

Musa acuminata and Musa paradisiaca Mashup: Developing Higher Resistant Starch Bioplastics

Introduction

The Plastic Problem

- Plastic pollution never fully degrades; it just turns into micro- and nano-plastics.

- Overuse of single-use plastic - a life-saving material in medicine that helps prevent cross-contamination, but now used daily for many unnecessary applications.

The Bioplastic Solution

- Bioplastic can be broken down by the environment and can be non-toxic.

- Microbes metabolize the bioplastic into compounds like CO_2 , H_2O , and CH_4 .

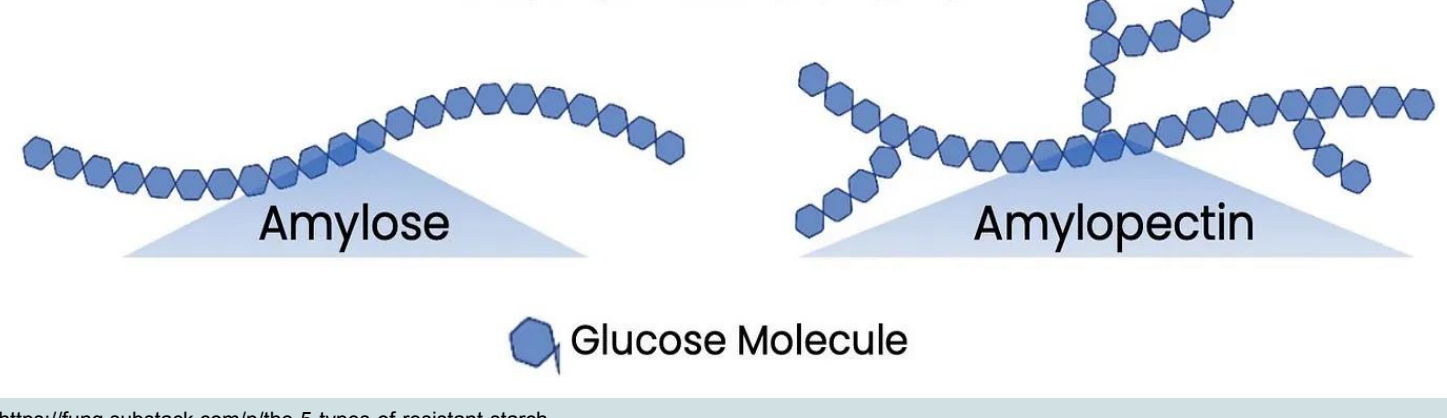
- Banana and Plantain Bioplastic
 - Using bananas (*Musa acuminata*) or plantains (*Musa paradisiaca*) may help reduce food waste: -20-30% of banana harvests -50% of plantain harvests

- Challenges to Banana and Plantain Bioplastic
 - Not a lot of research done and these bioplastics are not mass produced.
 - Pollution still happening to make bioplastics.
 - When the heavy machinery is used for harvesting, planting, or when a factory makes bioplastic, harmful chemicals are still released into the air and harm the environment.

Starch in Plantains

- Contain 70-80% starch by dry weight and have about 25% amylose (Viana et al., 2022), which is higher than bananas.
- Starch is made up of glucose monomers that form two polymers: amylopectin, which has a branching structure of glucose molecules, and amylose, with the glucose molecules arranged in a straight line, and making better bioplastics.

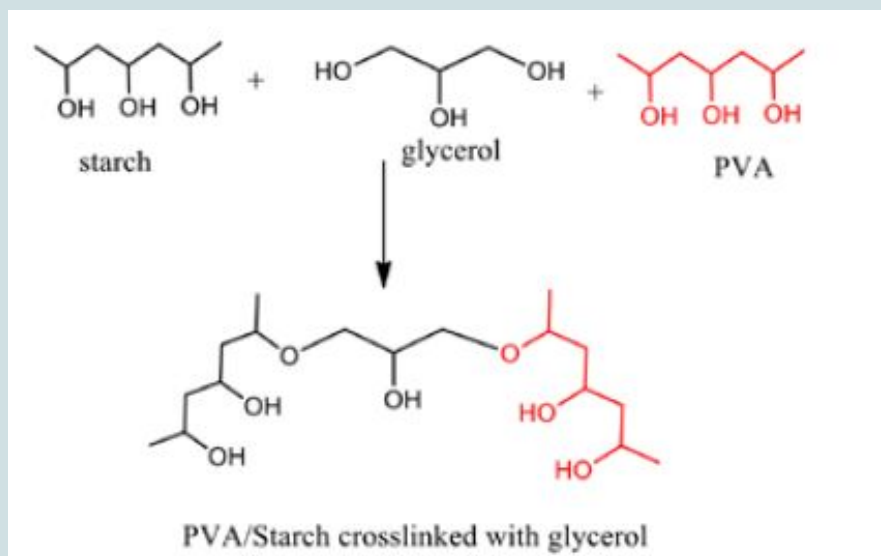
Starch Structure



- Amyloplasts are structures in eukaryotic cells that store starch (Buckley, 2024).
- Resistant starch mostly contains amylose, cannot be digested quickly, and is ideal for bioplastic. There are five different types of resistant starch:
 - One type is found in raw potatoes, bananas, and plantains.

