Raneem & Ruba Makrai

Dr. Christine Case

Biology 230

Biotechnology Alternative to Petroleum-based Plastics

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Background

Plastics are used in almost every place such as pharmaceutical manufacturing industries, and the packaging of food to be transported and sold across the world. They are useful as synthetic polymers because their structure can be chemically manipulated to a number of strengths and shapes to obtain higher molecular weight, low reactivity and long durable substances(5). Therefore, they are useful as shampoo containers in which they are able to store the shampoo material for a long time. In addition, their low reactivity helps prevent the reaction of the chemicals within the product, allowing for safe use of that product. In addition, plastics are easily disposed of after single use which helps prevent the spread of bacterial and infectious diseases in hospitals. Being cost-effective, they prevent huge losses for hospitals.

However, being composed mainly of petroleum, a nonrenewable source, it becomes hard to recycle petroleum-based plastic completely, thus leaving a negative impact on the planet. Of all the plastics used, 79% of them make it to landfills while 19% are burned (Fig.1). The litter in the landfill is transported to other parts of the environment and is ingested by animals. The burned plastics release CO_2 into the environment and thus raise the temperature and worsen global warming (3). Therefore, in order to prevent that problem from continuing, a switch to a starch-based bioplastic must take place in order to secure a healthy future for the environment.

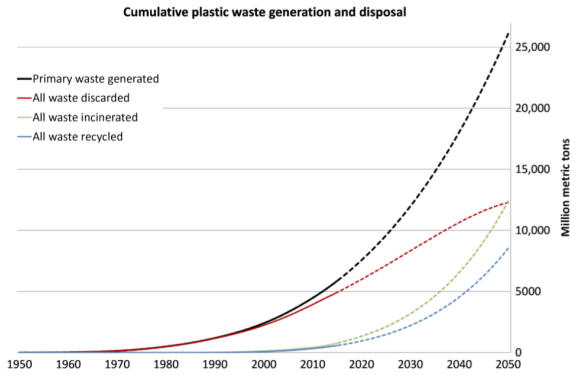

Figure 1: The amount of waste generated from plastics in million metric tons over time in comparison to the amount of the waste that is

discarded, incinerated, and recycled and the projected data for 2050 (5).

Alternative

Starch-based bioplastics can be directed towards the compost, where it will make its way into the soil during plantation and agriculture where the starch content will be consumed by soil microorganisms, breaking the polymer chain and biodegrading the bioplastics (2). A study was done in order to prove the biodegradation of starch-based bioplastic where yam, potato, and petroleum-based plastic were tested for change in weight, which can indicate biodegradation activity. The weight loss of the potato is 43.0%, making it higher than the weight loss of the yam which is 25.5% (Table 1). This is due to the amount of starch in each substance. Traditional plastics are not able to be completely degraded at all, which shows their hazardous effects to the environment. Instead, they break down and

	Mass of yam (g)			Mass of potato (g)			Mass of plastic (g)		
	Initial	Final	Weight Loss (%)	Initial	Final	Weight Loss (%)	Initial	Final	Weight Loss (%)
1	0.616	0.202	67.2	0.639	0.434	3.9	0.643	0.643	0.000
2	0.654	0.625	4.4	0.650	0.280	56.9	0.638	0.638	0.000
3	0.508	0.483	4.9	0.659	0.210	68.1	0.649	0.649	0.000
Average	0.593	0.437	25.5	0.649	0.308	43.0	0.643	0.643	0.000

Table 1: Weight loss of plastic, yam and potato, both rich in starch, in a 5-day soil burial test, indicating the amount of biodegradation by microorganisms taking place (4).

fragment into smaller and smaller particles, where they are often carried out into our water stream and are, mistangingly, placed into our food chain when animals eat them. Unlike traditional plastics, starch-based bioplastics are placed into compostes, are used for plantation, and are absorbed into the earth and become nutrients for the soil, preventing any biohazardous wastes from being released into the environment (6). In fact, in many countries now, bioplastics are used mostly by the food industry as they are safer for the consumers and the environment (Fig. 2).

Figure 2: The use of starch-based bioplastics in different aspects of the economy (7).

To further prove that starch is easily biodegradable by bacteria and other microorganisms, a study was conducted at four different stations in Puerto Rico: two offshore, on one shallow end of a reef, and a fourth one at the deeper levels of the water. At each station, hydroxybutyrate and hydroxyvalerate (i.e. PHBV), a form plastic that has been marketed, and different starch-concentrated bioplastics were used in order to understand the effect of starch on the growth of microorganism and the plastics' degradation over a 1-year period.

