

Abstract:

Over the past few decades, plastic production has increased 150 fold and accounts for 12% of the world's municipal solid waste. Bioplastics, composed of biological compounds, serve as a potential solution to reduce the amount of plastic waste entering the environment; however, these bioplastics are often treated with chemicals. These chemicals can negatively impact the groundwater supply, marine life, and the surrounding ecosystems. Bio-based plastics offer a promising alternative to bioplastics since bio-based plastics are made entirely from organic matter and do not undergo chemical modifications. Recognizing that food waste contributes 1.3 billion tons to landfills annually, this study aims to develop a cost-effective bio-based plastic that incorporates everyday food waste items. Four different bio-based plastics were developed, each one from a different food waste (milk, avocado pits, potatoes, and bread). The four bio-based plastics, a commercially available bioplastic, and a commercially available plastic were subject to a battery of tests (heat test, water absorption test, plant growth test). The bio-based plastics were compared to the commercially available bioplastic, and it was found that the bio-based plastics were more heat resistant, water-absorbent, and served as better plant fertilizers than commercially available bioplastics and plastics. Overall, the bio-based plastics show promise as a formidable, eco-friendly alternative. The bio-based plastics are more cost-effective and are composed of materials available in low-resource areas. Bio-based plastics can help redirect food waste and potentially replace currently available food packaging, medical equipment, and single-use plastics.

Background Research

Food waste has been a major issue in the past few decades: overproduction leads to a surplus of wasted material. Specifically, 40% of all the food generated in 2020 was wasted amounting to 216 billion dollars wasted [2]. Food waste releases greenhouse gasses and contributes to groundwater contamination. A potential solution for excess food waste is to use food materials to develop bio-based plastics. Bio-based plastics are composed of solely organic materials while biodegradable plastics are degradable and compostable materials [4].

Biodegradable plastics dominate the eco-friendly materials market but are often misleading. Although commercial biodegradable plastics promise complete degradation over a short period of time, they often fractionate into microscopic pieces and contaminate soil and seawater [6]. When these fractionated pieces of plastic are introduced in the environment they can enter the organ systems of animals, leading to health issues and potentially even death [3] [7]. Not only are biodegradable plastics costly and require certain conditions to biodegrade, but these types also produce a high amount of greenhouse gasses and produce leachate when in a landfill environment without adequate oxygen. Although these biodegradable plastics may have the right intent of being an environmentally friendly alternative to plastic, these types of plastics contribute to eliminating animal species and greenhouse gas emissions.

While currently available eco-friendly alternatives are formidable options, they are often harmful to the health of wildlife and require particular conditions for biodegradation to occur, in addition to their overall costliness. [4]. Bio-based plastics are relatively new to the consumer market and are composed of by-products, organic materials, and degrade naturally over the span of several months.

There are a limited number of bio-based plastics available on the market however they are extremely costly. There is a need for a bio-based, biodegradable material that can be

constructed with materials that are safe, environmentally friendly, and inexpensive so they can ultimately be accessible to consumers.

Materials:

- Stove
- Blender
- Strainer
- Dehydrator
- Measuring cups and tools
- Pots
- Tinfoil/ Baking Paper
- Food Coloring
- Potato Starch (18 g)
- Acetic Acid (45 mL)
- Glycerol- (75 mL)
- Vegetable oil (1 tsp)
- Bread (35 g)
- Gelatin (95 mL)
- Milk (1 cup)
- Grounded Avocado pits (45 g)

Methodology:

1. Develop one of each bio-based plastic (bread, avocado, milk, and potato)
2. Set 3 grams of 3 of each of the bio-based plastics for the water absorption test
3. Perform the water absorption test by submerging each test group into 150 mL of water and measure the mass of each sample every 10 minutes
4. Set 3 grams of 3 of each bio-based plastics for the heat test
5. Perform the heat test and place all the samples in an oven for 50 minutes and observe the change in structure every 5 minutes.
6. Analyze the final results and the extent of environmental-friendliness of each biodegradable plastic made.