Bioplastics from Starch

- Glycerol and polyvinyl alcohol (PVA) bind with starch to make crosslinks, making a strong bioplastic that is less degradable with a durable film (Shrestha et al., 2023).
 - Glycerol is a plasticizer that bonds starch molecules together
 - PVA is also soluble in glycerol and is compatible with starch.



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Purpose

The purpose of this study is to determine if plantains have more amyloplasts and starch, and plantain bioplastic has lower viscosity, higher tensile strength, and higher breaking distance compared to banana bioplastic.

Hypotheses

Null Hypothesis: The null hypothesis is that there will be no difference in the amyloplasts, amount of starch, viscosity, tensile strength, and breaking distance between plantain and banana flesh.

Alternative Hypothesis: The alternative hypothesis is that there will be a difference in the amyloplasts, amount of starch, viscosity, tensile strength, and breaking distance between plantain and banana flesh.

Experimental Design

Independent variable: Green plantain flesh

Control: Green banana flesh

Dependent variable: Amyloplasts, amount of starch, viscosity, tensile strength, and breaking distance

Constants: amount of flesh, amount and concentration, of chemicals, starch isolation method, temperature, amount of time, polymerization method

Statistical Procedures

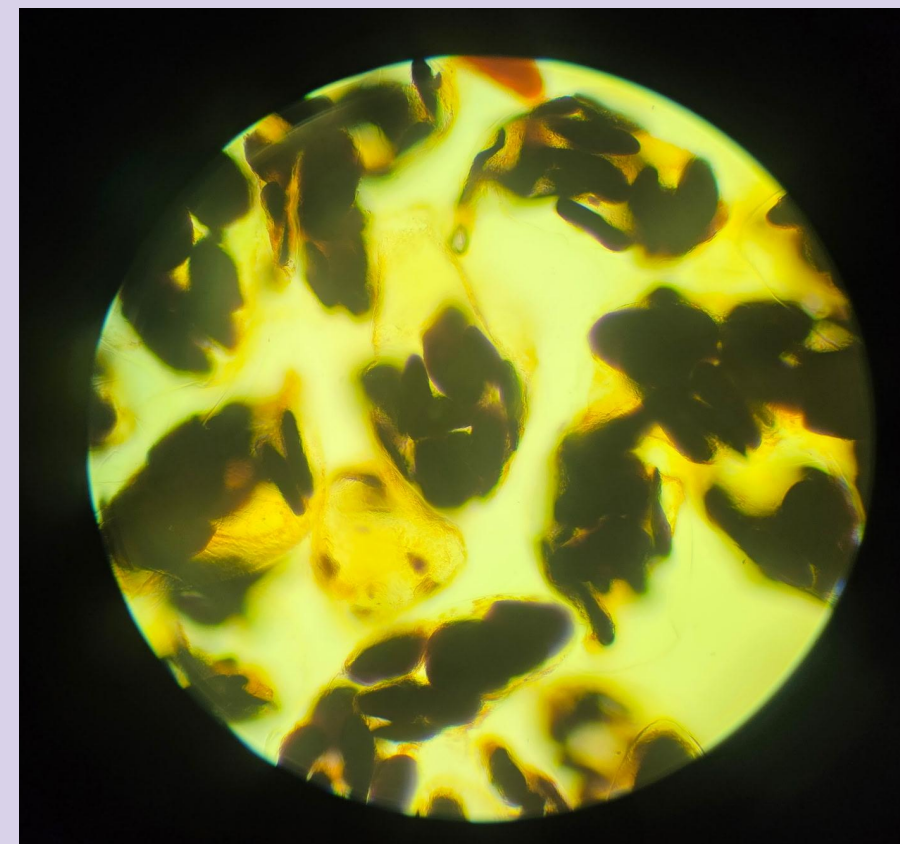
The data was averaged from all of the trials and put into bar graphs. Standard error was calculated and error bars (± 2 SEM) were added to graphs to show the distribution of data. Ten to one hundred replicates were done for each sample type when possible.

Part 1: Testing Amyloplasts

- A sample of green banana pulp was prepared for the microscope with water and iodine to view the starch in amyloplasts.
- Then, the mixture was placed on a slide with a cover and examined under a microscope.
- Individual cells were viewed at 400x and amyloplasts were counted. A total of 100 cells were viewed and counted to determine how many amyloplasts there were.
- Procedures were repeated for plantains.

