

# A Taste of Sweetness in Bioplastics

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## SUMMARY

In this study, we used an agricultural waste commonly found in Taiwan, sweet potato peels, to make bioplastic. We manipulated the amount of glycerol added when making the plastic and measured the resulting plastic's properties. We predicted that reducing the amount of glycerol would result in a firmer and less malleable plastic because glycerol acts as a plasticizer, preventing the polymers from forming brittle, inflexible structures. The process began with extracting starch from sweet potato peels. We also ran the peels and their starch under a flame test to investigate the type of metal ions they contained, which we determined to be  $\text{Cu}^{2+}$  and  $\text{Cu}^+$ , respectively. Then, we made bioplastic by heating up the starch mixture with acetic acid, different amounts of glycerol, and water. Allowing the mixture to set, we were left with a thin piece of plastic film. In the final stage of the experiment, we conducted a stress test to evaluate the malleability of plastic mixtures. Our results supported our initial prediction as the plastic containing the greatest amount of glycerol expanded the most, indicating that it had the greatest malleability. We concluded that the ratio of 1:2.4 starch to glycerol would yield the ideal plastic film with a flexible yet firm texture, properties which allow for the plastics to be molded into different structures yet still retain their shapes. Even though we didn't manage to make a substantial amount of plastic, we have determined a recipe for making bioplastics from agricultural waste such as sweet potato peels. This opens a door for possibilities in slowing down the rate of pollution caused by widespread use of conventional plastics.

## INTRODUCTION

Plastic, a word that originally meant "pliable and easily shaped", is a fundamental material found in all parts of human society [1]. In 1907, Leo Baekeland invented Bakelite, the first fully synthetic plastic [1]. The issue of synthetic plastic gained public attention after World War II, when plastic debris was observed in the ocean [1]. During the 1970s and the 1980s, people were even more concerned about plastic waste, as they became aware of the longevity of plastic [1]. Today, plastic is found everywhere in our lives — from plastic bottle caps to straws, bags, and milk jugs. This purported miracle material has been a building block for development, but now we're surrounded by it because it cannot be decomposed in a short period of time [2]. Furthermore, more than 40% of

plastics are used only once, which is a serious environmental issue [2]. Therefore, we wondered if there was a way for us to alter the nature of plastic to make it biodegradable in nature.

To achieve this goal, we used sweet potato peels, an agricultural waste commonly found in Taiwan, to make bioplastic. Sweet potatoes are one of the most common starches in Taiwan; they are added in porridges, fried in the shapes of spheres in food stalls in night markets, and even sold as baked sweet potatoes in convenience stores. Most of the time, however, the peels are forgotten and thrown straight into the trash bin. We believe that using sweet potato peels to make plastic has the potential to alleviate the carbon footprint petroleum-based plastic has on the environment. Starch is an ideal choice for bioplastic because it has high elongation, tensile, and flexural strength, meaning after processing, starch-based plastic can be molded into different forms for various purposes [3]. Not only were we recycling kitchen waste to produce useful materials, but we were also giving these peels more purpose, fully utilizing sweet potatoes from porridges to the peels in plastics. Therefore, we wanted to test whether it was possible to make plastic from the peels, to turn waste into a usable product which may alleviate some of the environmental issues we are facing today.

In this study, we adopted the measurements provided by the Royal Society of Chemistry but also modified the measurements to form the firm-yet-flexible films we wanted [4]. We manipulated the amount of glycerol added to the starch and acetic acid to observe the differences in physical properties of the plastic films. We wanted to make plastics with different malleability to find out which sample had the highest strength and flexibility; such plastics can be potentially shaped into different structures but still hold their shape. The biologically based plastics we made from starch can be categorized as biodegradable plastics because the materials used to make the plastic, including starch, acetic acid, and glycerol, are all biodegradable. On the other hand, conventional plastics take around 400 years to biodegrade [2]. We hypothesized that adding less glycerol would cause the plastic to be firmer and more inflexible. This is because glycerol prevents polymers from having brittle, inflexible textures. The purpose of our experiment was to find the ratio between starch and glycerol that yielded the most firm-yet-flexible plastic.