Procedures:**Potato Starch:**

1. Measure and Combine 21 grams of potato starch, 30 mL of acetic acid, 35 grams of water, 20 mL grams of glycerol, and food coloring
2. Stir the contents until properly combined for approximately 30 seconds
3. Cut a piece of tinfoil and with $\frac{1}{4}$ a teaspoon of vegetable oil all over the sheet
4. Heat a pot on a stove at low flame for about 45 seconds
5. Place $\frac{1}{2}$ teaspoon of vegetable oil into the pot
6. After 15 seconds, combine the potato starch contents into the pot
7. Continuously mix the potato starch contents in the pot until the texture turns from liquid to a thick, stretchy, sticky substance
8. Transfer the contents onto the tinfoil
9. Fold on both ends of the tinfoil in have with the content in the middle, and using pressure flatten it

10. Open the tinfoil and let the contents cool for 24 hours

Bread Bio-Based Plastic:

1. Dehydrate 2 pieces of bread in the oven for about 30 min
2. Blend the dehydrated bread in a blender until it becomes a fine powder
3. In a pot, heat and combine 60 mL water and 7.55 g gelatin and later add in 25 mL of glycerol, and 35 g of the bread powder and stir until well combined and is simmering
4. Pour the mixture into a mold and weight 48 hours to dry

Avocado Bio-Based Plastic:

1. Separate 3 avocado pits and dry them for 72 hours
2. Cude each pit into small pieces and using a dehydrator, dehydrate the pits for 3 hours
3. Blend the pits until the pits turn into a fine orange powder
4. In a pot, heat and combine 45 mL water, 7.55g gelatin, 25 mL of glycerol and then add 45g of avocado mixture and stir until well combined
5. Once the mixture comes to a boil, pour the mixture into a cooling sheet and leave the mixture to dry for 48 hours

Milk Bio-Based Plastic:

1. Set 1 cup of milk, 1/2 tsp of oil, 30 mL of water, and 25 mL of glycerol in a pot and let the milk come to a boil
2. Once the milk comes to a boil, add 15 mL of acetic acid to the mixture
3. When the milk starts to separate strain the mixture
4. Keep the spongy milk mixture and pad it dry with a paper towel
5. Leave the milk-based substance to dry for 5 days

Experimental Results

Heat Test

Type of Plastic	Time in Minutes for Visible Structural Changes
Commercial Bioplastic	1 min 27 seconds
Avocado Bio-Based Plastic	Maintained the same structure throughout the 50-minute duration
Milk Bio-Based Plastic	Maintained the same structure throughout the 50-minute duration
Potato Starch Bio-Based Plastic	Maintained the same structure throughout the 50-minute duration
Bread Bio-Based Plastic	Maintained the same structure throughout the 50-minute duration

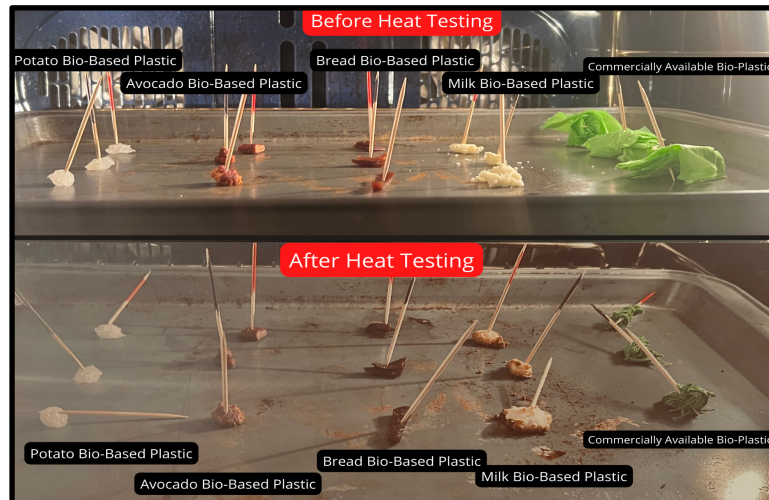


Figure 1.1 Before and after comparisons of the plastics following the heat test

The bread bio-based plastic maintained its structural integrity throughout the full duration of the heat test. However, the commercially available bio-plastics structure changed structure within the first two minutes of exposure to heat.