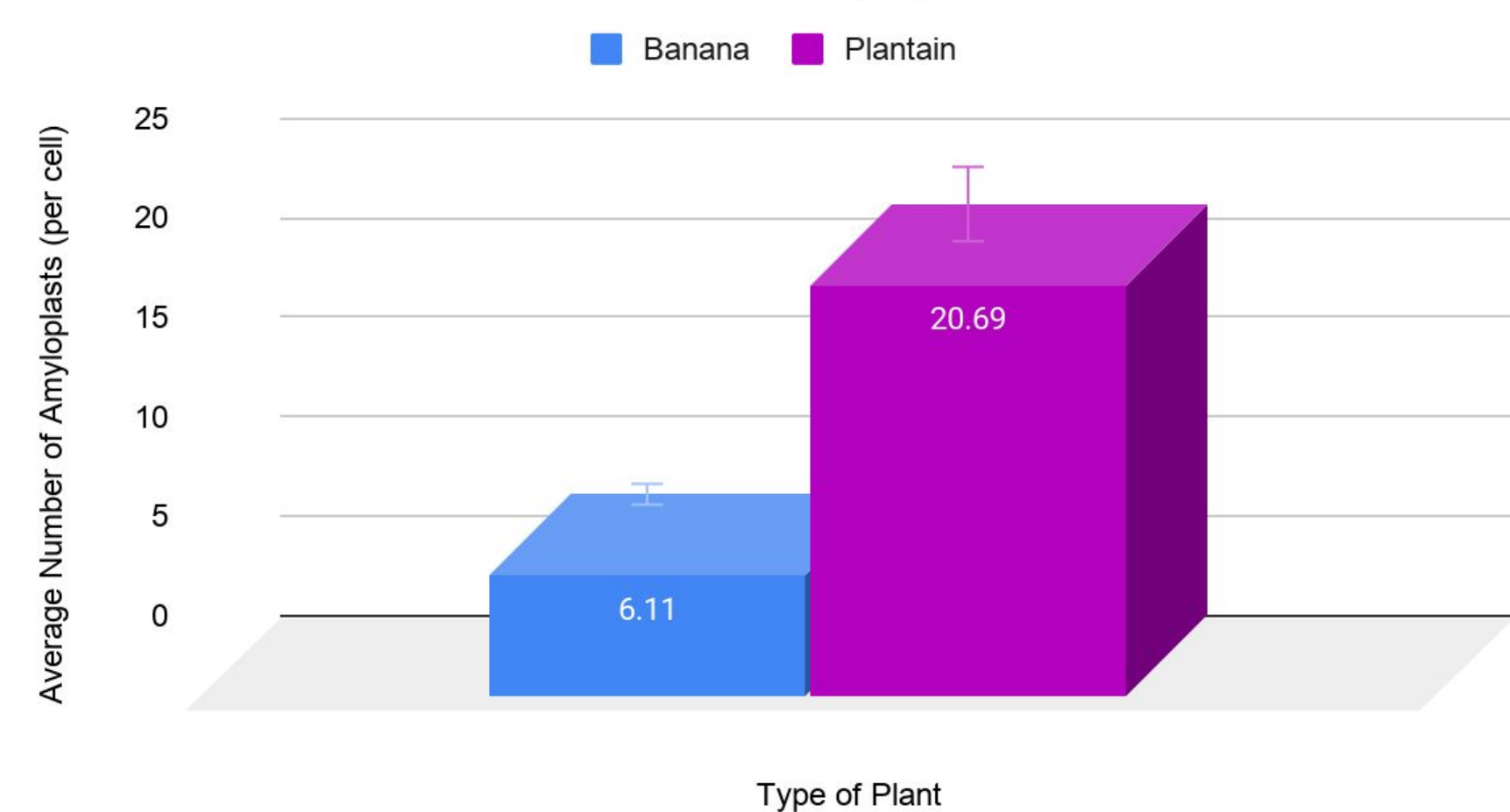


Viewing cells under the microscope. (Photo taken by Linda Rost).



Plantain cells with dyed amyloplasts at 400X with light microscope. (Photo taken by Linda Rost).