## RESULTS

There were four components to our experiment in our quest to make bioplastic: flame tests, extraction of starch from sweet potato peels, making sweet potato peel plastic,

and stress tests. First, we used a flame test to determine the presence of metal ions in the sweet potato peels. Knowing the ions found in the sample of sweet potatoes assisted in our plastic construction because then we could manipulate the properties of these ions. Different colors indicated the presence of different ions (**Table 1**). We placed some ground peels onto the wire and positioned the wire over the flames. The color of the flames turned bluish-green for sweet potato peels, indicating the possible presence of copper ions,  $\text{Cu}^{2+}$ , in the peels (**Table 1**) [5]. When we conducted a flame test on the starch and the plastic samples containing 5 mL and 8 mL of glycerol, the color of the flame had a tint of green, indicating changes to the copper ions. The color green suggested the presence of  $\text{Cu}^+$  metal ions (**Table 1**). However, when we conducted the flame test for 22 mL and 27 mL glycerol plastic, there was no color change (**Table 1**). This signified that the  $\text{Cu}^+$  ion that was present in the 5 mL and 8 mL glycerol plastic flame test was no longer present. A possible reason could be the excessive amount of glycerol used in the 22 mL and 27 mL glycerol plastic.

In the second part of the experiment, extracting the starch, we were able to obtain 18.35 g of starch in total. We then decided to compare how different amounts of glycerol would affect the quality of the plastic. Thus, we created two batches of plastic mixture: both had the same amounts of water, starch, and acetic acid with different quantities of glycerol, 22 mL and 27 mL; the 22 mL sample had a ratio of 1:2.4 starch to glycerol and the 27 mL sample had a ratio of 1:2.9.

After heating the solutions over a hot plate for 40 minutes, we noticed a change of texture. The solution was no longer liquid-like; instead, the solution was slimy and sticky. However, when we measured the pH of the plastic, the solution was very acidic, yielding a pH of 3.5. Not only was the solution acidic,

Original Flame Color	Sweet Potato Peel Flame Color	Sweet Potato Peel Starch Flame Color	Sweet Potato Peel Plastic (5 mL glycerol plastic) Flame Color	Sweet Potato Peel Plastic (22 mL glycerol plastic) Flame Color
Orange	Bluish-green	A tint of green	A tint of green	Orange
				
None	$\text{Cu}^{2+}$	$\text{Cu}^+$	$\text{Cu}^+$	None

**Table 1. Flame Test from Different Plastic Samples.** The comparison of different flame colors emitted from different samples of plastic and sweet potato peel used indicate the presence of ions in the sample. The original flame color serves as a basis for observing the color change in the flame tests. The ion detected in the samples were mainly copper ions, as seen through the picture of sweet potato peel, sweet potato peel starch, and 5 mL glycerol plastic. The flame test for plastic samples that contain 22 mL glycerol shows no color change in the flame test. This indicates that the  $\text{Cu}^+$  ion is no longer detectable. A possible explanation for the absence of  $\text{Cu}^+$  ions may be due to the excessive amount of glycerol present.

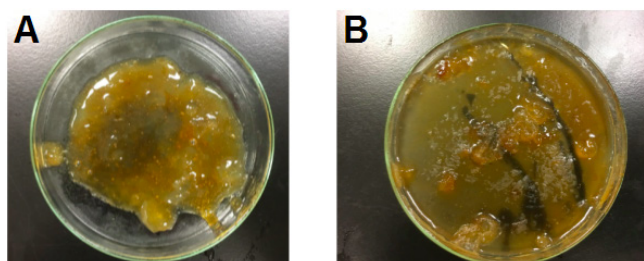
but the steam from boiling the solution was also very acidic, with a pH of 4. Thus, we added ammonia water, which is a weak base, to neutralize the solution. After adding ammonia water to the solution, the solution gradually turned from a pH of 3.5 to 7. Then we poured out the solution from the beakers into separate petri dishes.

We allowed the mixtures to set for three days. As the mixtures still retained a gel-like texture, we heated the mixtures for another 20 minutes to burn off the excess liquid, then allowed them to cool down again. However, the sample containing 27 mL of glycerol did not form a sturdy plastic film. Thus, we decided to put one of the 27 mL glycerol samples into the freezer and observe it for property changes. After placing the sample in the freezer for a day, the plastic remained gel-like (**Figure 1**).

Based on these results, we concluded that large amounts of glycerol (27 mL) affected the plastic mixture so that they could not form into a firm texture. Thus, we decided to create two other samples of plastic, each with significantly lower amounts of glycerol, one with a ratio of 1:1.3 starch to glycerol and the other with a ratio of 1:0.7 starch to glycerol. We heated the mixture containing starch, water, acetic acid, and glycerol for 20 minutes then left it to set for a day. However, the starch we used this time was not in powder form; instead, the starch was in clumps. In addition, the starch we used this time was from sweet potato peels which had already been used for starch extraction. Therefore, the starch yield might have been lower compared to the first time we extracted starch from the peels.