Formulation	Day 25		Day 75		Day 150		Day 380	
	TS	%E	TS	%E	TS	%E	TS	%E
100% PHBV	103[a]	87	105	89	37	35	—[b]	—
30% Starch	70	56	31	39	—	—	—	—
30% PEO-coated starch	60	47	24	35	—	—	—	—
50% Starch	32	40	—	—	—	—	—	—
50% PEO-coated starch	18	26	—	—	—	—	—	—
100% Starch	—	—	—	—	—	—	—	—

[a] The data are percentages of the initial (zero-time) values.
[b] —, severely deteriorated sample for which data could not be obtained.

Table 2: Physical deterioration of station 2, an offshore site, of the different plastics, 25 days, after the start of the experiment (4).

The physical deterioration correlated with the amount of starch present, where most of the starch-based materials have been impacted on Day 25 (Table 2). The higher the concentration of starch in a bioplastic, the faster and easier biodegradation becomes.The rate at which weight is lost for the 100% starch-based bioplastic demonstrates a sharp and fast increase compared to the other bioplastics (Fig. 3).

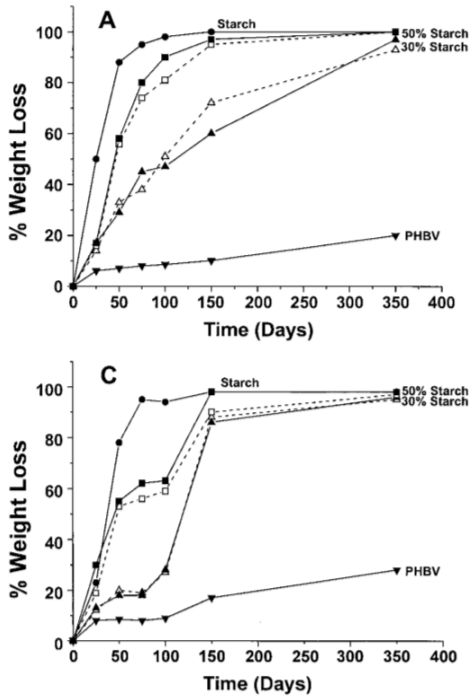

Figure 3: Weight loss of the different plastics tested at stations 1 and 3 (circles, 100% starch; ■, 50% starch;, 30% starch; triangles, 100% PHBV) (7).

In another experiment, three different kinds of bioplastics were analyzed: Poly (butylene succinate)-starch (PBS-starch), poly (butylene succinate) (PBS), and poly lactic acid (PLA), and a non-degradable petrochemical plastic (PA66). They were placed in a soil with an initial bacterial biomass of 1.4×10^9 cells/g-soil for 28 days (1).

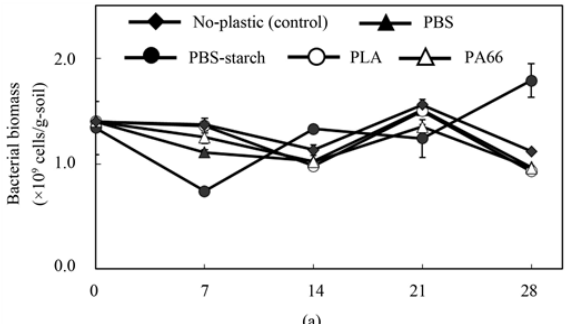

Figure 4: Bacterial biomass fluctuations, over a 28-day period, depending on the plastic form used (1).

The study sought to investigate environmental condition changes by analyzing the changes in microbial population. Since soil microorganisms are sensitive to environmental changes due to pollution, evaluation of their diversity and number fluctuations can indicate an environment's condition. The bacterial biomasses continue to fluctuate for the different plastics tested. At the end of the 28-day period, the bacterial biomass is at its highest for PBS-starch, which shows that the bioplastic containing starch was the most-easily degraded plastic form (Fig. 4).

Disadvantages of Starch Bioplastics

However, to all solutions, there are some limitations and drawbacks. For example, starch bioplastics must be correctly disposed of in order to be degraded by microorganisms, and prevent the release of toxins into the environment. In addition, starch-based bioplastics must not be recycled with traditional plastics, because they will not be degraded properly (7).

Conclusion

On the other hands, despite the disadvantages to starch-based bioplastics, it can be concluded that they have high biodegradable properties with decent thermal and mechanical properties and make them a suitable alternative for the existing conventional plastics. Furthermore, starch is a renewable resource, cheap and can be easily modified. This only shows that at one point in time, it will become unnecessary to rely on petroleum for plastics. Plastics will be made naturally and will serve to improve the environmental conditions. As studies have shown, the bacteria have portrayed the beneficial sides of degradation of the bioplastics. Compared to the conventional plastics, bioplastics created out of scratch will return nutrients into the soil and the environment. Starch-based Bioplastics do not need to be burned. Even if they are burned, the harmful greenhouse gases will not be released. The data presented show that no matter what the fate of the starch-based bioplastics is, they will end up being degraded and put back into the environment as useful resources without hurting our animals or our food chain. In the end, despite the disadvantages and limitations associated with bioplastics, they are still the best alternative there is to traditional plastics. It might be a small step but it is in the right direction.