Plantain vs. Banana Number of Amyloplasts

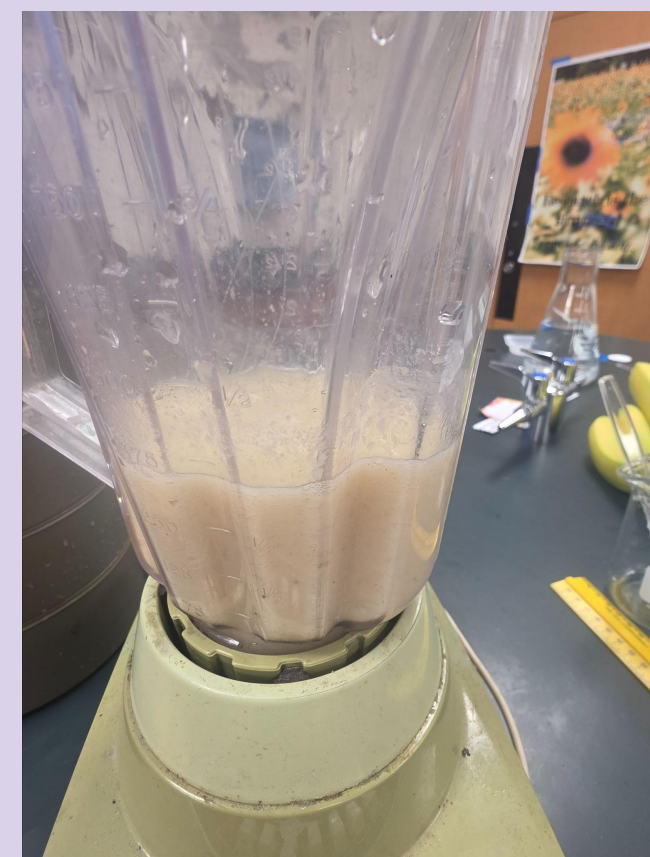


Average amount of amyloplasts counted per cell in 100 total cells per plant type. Error bars represent ± 2 standard error of the mean. (Graph created by Rye Rost using Google Sheets).

- Banana: average of 6.11 amyloplasts/cell.
- Plantain: average of 20.69 amyloplasts/cell.
- The error bars did not overlap, so there is a significant difference in the number of amyloplasts.
- Therefore, the data rejected the null hypothesis.
- Plantains have significantly more amyloplasts than bananas.

Part 2: Extracting Starch

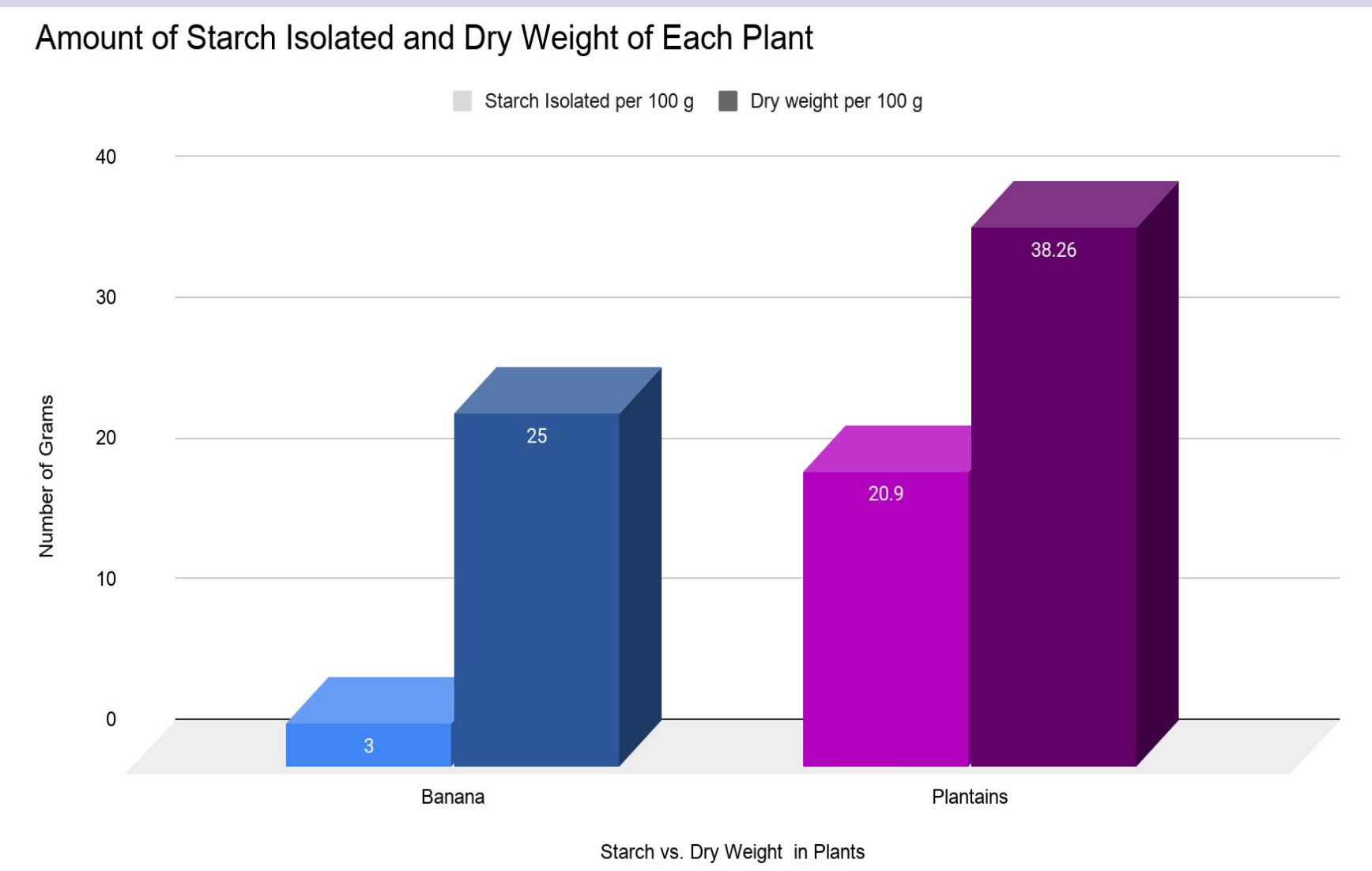
- Banana pulp added to a solution of sodium bisulfite to dissolve the cell walls and extract the starch, then blended, sieved, filtered, decanted, and allowed to settle.
- The filtrate was filtered through filter paper and dried in a dehydrator at 50°C for 24 hours.
- Procedures were repeated for plantains.



