid increase in single-use plastic (as is the case in Bangladesh), there will always be an environmental impact, regardless of how we manage it. However, ending this plastic use will not be solution, perhaps we need to shift towards more environmentally friendly solution like bioplastic that can replace the synthetic plastic without any associated environmental guilt. Therefore, this study aims to depict the scenario of plastic consumption and waste generation in Bangladesh and analyze the prospect of bioplastic.

2 Current Population and Future Projections in Bangladesh

The size of a population is a key factor in waste production. Appropriate management of waste is crucial to prevent harm to both people and the planet (Gupta et al., 2015). Empirical studies have demonstrated a direct and positive association between population size and the quantity of waste produced (Sharma et al., 2019; Supangkat et al., 2020). This relationship highlights the critical role of population growth in increasing the amount of waste that needs to be managed.

With a population of over 166 million people within an area of 131,000 sq km (excluding the water area), Bangladesh is the 8th most populated country in the world (Ali et al., 2015). Its population grew at an average rate of 1.47% per year between 1973 and the mid-1980s, increasing to 2.68% per year during 1986-2000, and declining to an average rate of almost 1.76% per year since 2001. As of July 2014, Bangladesh's population growth was estimated to be 1.6%. According to the UN Population Division's medium variant projection, the population of Bangladesh is expected to reach 200 million by 2050 (Ali et al., 2015; Mainuddin et al., 2015).

3 Waste Generation and Plastic Pollution

Worldwide, cities are facing an increasing amount of organic and inorganic waste due to population growth and industrial advancement. Furthermore, studies suggest that the production of garbage on a global scale varies between 1.7 and 1.9 billion metric tons annually, and it is anticipated that this amount will reach 27 billion metric tons by the year 2050. What's more, nearly one-third of this waste will come from Asia (Modak P et al., 2010; Mourshed et al., 2017). Despite the large amount of waste, only 50% - 70% is gathered for disposal, with unregulated landfilling accounting for 15% (Modak

P et al., 2010; Ramos et al., 2012). The gravity of the issue is magnified by the reality that plastic waste comprises nearly 5% of all garbage. Where in North America, people typically consume highest amount (100 kilograms) of plastic goods, whereas in Asia, the average is 20 kilograms (Mourshed et al., 2017). Despite that Asia, in particular, has been the biggest user of synthetic polymers for years (Fig. 1) and generates 30% of total plastic debris because of its large manufacturing industry (Mourshed et al., 2017).
Bangladesh, despite being challenged by high population density, is progressing with a growing economy. Currently, there are more than three thousand small and large plastic industries in Bangladesh, which was recognized as the 12th highest export earning sector in the country in the fiscal year 2017-2018 and contributes 1% to the national GDP (Hossain et al., 2021). The exportation of plastic items brought in around USD 340 million for Bangladesh during the course of the fiscal year 2013-2014 (Ahmed, 2014). These industries provide employment to about 2 million people (Islam, 2014). Over the years, the per capita use of plastics in Bangladesh has significantly increased (Fig. 1), rising from 2.07 kg in 2005 to 3.5 kg in 2014, with an increasing rate of 16.2%, which was lower than the global average of 25% (Mourshed et al., 2017). Due to the proliferation of large plastic items, Bangladesh struggles to manage the resulting plastic garbage. It is anticipated that the expanding plastic industry will generate a significant volume of plastic garbage, which presents a grave environmental hazard. While Bangladesh's per capita plastic consumption may appear modest in comparison to other first world and neighbouring countries, its contribution to the overall mismanagement of plastic waste is significantly substantial (Fig. 2). Bangladesh generates a cumulative 3000 tonnes of plastic per day, accounting for 8% of the total waste generated within the nation (Mahmudul I., 2019; Mourshed et al., 2017). The detrimental effects of plastic garbage accumulation on the marine ecology of the Bay of Bengal are extensive. A comprehensive study was conducted to collect 6,705 waste items from four beaches in Cox's Bazar. The results revealed that plastic waste amounted to a staggering 63% (Mehedi, 2018). These findings indicate that the significant amount of plastic waste, which has the potential to severely disrupt fish reproduction and even cause the extinction of beneficial species (Mehedi, 2018).