Water Absorption Test

Type of Plastic	Average Percent Water Absorbed
Commercial Bioplastic	231.167%
Avocado Bio-Based Plastic	158.913%
Milk Bio-Based Plastic	133.023%
Potato Starch Bio-Based Plastic	136.71%
Bread Bio-Based Plastic	171.263%



Figure 1.2 Visuals of plastics in the water-absorption test

Growth Test

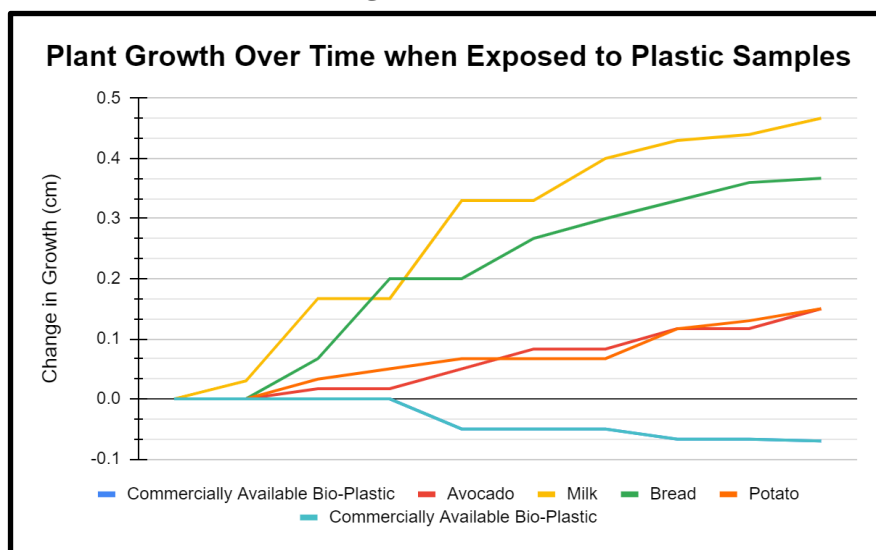


Figure 1.3 Visuals of the Growth Test Day

Statistical Analysis of Bio-Based Plastics

Type of Material	T-Value	P-Value	Null Hypothesis: Accept or Reject
Bread Bio-Based Plastic	-5.313	0.000024	Rejected

vs. Commercially Available Bioplastic			
Avocado Bio-Based Plastic vs. Commercially Available Bioplastic	-4.982	0.000048	Rejected
Milk Bio-Based Plastic vs. Commercially Available Bioplastic	-5.609	0.000013	Rejected
Potato-Starch Bio-Based Plastic vs. Commercially Available Bioplastic	-5.438	0.000018	Rejected

Understanding Statistics

The null hypothesis is always rejected if the calculated value is greater than the table value. This means that the mean of the experimental group is different from the mean of the control. A true difference exists between the means, and the populations are different. The P-value tells you the probability that you have rejected the null hypothesis in error.

Cost Analysis for Potato Starch-based Bioplastic

Item Amount	Cost in Dollars
Potato Starch	\$0.69
Acetic Acid	\$0.02
Vegetable Oil	\$0.02
Glycerol	\$0.16
Total Amount	\$1.25

Cost Analysis for Bread Bio-Based Bioplastic

Item Amount	Cost in Dollars
Bread	\$0.05
Gelatin	\$0.22
Glycerol	\$0.16
Total Amount	\$0.43

Cost Analysis for Avocado Bio-Based Bioplastic

Item Amount	Cost in Dollars
Avocados	\$0.51
Gelatin	\$0.22
Glycerol	\$0.16
Total Amount	\$0.89

Cost Analysis for Milk Bio-Based Bioplastic

Item Amount	Cost in Dollars
Milk	\$0.25
Glycerol	\$0.16
Vegetable Oil	\$0.02
Acetic Acid	\$0.02
Total Amount	\$0.45

Cost Analysis for Commerical Bio-Plastic

Item Amount	Cost in Dollars
Commerical Bio-Plastic	\$0.56
Total Amount	\$0.56

Conclusion

The heat test, water-absorption, and growth test served to assess key components of the plastics as a whole. The heat test showed the structural integrity of the plastic under high heat conditions. The water-absorption test showed the ability of the plastic to retain water beyond its weight. The growth test showed the fertilizer capability of the plastics. Following the battery of tests, Bread Bio-Based Plastic is a far more effective fertilizer and is more durable when compared to the commercially-available bioplastic. When comparing the Milk, Avocado, Potato-Starch, and Bread Bio-Based Plastic to the Commercially Available Bioplastic, it was found that plant samples exposed to Bread Bio-Based Plastic showed 5 ½ times more growth over a 10 day period compared to the commercially available bioplastic, indicating that the Bread Bio-Based Plastic is an environmentally-friendly alternative to commercially available bioplastics.