Blended pulp-sodium bisulfite solution. (Photo taken by Linda Rost).



Sieving pulp-sodium bisulfite solution to 125 microns. (Photo taken by Linda Rost).



Amount of starch extracted from each type of plant flesh. (Graph created by Rye Rost using Google Sheets).

- Banana: 3g of starch and 25 g of total dry weight, or 12%, in 100 g banana.
- Plantain: 20.9 g of starch and 38.26 g of total dry weight, or 55%, in 100 g plantain.
- The plantains had more total starch and a higher percentage of starch compared to their dry weight, and the data rejected the null hypothesis.

Part 3: Making Bioplastic and Testing Viscosity

- Banana starch was dissolved in water, heated, and combined with glycerol and polyvinyl alcohol.
- Bioplastic gel was heated and stirred until smooth. Viscosity was tested with a viscometer.
- The mixture was poured into a glass petri dish at 1 mm thickness, covered, and dehydrated, then peeled, and stored in a humid environment.

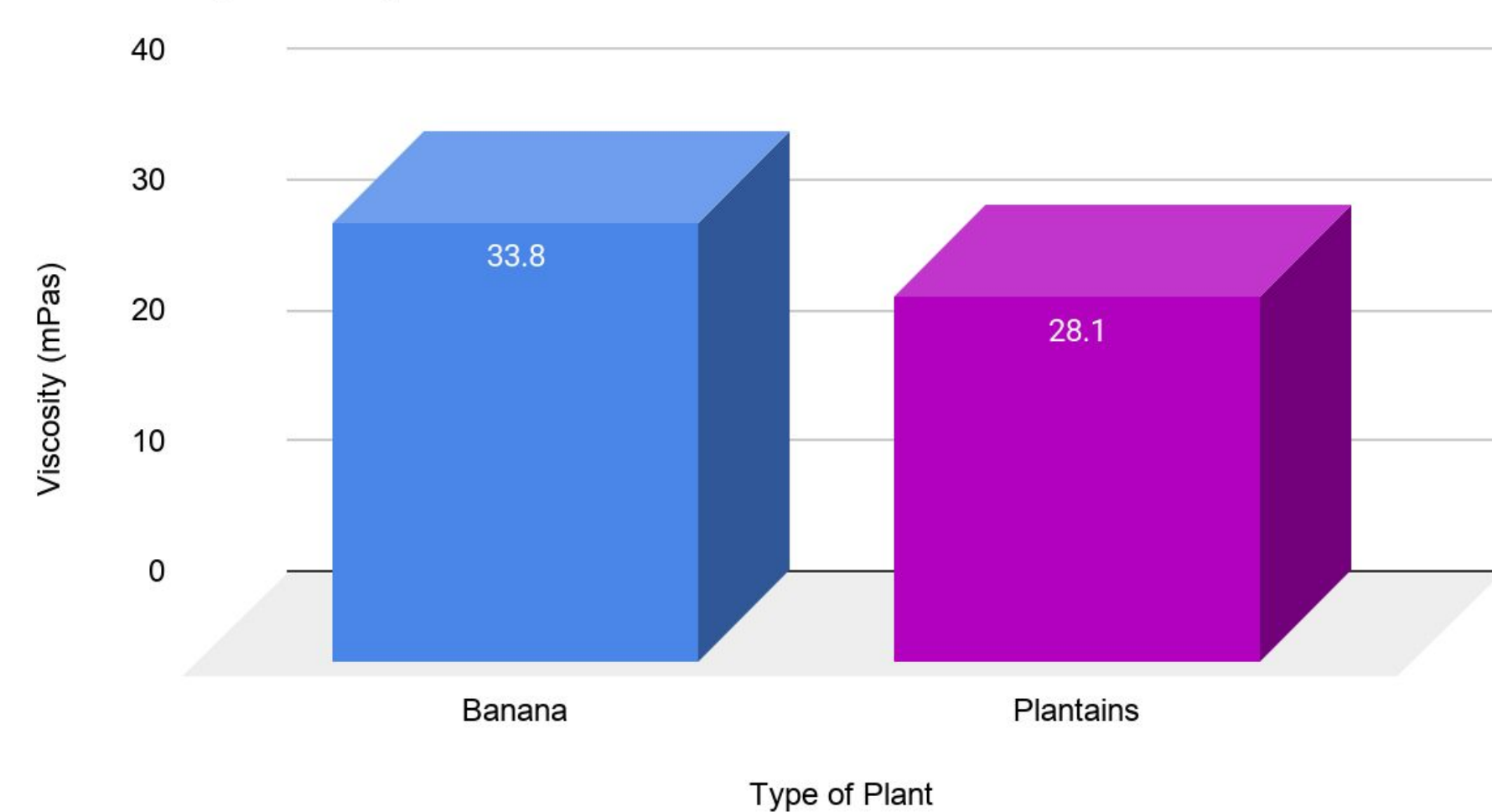