Recycling is the most environmentally beneficial and cost-effective approach to handle the huge plastic trash, yet recycling techniques are still in their infancy in Bangladesh. Plastic garbage is more easily disposed of in open areas, particularly in proximity to roadways, rivers, or coastlines (Mourshed et al., 2017). To illustrate, the nation consumed 545,300 tons of plastic in 2014, whereas the amount of plastic garbage available for recycling amounted to a mere 50,213 tons. This finding suggests that a mere 9.2% of the overall plastic utilized was suitable for recycling purposes (Khondaker GM., 2016). Awareness of the health risks associated with plastic pollution, the expense of recycling, and the unavailability of suitable technology are factors that contribute to the disposal of waste plastic in water bodies (channels, lakes, rivers, and even the ocean). Such practices ultimately endanger human health (Mourshed et al., 2017). At present, urban regions in Bangladesh generate 633,129 tons of plastic garbage annually, of which 51% is disposed of through recycling processes. Recycling the remaining plastic waste could save USD 801 million annually (Hossain et al., 2021). It's concerning to learn that per capita plastic consumption has risen by 16.2% from

2005 to 2014 (Mourshed et al., 2017). The data is concerning: if current trends continue, projections indicate that by 2050, a population of 200 million will consume 18.28 kg per capita, resulting in a staggering 3,657,560 metric tons of plastic produced annually. It is beyond description that Bangladesh is facing a critical and rapidly growing problem that demands our immediate attention.

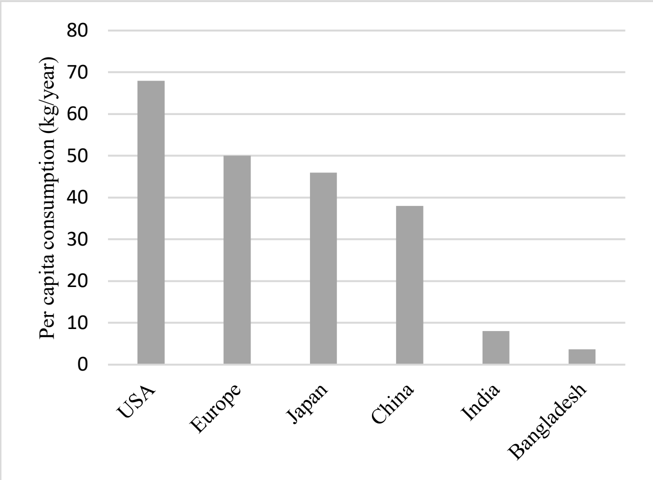

Fig. 1. Per capita plastic consumption around the globe

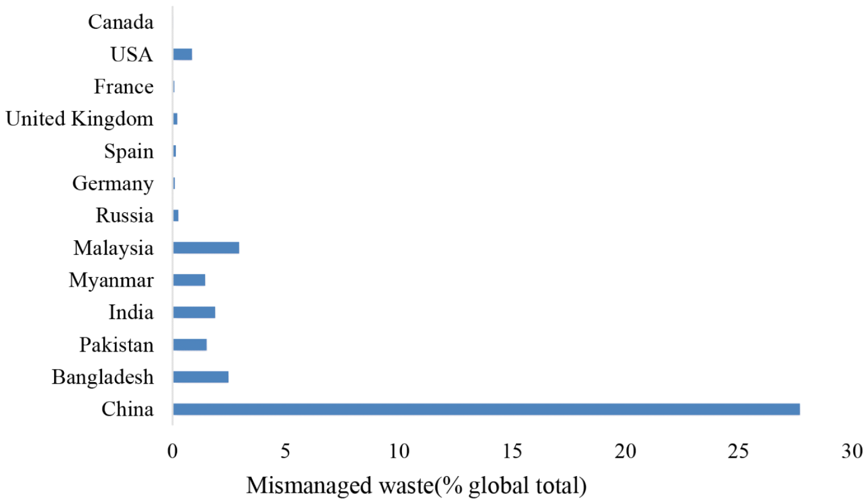

Fig. 2. Percentage of global mismanaged plastic waste contributed by different countries (Hossain et. al., 2021)