After the plastic mixtures settled into thin films, we conducted a malleability test by dropping a volleyball onto 5 mL, 8 mL, 22 mL, and 27 mL glycerol plastic for five times. After dropping the volleyball five times, we observed and measured the increase in area of the plastic sample. The 22 mL glycerol sample expanded the most, as its area increased by 337% and the difference in area before and after the malleability test was the greatest (**Table 2, Figure 2**). In contrast, the 27 mL glycerol sample expanded the least, as its area only increased by 3.45% and the difference in area before and after the malleability test was the least.

In addition to the malleability test, we tested whether our



**Figure 1. 27 mL glycerol plastic sample and 22 mL glycerol plastic sample.** A) The 27 mL glycerol plastic sample after being in the freezer for one day. B) The 22 mL glycerol plastic sample after being in the freezer for one day. The plastic has already settled into a thin film, allowing the stress test to be conducted.

plastic dissolves in water or not. After soaking a 1.0 g sample of the 22 mL glycerol plastic in water with a magnetic stirrer for 30 minutes, the plastic did not dissolve.

### DISCUSSION

From the flame test results (Table 1), we noticed that although there were tints of green for 5 mL and 8 mL plastic (1:0.54 and 1:0.87 starch to glycerol ratio), the flames returned to their original orange color for 22 mL and 27 mL samples (1:2.4 and 1:2.9). We speculated that copper was no longer observed for 1:2.4 and 1:2.9 starch to glycerol samples because the quantity of glycerol was too great to the extent that the metal ions in the starch were no longer detectable. Moreover, although we speculated that the bluish-green colored flames might be indicators of the presence of  $Cu^{2+}$  ions, other metal ions such as zinc and phosphorus also emit bluish-green flames [6]. We couldn't be certain that the bluish-green flames observed derived solely from copper ions. One area of improvement to consider, therefore, is to conduct more trials on the starch and each plastic sample to increase data accuracy.

Based on our experimental results, we concluded that the plastic with a starch to glycerol ratio of 1:2.4 (the one with 22 mL of glycerol) yields a firm yet flexible plastic film. We demonstrated this by making different samples of plastic with 91.75 mL water, 9.175 g starch, 3.67 mL acetic acid and different volumes of glycerol (5mL, 8mL, 22 mL, and 27mL) to compare their properties. The amount of glycerol affected the properties of the plastic. We could tell the difference just from raw observation: the 27mL and 22 mL glycerol plastic was more gel-like compared to the 8 mL and 5 mL glycerol plastic. This suggested that as the amount of glycerol increases, the tensile strength of the plastic will decrease. The 27 mL

glycerol plastic's area increased by 3.45% and the 22 mL glycerol plastic's area increased by 337%. This alluded to the fact that as the amount of glycerol increases, the malleability of the plastic also increases (Table 2, Figure 2).

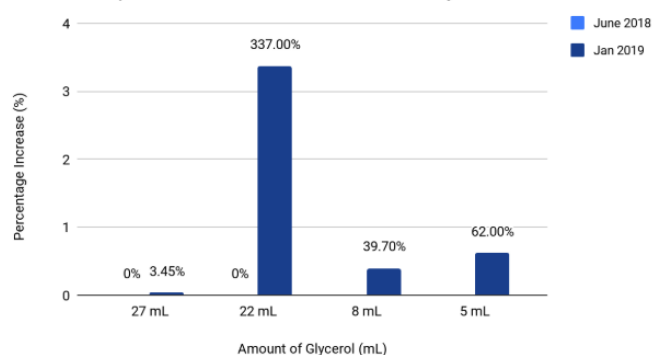
Recalling the results from the solubility test, the plastic we made has a wide range of uses, as the plastic remained intact when soaked in water. This feature allowed the plastic to contain a variety of matter, including liquids. Also, the plastics we made consist mainly of natural ingredients, such as sweet potato peels. The synthetic ingredients added during the process of making plastic are also non-toxic ingredients, such as glycerol and acetic acid. Therefore, we predicted that our plastic is biodegradable, as the ingredients added do not harm the environment and are easy to decompose. Given these properties, our plastic was eco-friendly and had a wide range of usages. For the 22 mL glycerol plastic, the plastic did not dissolve in water and the area expanded significantly after dropping the volleyball onto the sample five times. This showed that our plastic was very malleable. Hence, the 22 mL glycerol plastic could be made into thin plastic films that can be used as plastic wrappings for food. The other plastic samples where less glycerol was added, such as the 5 mL and 8 mL glycerol plastic, could be used for making sturdier products, such as plastic utensils. However, the cost behind making these bioplastics served as a concern. Taking note that 22 mL of glycerol costs 1 USD and 22 mL of glycerol only yields about 5 grams of plastic, we could infer that the cost of making bioplastics is significantly greater than conventional, petrol-based plastic. However, the cost of making bioplastics could possibly be reduced if bioplastics become a mass product.