Testing viscosity of bioplastic using a viscometer. (Photo taken by Rye Rost).



Drying bioplastic in dehydrator. (Photo taken by Rye Rost).

Viscosity of Bioplastic Gel of Banana and Plantain



Viscosity of bioplastic gel made from banana vs. plantain, measured with a viscometer. (Graph created by Rye Rost using Google Sheets).

- Viscosity of the banana bioplastic gel: 33.8 mPa.s.
- Viscosity of plantain bioplastic gel: 28.1 mPa.s.
- The higher viscosity means that the gel was thicker.
- Less viscous gel is used for more flexible plastic that can flow and self-level.
- More viscous gel is used to make stronger and less flexible plastic.

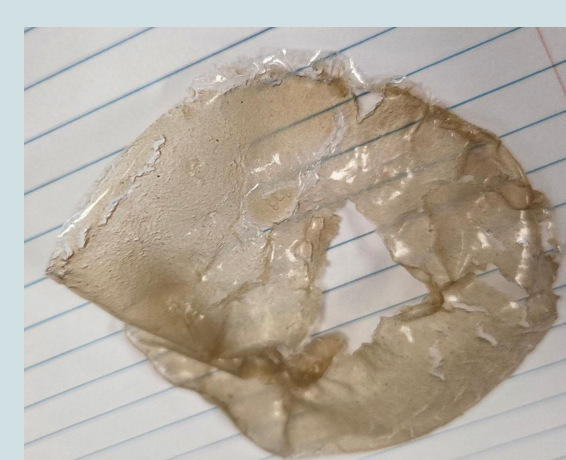
By: Rye Rost

Part 4: Testing the Bioplastic

- The bioplastic film was cut into pieces and tensile strength was measured using a digital pull force tester to determine breaking point, the point at which the plastic fully ripped.
- Parafilm was also tested because it had a similar texture and consistency to the bioplastic to compare the characteristics.