4 Prospect of Organic Waste Valorization into Bioplastic in Bangladesh

Modern society relies heavily on plastics, but their place in a sustainable future is often questioned due to the non-renewable nature of their source materials and the persistence of plastic waste in the environment. To address this issue, "Bioplastics" can serve as a viable solution. Unlike conventional plastics, biopolymers or bio-derived plastics (BDPs) are made from renewable resources. Cellulose was used to create some of the earliest plastics, but it has only been in recent decades that there has been a push to develop new BDPs. Initially, the focus was on creating plastics that were both bio-derived and biodegradable. The latter offers potential for alternative end-of-life management processes (Song et al., 2009), including the recovery of soil nutrients through composting or the retrieval of nutrients and energy via anaerobic digestion. If a plastic material can biodegrade, is made from renewable resources, or both, it can be classified as bioplastic (European Bioplastics, 2016; Plastic Europe, 2016). Fig. 3 provides a visual representation of these concepts. Biodegradable bioplastic (BBP) offers a promising solution for diverting food waste from landfills and reducing plastic pollution. These types of plastics come from natural resources and exhibit biodegradable properties at some point, such as thermoplastic starch (TPS), polyhydroxyalkanoates (PHA), polylactide (PLA), and polybutylene succinate (PBS). Polylactic acid (PLA), derived from starch, is one of the most commercially advanced biodegradable BDPs and is used in various packaging types, such as bottles, trays, and clamshells (Colwill et al., 2012). Bioplastics that are 100% bio-based are produced at a scale of approximately two million tonnes per year (Rosenboom et al., 2022). The use of bioplastics is seen as a vital part of future circular economies that can help achieve some of the United Nations' (UN) Sustainable Development Goals by decreasing the use of fossil resources, introducing new recycling and degradation methods, and using less-toxic reagents and solvents in production processes. (Cheng et al., 2020; Karan et al., 2019; Rosenboom et al., 2022).

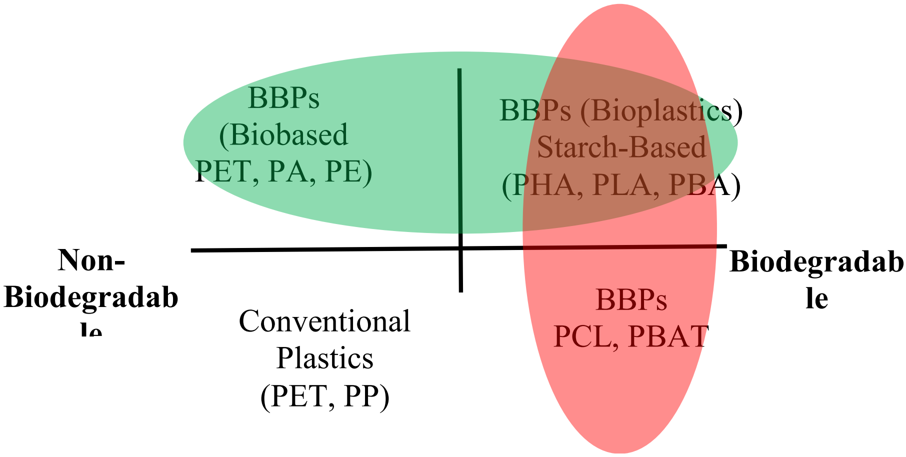

Figure 3: Classification of plastics; PET: Polyethylene Terephthalate; PE: Polyethylene; PA: Polyamide; PP: Polypropylene; PLA: Polylactic Acid; PHA Polyhydroxyalkanoate; PBS: Polybutylene Succinate; PBAT: Polybutylene Adipate Terephthalate; PCL: Polycaprolactone (European Bioplastics, 2016).