Literature Cited

(1)Adhikari, Mukai, Kubota, Kai, Kaneko and Kubo. 2016. "Degradation of Bioplastics in Soil and Their Degradation Effects on Environmental Microorganisms." *Journal of Agricultural Chemistry and Environment* **5**:23-34.
The authors, researchers at Ritsumeikan University in Japan, analyze the effect of different plastics on the biomass of the bacterial colonies growing within a soil. They present their experimentation findings and results in order to understand the relationship between the two factors: bacterial biomass and plastic biodegradation. They support the idea that bioplastics, made up of starch, cause an increase in the microorganisms and bacteria and therefore, are easily degradable.

(2)Andrady A. and Neal M. 2009. "Application and Societal Benefits of Plastics. *Philos Trans R. Soc Lond B Biol. Sci.* 364: 1977-1984.
The authors, researchers at the Research Triangle Institute in Durham, cite evidence and data from their experimentation to support their hypothesis. The use of plastics in any manufacturing industry and hospitals helps prevent huge economic losses. This journal, compared to the cited journal above, makes little mention of the disadvantages of traditional plastics and focuses, instead, on their benefits and usefulness.

(3)Imam, Gordon, Shogren, Tosteson and Greene. 1999. "Degradation of Starch–Poly(b-Hydroxybutyrate-Co-b-Hydroxyvalerate) Bioplastic in Tropical Coastal Waters." *Applied and Environmental Microbiology* 65: 431-437.
The authors, researchers at University of Puerto Rico, discuss the starch-based bioplastics in great detail and provide experimentation to support the use of bioplastics as the alternative.They present data to showcase the weight loss of different starch-concentrated bioplastics and compare it to the weight loss of traditional bioplastics. The data provided strongly support the hypothesis and the use of starch-based bioplastics. The greater concentration of starch in a bioplastic resulted in higher amount of degradability and weight loss.

(4)Ismaila, Tahirb, Yahyac, Wahidd, Khairuddin, and Abdullah. 2015. "Synthesis and Characterization of Biodegradable Starch-based Bioplastics." *Materials Science Forums* 846: 673-678.
The authors, researchers and professors at Universiti Teknologi MARA in Malaysia, examined the synthesis of bioplastic from potato and yam starch. They provide background information to bioplastics and a starting place to begin understanding the role of starch-based bioplastics in the environment. The data collected from their experimentation support the claim that starch bioplastics are biodegradable by microorganisms than traditional plastics. The experiments done involved burial of bioplastics made up of potato starch and yam starch and petroleum-based

plastics in soil, and observing the weight loss after a few days.

(5)Law, K., Jambeck, J. and Geyer, R. 2017. "Production, Use, and Fate of all Plastics Ever Made." *Science Advances* 3:1-5.
The authors, researchers at UC Santa Barbara and University of Georgia, use data from sources such as the American Chemistry Council to test their belief on the negative impacts of petroleum-based plastics.They find their hypothesis strongly supported in traditional plastics. Plastics are not fully recycled and, when burned, release CO2 into the atmosphere. Compared to the journal listed below, this article lists more disadvantages of traditional plastics and makes little mention of their benefits.

(6)Webb, Arnott, Crawford, and Ivanova. 2012. "Plastic Degradation and Its Environmental Implications with Special Reference to Poly(ethylene terephthalate)." *Polymers* 5:1-18.
The authors, researchers at Swinburne University of Technology in Australia, discuss the different types of plastics that are out there, and their impact on the environment. The article outlines the problems associated with plastic pollution and the different methods for waste-handling, emphasizing the need for a biodegradable alternative. The authors provide data from experimentation done at the Swinburne University of Technology, to support the need for bioplastics, portraying the negative effects of the handling methods of bioplastics.

(7)Reddy, L., Reddy, S., and Gupta A. 2013. "Study of Bio-plastics As Green & Sustainable Alternative to Plastics." *International Journal of Emerging Technology and Advanced Engineering* 3: 82-89.
The authors, researchers at the Department of Chemical Engineering in India, introduce biodegradable bioplastics and their compositions: starch and sugarcane. They, using data from their own experimentation, mainly examine the advantages of bioplastics, and compare it to the traditional plastics, strongly supporting their hypothesis. Starch-based bioplastic are 100% compostable and degardable within 180 days, compared to traditional plastics that take years to biodegrade. They compare starch-based bioplastics to petroleum-based plastics, and show the similarities between their cycles, and differences between their end-life.