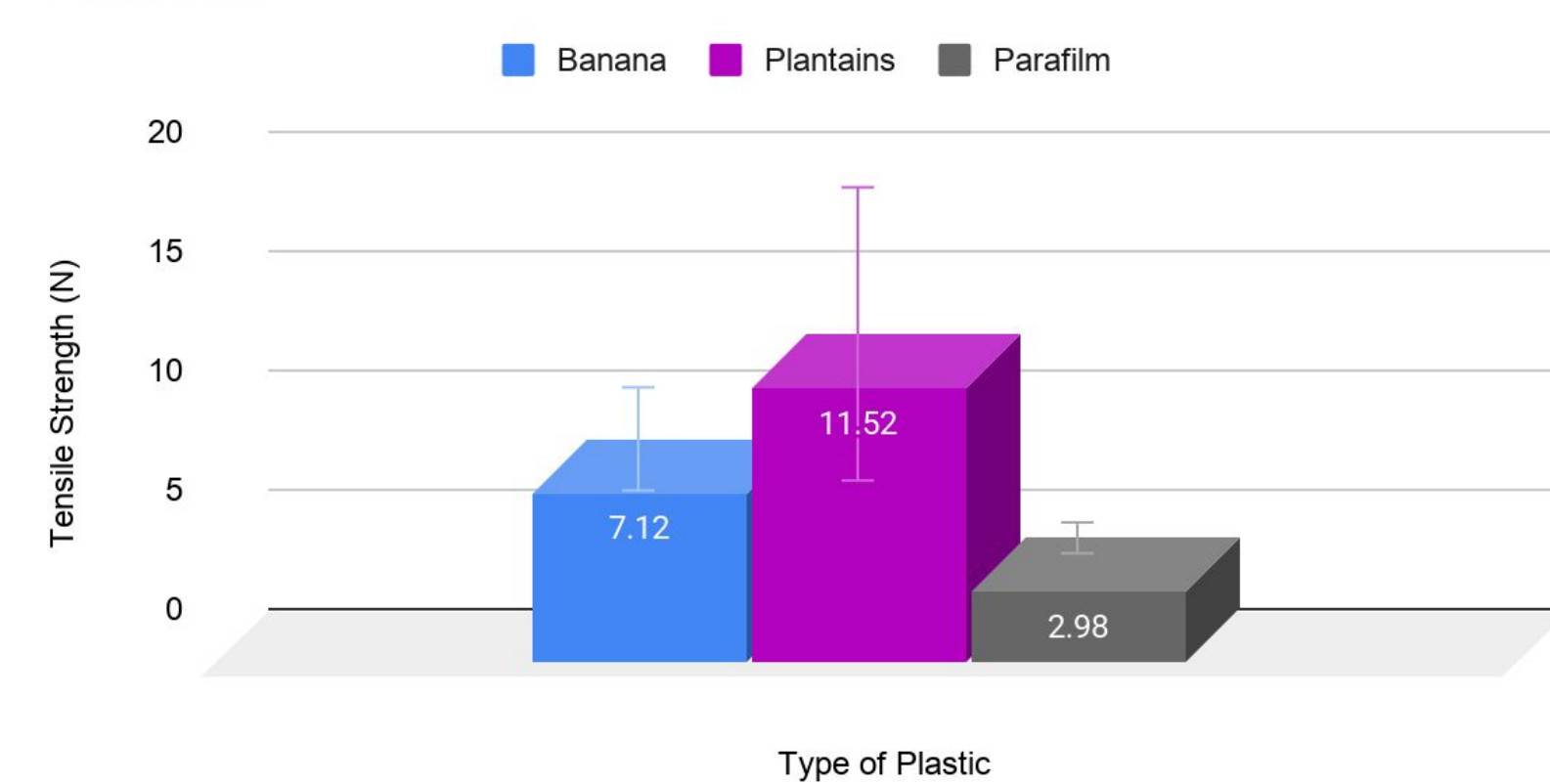


From clockwise: Bioplastic made from banana (top left), plantain (top right), and plantain (bottom). (Photo taken by Rye Rost).



Testing bioplastic with digital pull force tester. (Photo taken by Linda Rost).