The transformation of organic municipal solid waste (O-MSW) into valuable resources using biological methods is an encouraging prospect due to the abundance of biodegradable materials, wide availability, and affordability (Sharma et al., 2017). O-MSW primarily comprises of lignocellulosic and starchy waste that can serve as a renewable raw material for creating bioenergy and bioplastics using biological processes, providing a practical solution. Research has indicated that *Enterobacter aerogenes* bacteria as fermented agents can generate 40 g of PHAs from 1 kg of O-MSW, in addition to 28.6 g acetic acid, 139.1 g 2,3-butanediol, 98.3 g ethanol, and 71.4 L biohydrogen, which equates to about 8236.9 kJ of energy (Ebrahimian et al., 2020). O-MSW has shown promising potential in the production of PHAs, and it's worth noting that food waste can also be utilized effectively as a resource for PHAs production. Preethi et al., 2012, discovered that Jambul (*Syzygium cumini*) seeds can efficiently produce PHAs up to 42%. PHAs can also be produced by oil-based (pam oil and cooking oil) products with a production efficiency of 83% (Obruca et al., 2010). These findings not only highlight the untapped resource of food waste, but also offer a promising solution to our urgent need for sustainable alternatives to traditional plastics. This underscores the considerable potential of O-MSW and food waste in producing valuable materials and energy.

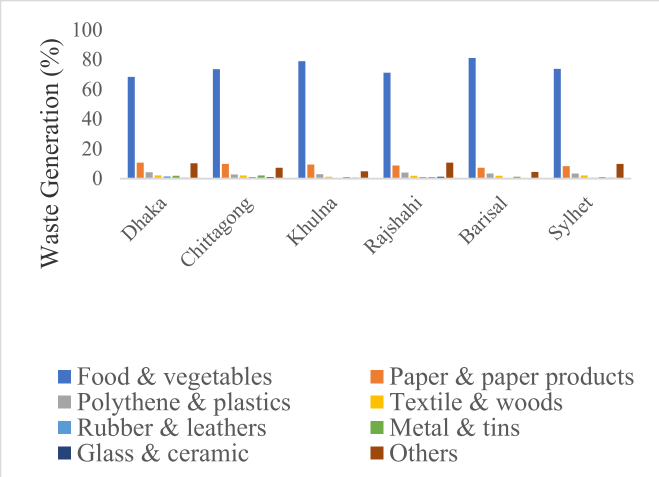

Fig. 4: The percentage of MSW generated in major urban areas of Bangladesh (Alam et al., 2020).

Bangladesh is categorized as a developing Asian country that consists of more than 522 urban centres. These urban areas collectively produce thousands of tons of MSW every day from a variety of sources (Alam et al., 2020; Uddin et al., 2009, 2011; Yasin et al., 2013). Household solid waste (HSW) accounts for approximately 90% of the total MSW generated, and approximately 80%–92% of HSW is organic solid waste (Fig. 4) (Ahmed et al., 2010). In Bangladesh, 29.4% of the total population resides in urban areas. The waste generation rate in different cities ranges between 0.25 to 0.70 kg/capita/day, where maximum waste generation occurs in Chittagong city (0.56 kg/capita/day) and Dhaka city (0.70 kg/capita/day). In 2005, the entire waste generation rate was 13,332 tons/day, with an average of 0.41 kg/cap/day, for a total of 32.76 million urban population (Alam et al., 2020; Enayetullah et al., 2005). However, due to the expansion of urban areas and population growth, the MSW generation increased to 23,688 tons/day by 2014, with a total population of 41.94 million and an average of 0.56 kg/cap/day (Waste Concern, 2014). The projected urban population is estimated to reach 78.44 million by 2025, with an estimated total waste generation rate of 47,000 tons/day and an average of 0.6 kg/cap/day (Alam et al., 2020; Waste Concern, 2009). At a 40% efficiency rate, a staggering 18,800,000 kg of PHAs can be produced daily by bio-transforming organic fraction of MSW. This results in an annual production of 6,872,000 metric tons of PHAs, which is approximately twice the anticipated demand i.e. 3,657,560 metric tons of plastic product in 2050. In simpler terms, the predicted MSW production for 2025 has the potential to satisfy the demand for plastic usage for the projected 2050 population, provided that the consumption rate remains at 18.28 kg per capita.