Numerous factors could have affected our experimental results. First, for the flame test, contamination from the

	27 mL glycerol plastic	22 mL glycerol plastic	8 mL glycerol plastic	5 mL glycerol plastic
Texture	The plastic is mainly in liquid form. Yet we can still find certain areas where a plastic film has formed. [Figure 2]	The plastic is gel-like with clumps of plastic within the solution. [Figure 2]	The plastic has clumps of starch in it and it is mushy.	The plastic has clumps of starch in it and it is mushy.
Malleability Test Conducted in June 2018	The area of the plastic increased by 0.03% (from 3.801 cm <sup>2</sup> to 3.932 cm <sup>2</sup> ).	The area did not change.	The sample was not testable.	The sample was not testable.
Malleability Test Conducted in January 2019	The area of the plastic increased by 3.45% (from 3.801 cm <sup>2</sup> to 3.932 cm <sup>2</sup> ).	The area of the plastic increased by 337% (from 3.801 cm <sup>2</sup> to 16.62 cm <sup>2</sup> ).	The area of the plastic increased by 39.7% (from 3.801 cm <sup>2</sup> to 5.309 cm <sup>2</sup> ).	The area of the plastic increased by 62.0% (from 3.801 cm <sup>2</sup> to 6.158 cm <sup>2</sup> ).

**Table 2. Comparison and Summary of Plastic Samples by Texture.** Results from the malleability test #1 and #2 demonstrate the plastic made from 22 mL of glycerol has the highest percentage increase in area (337%), which fits our criteria of a malleable yet firm plastic.

**Plastic Sample Area Before and After Malleability Test**



**Figure 2. Percentage Increase of Plastic Samples After Malleability Test.** The percentage increase in the area of different plastic samples indicates the sample's malleability. As seen through the graph, the plastic sample with 22 mL of glycerol expanded the most whereas the 27 mL glycerol plastic increased the least. This suggests that the 22 mL glycerol plastic is very malleable compared to the other three trials. The absence of data for the June 2018 5 mL and 8 mL glycerol plastic experiment is due to the fact that we were unable to conduct the malleability test from the plastic sample we produced at that time.

equipment used could have increased the uncertainties. For instance, if the nichrome wire was not cleaned enough for every trial, there may have been residue of other chemical compounds remaining on the wire, resulting in inaccuracies. Second, when making the plastic films, inconsistencies with the surface area and quality of the starch could also have affected the properties of the plastic. For instance, the plastic samples made from starch in powder form, having greater surface areas, could have expanded more evenly in the stress tests than the samples made from the starch in clumps. Moreover, although we tried to ensure that the surface areas of the plastic samples were consistent for each variation of the stress test, we could not be certain that the amount of plastic experimented on was the same throughout. The more plastic we had, the greater in area the plastic sample would expand. To correct this error, each sample could be weighed to make sure the same amount was used. Although the results showed promise for biodegradable, sweet potato starch-based plastic, more investigations need to be conducted to make sure it could substitute for conventional petroleum-based plastic. Further research should be done to test its properties such as heat resistance and durability.

There were discrepancies between the results recorded in June 2018 and January 2019. We believed they may be due to the following reasons. First, we failed to maintain some factors constant, including the conditions in which we conducted the experiments and the form of the starch. For instance, the total rainfall received in June 2018 in Taipei is 119.8mm, while the precipitation in January 2019 is 45.0mm [7]. The low humidity experienced in January 2019 may have caused the elongation properties to be more prominent than in June 2018 because more water had evaporated out after 40 minutes on the hot plate. Moreover, the forms of the starch experimented on were inconsistent. The starch used for all the trials in January 2019 were all in powder form, yet the starch for 5 mL and 8 mL samples were in clumps rather than powder form.