Tensile Strength of Plastic and Bioplastic with Bananas vs. Plantains

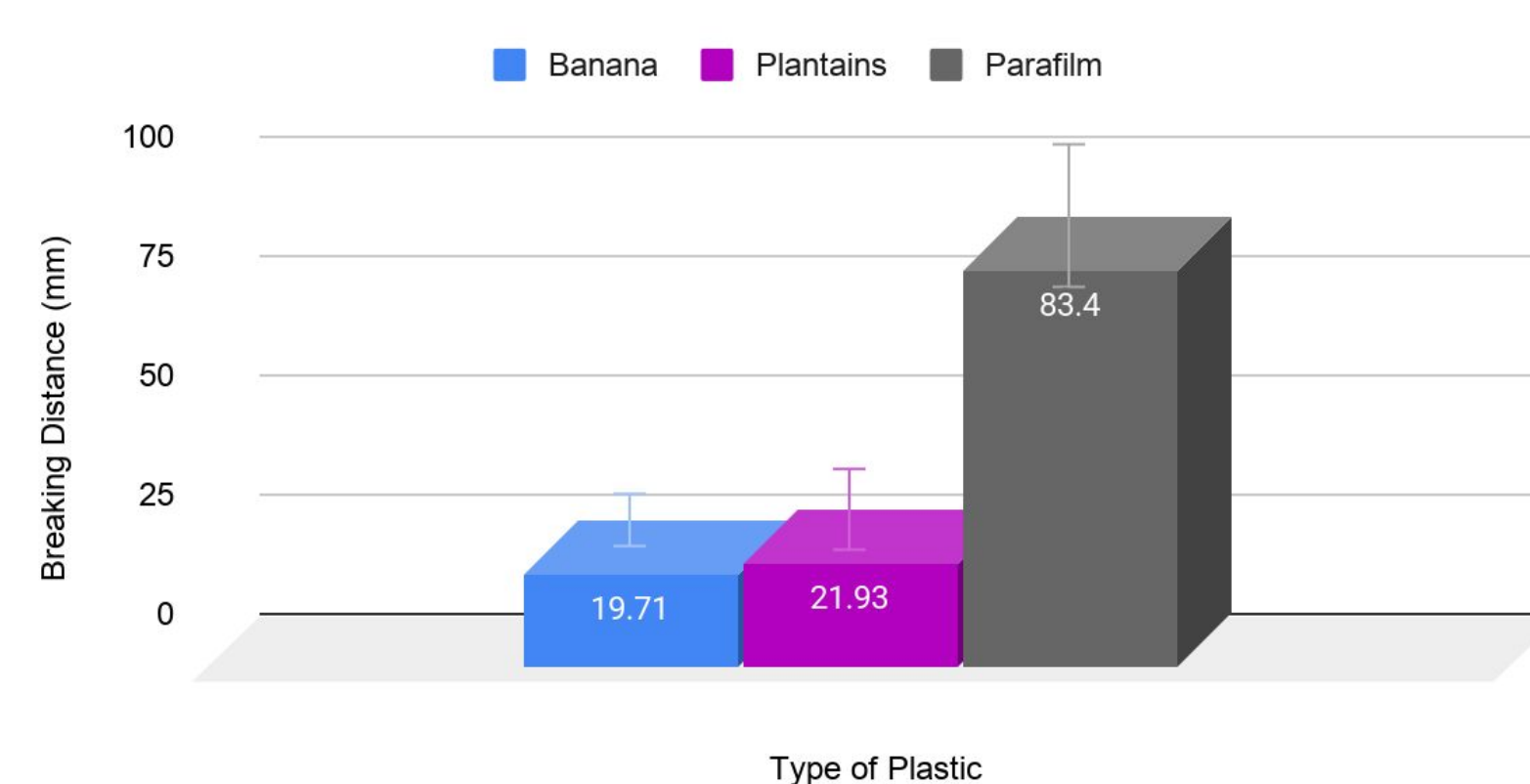


Average tensile strength from ten pieces of bioplastic for each type measured using a digital pull force tester. Error bars represent ± 2 standard error of the mean. (Graph created by Rye Rost using Google Sheets).

Tensile Strength

- Plantain: highest average tensile strength of 11.52 N; highest value of 36.9 N.
- Banana: moderate average tensile strength of 7.26 N; highest value of 13.2 N.
- Parafilm: lowest average tensile strength of 2.98 N; highest value of 4.2 N.
- Error bars (± 2 SEM) overlap between banana and plantain, so there is no significant difference.

Breaking Distance of Plastic and Bioplastic with Banana vs. Plantain



Average breaking distance from ten pieces of bioplastic for each type measured using a digital pull force tester. Error bars represent ± 2 standard error of the mean. (Graph created by Rye Rost using Google Sheets).

Breaking Distance

- Plantain bioplastic: average breaking distance 21.93 mm; highest value 50.14 mm
- Banana bioplastic: average breaking distance 20.07 mm; highest value 36.97 mm
- Parafilm: longest breaking distance; average distance of 83.40 mm; highest value 99.29 mm
 - Parafilm is used to stretch and cover containers in the lab, so it has high stretchability.

- Error bars (± 2 SEM) overlap between banana and plantain, so there is no significant difference.

Conclusion

Plantain Bioplastic

- Overall, the plantain starch made better bioplastic.
 - More starch to make more bioplastic: Most amyloplasts and most starch
 - Lower viscosity to make a more flexible, self-leveling plastic
 - Plantain bioplastic was much easier to remove.
 - I will try removing the bioplastic from a silicon mold rather than a glass container.
- While the differences in tensile strength and breaking distance were not significant, plantains numerically had the highest tensile strength and second highest breaking distance (compared to parafilm). Measurements had a high variability and there were few samples.
 - Creating a more consistent product and testing 100 or more samples could help determine whether there is a significant difference between plantain and banana bioplastic.

Final Takeaways

- Plantain bioplastic was the best out of the two due to higher starch production and lower viscosity.
- The plantain bioplastic would be good for certain uses that you do not necessarily want to stretch as much and want to have a high tensile strength and be flexible, such as packaging.

Challenges and Future Research

- I am working on creating bioplastics using food waste, such as banana and plantain peels, though the fruit flesh also goes to waste.
- The bioplastic must be able to withstand exposure to water without falling apart and biodegrading too soon.
- I am working on making a water-resistant, environmentally-safe, waterproof-coating that has both polar and nonpolar properties, so the polar part sticks to the bioplastic and the nonpolar part repels water, perhaps using parts of the peels.