5 Economical and Ecological Aspects

The production of plastics has experienced a steady rise on a global scale. Although plastics offer numerous benefits, their drawbacks are becoming more evident (Andrady et al., 2009). According to the United Nations Environment Programme's report in 2014, around 100 million tons of polymers are responsible for impairing ecosystem services, which incurs a cost of approximately US$13 billion annually (Dobrucka, 2019). By 2050, Bangladesh's population is anticipated to demand a substantial quantity of plastic, and the projected cost of manufacturing traditional plastic to fulfil this demand is remarkably high. It is estimated that the cost will be around US$474.29 million in ecosystem service ($0.13 per kilogram of polymer). Furthermore, conventional plastic production is known to cause significant harm to the environment (Fig. 5). On the other hand, bioplastic production causes 20-50% less harm to the environment, making it a more environmentally friendly alternative to conventional plastic (Padmavathy, C. K. et al., 2017).

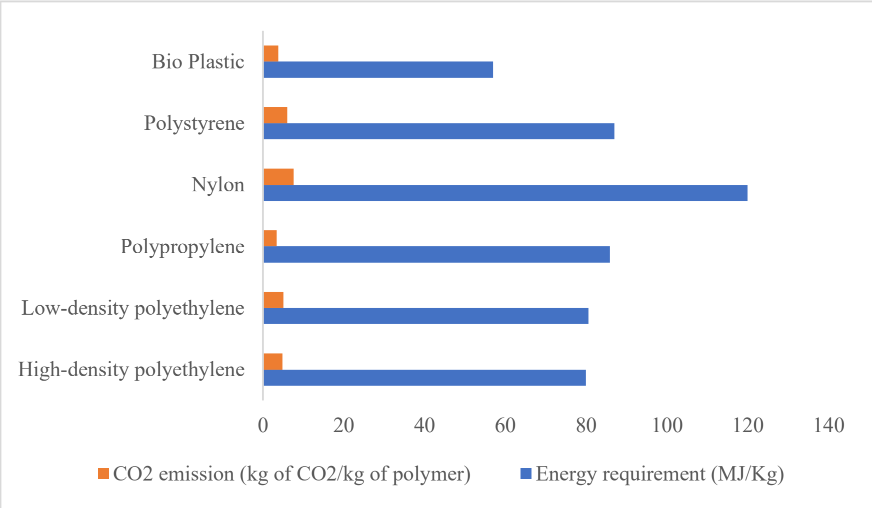

Fig. 5: Environmental impact of plastic production (Padmavathy, C. K. et al., 2017)

While bioplastics are still in their nascent stages of production, recent studies indicate that the potential market value of PHAs is four times higher than that of traditional plastics (PHA: US$1.3/Kg; Conventional Polymer: US$0.13-1.2/kg) (Alloul et al., 2018; Crutchik et al., 2020; Kleerebezem et al., 2015). Despite the currently higher production cost of bioplastics, which is estimated to be around US$4,750.43 million to meet the demands of the population by 2050, the utilization of advanced technology can potentially decrease the cost by 15-19% (Padmavathy, C. K. et al., 2017; Crutchik et al., 2020). This is a positive development, as it presents a hopeful solution to alleviate the detrimental effects of plastic production on the environment.

6 Conclusion

Without a doubt, plastics have become a significant aspect of our daily lives. However, with the global population on the rise and our limited fossil fuel resources depleting, it has become imperative to manufacture sustainable and biodegradable bioplastics using renewable resources. One promising solution is the microbial production of bioplastics from MSW. This approach can not only meet the growing demand for plastics but also contribute to a more environmentally friendly world. Bangladesh, in particular, should prioritize this sector to establish a sustainable environment. By reducing waste generation and plastic pollution, it is possible to create a cleaner and healthier world for generations to come.

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