Given this reason, we believed the results from January 2019 were more accurate since a physical characteristic of starch was kept constant. From the results of the January 2019 stress test, we concluded that a starch-to-glycerol ratio of 1:2.4 yields a malleable-yet-firm structure, thus producing an excellent plastic film. Yet we could not neglect the major discrepancies between the results from June 2018 and January 2019. For instance, the film from June 2018 expanded 0% while the one from January 2019 expanded 337%. We decided to base our discussion around the results from January 2019. Having made careless experimental errors such as not keeping a variable constant throughout all trials (whether the starch is in powder form or in clumps), we believed the results from January 2019 were more reliable. This is also why if we were to perform a third set of trials, we predict the results will be closer to the results from January 2019. The range in data results illustrated how variable bioplastic is; for instance, with a slight change in humidity,

there could be drastic changes to plastic properties.

Creating bioplastics involved careful monitoring of all kinds of variables; thus, bioplastic industries around the world may have the same intention of producing an alternative to petroleum-based plastic, yet depending on variables such as temperature, humidity, source of plastic, time, etc., they could all be creating products with variable properties. By demonstrating the plastic with a starch to glycerol ratio of 1:2.4 (the one with 22 mL of glycerol) yielded a firm yet flexible plastic film, we offered insight into the rapidly expanding world of the bioplastic industry, where people are constantly seeking for alternatives to petroleum-based plastic. With this study, we aimed to show there is a possibility to find a substitute in sweet potatoes.

## METHODS

### Flame Test

Dry sweet potato peels were placed in a mortar and ground with a pestle. Then, 2 mL of methanol was added into the mortar while continuing the grinding process. After the sweet potato peels were ground into a mushy texture, a nichrome wire was used and the tip of the wire was coiled. Nichrome, which consists of 80% nickel and 20% chromium, is an ideal material for the flame tests because it is oxidation resistant and has a melting point of 1400°C [8]. The wire served as a medium to deliver the peels onto the flames. Since the wire was likely to be contaminated, the nichrome wire was cleaned by dipping the tip of the wire into hydrochloric acid and burning it off with a flame. This step was repeated until the tip of the nichrome wire is cleaned and not contaminated. Finally, after placing a sweet potato peel sample at the tip of the nichrome wire and placing it over a flame, color changes were observed and the results were recorded. The results from the flame test could give us insight into the ions present in the particular sweet potato sample used. We believed knowing this information can help us with constructing bioplastics.

### Extracting Starch from Sweet Potato Peels

To extract the starch from the sweet potato peels, we added enough water to submerge and grind the peels. Then the water solution was transferred into another beaker, leaving the potato peels behind in the mortar. Water was then added into the sweet potato peels again and the sweet potato peels were ground until the solution became misty. The water solution was transferred into the beaker and allowed to settle in the beaker for five minutes. When the starch settled at the bottom of the beaker, water was gently poured out of the beaker, leaving the starch behind. Then the starch was removed from the bottom of the beaker and placed on a petri dish to dry.

### Making Sweet Potato Peel Plastic

An experimental protocol written by Royal Society Chemistry was referred to and the measurements provided

were followed (Royal Society of Chemistry). 91.75 mL water, 9.175 g starch, 3.67 mL acetic acid and different volumes of glycerol (propan-1,2,3-triol) (5mL, 8mL, 22 mL, and 27mL) were added into four different beakers. The quantities 22 mL and 27 mL were chosen initially based on the ratio provided by the Royal Society of Chemistry. However, after we discovered the 27 mL plastic was not firm yet flexible, we decreased the amount to 5 mL and 8 mL to see the difference in plastic properties. Then, the mixtures were mixed and placed over a hot plate to heat up the mixture. The mixtures were carefully brought to a light simmer and kept over the flame for around 40 minutes. During the heating process, an indicator paper was used to measure the pH. Enough ammonia water was added to neutralize the water, and the pH value was tested after each addition. After the mixture has been heated for 40 minutes, the mixtures were poured into petri dishes and were allowed to dry and solidify.

### Stress Test

A piece of the plastic sample was cut out and placed onto a clean piece of cardboard. Then, the borders of the plastic sample were outlined with a marker. The approximate area of the plastic was calculated and the value was recorded. From the same height of 84cm, a Molten V5M5000 volleyball that weighed 279.15 g was dropped onto the plastic sample five times and the expanded area of the plastic sample was recorded. The ball was dropped exactly five times to increase the possibilities of it actually hitting the sample and expanding the area of the sample.

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