Mother Nature's Cry for Help:

A Comparison of Bioplastic Bases

Elizabeth Campisi

Mentor: Dr. Kerry Ann Cedergren

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Abstract

As the demand for plastic rapidly increases in an ever developing and industrializing world, forests and oceans are left to flounder. Plastics are made up of synthetic polymers, such as polyethylene and polypropylene, and are therefore resistant to microbial degradation. Microplastics are a prevalent form of pollution in oceans that result when solar radiation degrades plastic products and can exist in the ocean for up to 1,000 years. This study will focus on comparing different biodegradable materials that can be utilized as replacements for the synthetic polymers used in plastics. The main purpose of this study is to identify which starch base would yield the most flexible and effective bioplastic. Bases tested will include tapioca, arrowroot, and potato starch. These bioplastic films will be prepared according to the film-casting method, and their strength, flexibility and ability to biodegrade will be tested in a variety of environments.

Though small in size, microplastics pose a large threat to wildlife and humans alike and continue to pollute the ocean as the world industrializes and solar degradation continues. Due to the small size of microplastics (1 cm in diameter), many different species can unknowingly ingest them, resulting in an accumulation of microplastics in their digestive systems (1). Chemicals added to enhance the performance of plastic, such as phthalates, bisphenol A, and polybrominated diphenyl ethers, can directly impact humans as well as wildlife that come into contact with plastics (2). These toxic chemicals, as well as other carcinogens released during manufacturing and incineration, result in pollution that potentially causes endocrine disruption, cancer, and immune system suppression (3). Furthermore, plastics are made up of synthetic polymers, such as polyethylene and polypropylene, and are therefore resistant to microbial degradation and can take up to 1,000 years to decompose (4). Since they degrade very slowly, the only other ways to dispose of them are through recycling, which is very costly or incineration, which emits dangerous, toxic chemicals (3).

Fortunately, due to the depletion of petroleum sources (many plastics are made from crude oil) and the harmful environmental effects of traditional plastic, bioplastic films are being studied more extensively as an alternative to traditional plastics (5). Specifically, starch appears to be a promising alternative for a bioplastic base due to its inexpensive price, abundance, and thermoplastic behavior (4). Starches such as potato, tapioca, and arrowroot starch, all of which will be examined in this study, can be used to make polylactic acid (PLA) (6), a polymer used in a variety of bioplastics due to its ability to decompose when water is added to it (7, Appendix A). This ability to decompose is extremely important in achieving our main goal: helping reduce the abundance of plastic pollution. Additionally, the polymerization process of lactide molecules into PLA is quite similar to the polymerization of synthetic polymers, such as ethylene into polyethylene, indicating that PLA will maintain many qualities of traditional plastic (7, Appendix A). Thus, the starches' ability to form PLA makes them a promising alternative for bioplastic films.

Another factor considered in finding an acceptable base for bioplastics was amylose content. Amylose is one of two major components in starch (the other being amylopectin, a highly branched polymer that aids in flexibility) and is a linear polysaccharide. Starches with high amylose content are shown to be good film formers and result in a firm gel when heated (8). This is most likely due to amylose's ability to intertwine between layers of amylopectin, making the bioplastic film strong and stable (8). Futhermore, as stated above, amylose is a linear polymer, which is composed of D-glucose residues linked through alpha 1,4-D glucose bonds (8). The linear structure of this polymer will also aid in the strength of the bioplastic, as linear polymers are typically well-packed together and have a high magnitude of intermolecular forces of attraction, giving these polymers high tensile strength (8, Appendix B). Therefore, the high percentages of amylose present in arrowroot, potato, and tapioca starch (30.4%, 23%, and 15-18% respectively) make these starches particularly promising bases for bioplastic.

A common base that has been used to make bioplastics in the past is corn, as corn starch-based bioplastic films have an incredibly high amylose content (25-75%). However, many fear that these corn bioplastics are potentially damaging for the environment due to the vast amount of farmland they take up. In the United States, corn is the largest crop by volume, taking up more acres than any other crop (10). While cornbased bioplastics are the main bioplastics in use now, it is necessary to find other promising alternatives that take up less farmland and are better for the environment if we are looking to completely replace plastics in the near future. Although the root starches that will be used in this study have less amylose than corn, these bases take up far less farmland and are therefore better for the environment long-term.

I aim to use a film-casting method to create the bioplastic films from tapioca, potato, and arrowroot starch, taking inspiration from the successful creation of bioplastic films using sago starch and seaweed-extracted agar discussed in the *Journal of Engineering Science and Technology* (5). I chose this particular film-casting method due to the soft and flexible nature of the bioplastic films produced (5) and the similarities between the sago starch used in this procedure and the root starches I will use (11). Both sago starch and the starches I will be using for my bioplastic bases have very similar amylose contents and are root starches, indicating they will react similarly to this successful film-casting method (11). However, sago starch will not be a base tested during this study, as sago starch is extracted from tropical palm stems. In order to grow these palms, forests are often burned and destroyed leading to greenhouse gas emissions. Thus, using the sago starch, which is a product of these palms, in the biofilms would defeat the purpose of creating a biofilm that benefits the environment.