A statistical analysis using a T-test compared the commercially available bioplastics to the four bio-based plastics. The T-test showed that the null hypothesis was rejected indicating that our results were statistically significant. All four bio-based plastics performed significantly better on the heat test and the growth test, however, the milk and avocado bio-based plastics were less capable than the commercially available bioplastic in absorbing water.

After conducting a cost-analysis of the bio-plastics it was found that the Bread Bio-Based Plastic and the Milk Bio-Based plastics are cheaper than the commercially available bioplastics by 13.13% and 10.89% respectively. The low cost of the bio-based plastics indicates to us that they can be more accessible to those in low-resource areas. Additionally, it is important to note that if bio-based plastics are mass-produced, the costs can be even lower.

When comparing the growth of each plant that occurred in the 10-day period, it was found that the bread bio-based plastic acted as a better fertilizer as compared to the commercially available bioplastic. The bread bio-based plastic grew on average 3.67 cm in the 10-day window while the commercially available bioplastic grew 0.67 cm in the experimental period. All of the bio-based plastics materials (bread, milk, avocado, and potato) are commonly thrown away in mass amounts due to overconsumption worldwide; using such products in a real-based setting would allow for these certain bio-based plastics to be developed more cost-effectively.

In conclusion, the bread-bioplastic was a far more effective fertilizer, more durable, and heat resistant when compared to the commercially available bioplastic. The bread bio-based plastic can potentially be used for multiple purposes such as single-use plastics in the food industry, packaging purposes, and can replace the plastic materials used in medical equipment. Overall, the bio-based plastics developed in a home-based setting offer a promising solution to alleviating the plastic strain worldwide.

Future Applications

1. The developed bio-based plastics can be used as a replacement for plastic packaging used in e-commerce or industrial packing. Packaging generates 82.2 million tons of waste which account for 28.1% of all municipal solid waste in landfills in the US alone in 2018 [4]. Commonly used plastic packaging containers made from polyethylene terephthalate (PET) or high-density polyethylene (HDPE) can be substituted with bio-based materials created in this experiment.
2. Medical Equipment commonly used in healthcare facilities includes heavy amounts of single-use products due to the need for sterility of these facilities. Health care facilities commonly used polyethylene, nylon, polypropylene materials for these single-use medical resources. The following bio-based plastics replicate the actions and structures of polyethylene and can be used as a replacement for dialysis bags, disposable gloves, pharmaceutical caps, and containers for medicines, tubing, and types of cartridges in the medical field [5].
3. In supermarkets, approximately 84% of food is packaged and in the US alone, 5% of municipal solid waste is derived from food packaging which is about 14.5 million tons[3]. Single-use plastic packaging and common single-use plastics found in fast-food restaurants and in supermarkets (utensils, cutlery, plastic cups, lids, water bottles, milk and water jugs, egg cartons, produce baskets, and saran wrap), are made from harmful plastic materials such as high-density polyethylene (HDPE), and low-density polyethylene (LDPE). Such items can be replaced with the bio-based plastics created from this experiment.

Future Research

1. Plastic debris alone accounts for 80% of the pollution in the ocean and plastics in the ocean are threatening the existence of marine animals [3]. As these plastics exist within the water, parts of the plastic dissociate into microscopic pieces which then are consumed by marine animals. The consumption of nano plastic particles leads several animals to starvation. In the future, research can be performed to alter the materials for these developed bio-based plastics to make these plastics edible for marine life. Daphne and Magna can be used to measure the health of marine life with their consumption of these bio-based plastics.
2. The current bio-based plastics are healthier alternatives to commercial plastics and biodegradable plastics, however, the bio-based plastics are not as elastic compared to the commercial ones due to the presence of a polyethylene coating. By using similar ingredients like glycerol, future research can be done by altering or adding similar substances to make the developed bio-based plastics more elastic. Adding a more elastic component to these bio-based plastics allow for these plastics to be used for more versatile uses such as disposable gloves, plastic bags, or packaging similar to saran wrap.
3. Leachate is produced when products in landfills are exposed to rainfall and can be hazardous to animal and human health once this leachate enters the groundwater. Research can be performed to view how much leachate is produced when bio-based plastics are mixed with normal landfill waste, Since bio-based plastics have a better effect on the healthiness of soil, research can be performed to see if these bio-based plastics can combat the production of leachate contamination in landfills.

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