To recreate this film-casting method with technology found at most universities, the following procedure will be utilized. First, 240mL of distilled water will be added to a beaker with a magnetic stirrer to continually mix the solution. 6.8g of a chosen starch (Bob's Red Mill Tapioca, Potato, or Arrowroot Starch) or a mixture of starches will be added to the water bath, which will gradually heat to 90°C. Due to the magnetic stirrer and heating process, the starches will homogenize (when small particles distribute uniformly throughout the solution) and gelatinize (when intermolecular bonds of starch break down and the starch essentially dissolves). Research Products International Agar (1.2g) will then be added and vigorously stirred into the homogenized and gelatinized starch solution. This agar may eventually be extracted from seaweed, another cheap and abundant source for bioplastic creation. However, for this particular study, I aim to keep the agar amount precise and consistent, which can more easily be done with agar bought from a source rather than extracted. After being kept at this high temperature for 30 minutes, glycerol (2.0g) will be added as a plasticizer (promotes flexibly and reduces brittleness) and the solution will then be stirred for 5 minutes. The film-forming solution will then be casted onto two petri dishes lined with aluminum foil and placed in the freezer for 90 minutes. Once solidified, the petri dishes will be dried in the oven at 50°C overnight (8 hours).

Once the films are formed, it is necessary to both qualitatively and quantitatively analyze which starch yields which properties. One proposed method of accomplishing this task is through a soil burial test. A soil burial test will be done according to the method described by the *Journal of Engineering Science and Technology* with modifications to allow for testing of different soil types (5). Samples of the various bioplastics will be placed in 190 x 100mm containers surrounded by three different types of soil: potting soil, abbreviated lake soil, and soil from the forest. The different properties of these soils, such as sand, silt, and clay content and bacteria present, will allow us to see how various bioplastics will degrade in different environments and determine the best method for disposal of bioplastic products. The weight loss of the bioplastics will then be calculated after 2 weeks and 30 days using equation 1.

$$\text{Weight loss (\%)} = [(M_0-M_1)/M_0] \times 100 \quad (1)$$

This rate of weight loss will correspond to the rate at which the plastics will degrade, which is important to our goal of making plastics without detrimental environmental effects.

Another method used to determine the degradation of various bioplastics will be a water degradation method in which a small piece of each bioplastic film will be placed in a 10mL beaker of distilled water and a 10mL beaker of saline solution that mimics the salinity of the ocean. The weight loss of the bioplastics will then be calculated weekly using equation 1. This water degradation method allows us to see how the bioplastic films react to moisture over time. The results of the water degradation will allow us to not only determine which bioplastics will degrade most easily in the ocean, but also allow us to determine which bioplastics are able to withstand exposure to moisture over time and are therefore able to replace plastic products such as cups and bowls.

The flexibility and strength of these bioplastics will also be tested. The ability of each starch-based film to create strong and stable shapes, such as bottles and spoons, can be tested through placing the film-forming solution in different molds before freezing and drying. The ability of each starch to bend and hold weight can be determined using a spring scale. The ring will be hooked onto the bioplastic film and weight will be attached to the other end. Weight will continue to be added until the bioplastic film breaks and the weight is recorded. The same test will be done with traditional plastics to compare their relative strengths.

Though I plan to use a previous successful study for inspiration, I anticipate encountering multiple potential obstacles. First, I anticipate having difficulty ridding the bioplastic films of air bubbles to create the signature clear look of traditional plastic. Although this issue seems minute, an inability to create this clear look may result in a product that is less desirable for consumers. I may also have difficulty creating an even texture throughout the bioplastic when the film-forming solution is placed in a mold, as the uneven mold surface may cause the bioplastic to dry unevenly. Additionally, I anticipate difficulty matching the strength of these bioplastic films to that of traditional plastics due to the incredible strength of traditional plastic, as some plastics are 200 times stronger than glass. Despite potential challenges, testing a variety of bioplastics for strength, flexibility, and ability to biodegrade in a variety of settings brings us one step closer to replacing the plastics that pose a threat to our oceans, our wildlife, and ourselves.

References

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Appendix A: PLA-Related Figures

$$2\ H_2O + C_6H_8O_4\ \text{[PLA repeat unit]} \rightarrow 3\ CO_2 + 3\ CH_4$$

Figure 1: Ability of PLA to decompose when water is added to it

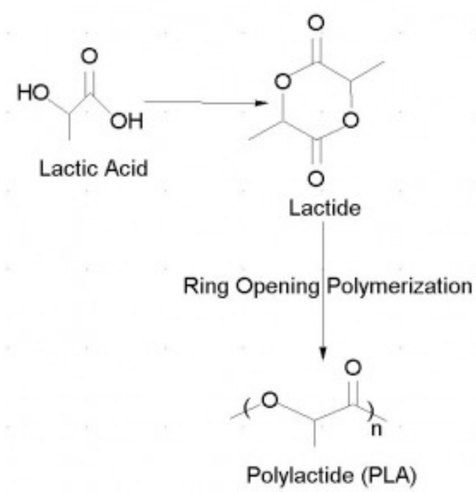

Figure 2: Polymerization process of PLA (lactide molecules are polymerized into PLA)

Appendix B: Amylose Structure

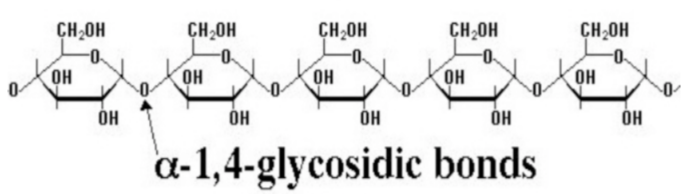

Figure 3: Amylose linear structure that results in strong films