Variations of Carbohydrates in Biodegradable plastics

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Abstract

Plastic pollution is a huge problem in the world. Every year there are many plastics wasted into the environment. This is a problem because plastics are insoluble and release dangerous chemical compounds like Polyvinyl Chloride which kills wildlifes and habitats. To mitigate the effects of plastic pollution. Bioengineers developed biodegradable plastics which solves both problems because they are soluble and contain environmentally friendly ingredients such as starch that comes from plants. Starch allows the biodegradable plastic to degrade in water, but there's a huge controversy on which starch is best for biodegradable plastic's degradation. This project will identify which starch is best for degradation by testing 4 commonly argued starches. The starches used were oat, corn, rice, and potato. The corn starch was the control because it was commonly argued for, and the hypothesis was that oat starch biodegradable plastics will degrade the most. To prove the hypothesis, biodegradable plastics were synthesized using 4 ingredients which are water, the type of starch, glycerin, and vinegar. Once they were created, the plastics were put into a graduated cylinder and filled up with water until 100 mL. When the biodegradable plastics degrade, the water level decreases as a result. At the end, the data showed that the oat starch plastic degraded the most and were significantly different compared to the other plastics. This supported the hypothesis of this experiment, and the results may be because of the weaker bonds within the oat starch's molecular structure.

Keywords: biodegradable plastics, starch, degradation,

Introduction

As of recent years, pollution has become a significant problem in every society. A tributing factor that leads to rising pollution is the amount of solid waste thrown out in the environment. The most common solid waste thrown out into the environment is plastic. With its increasing production, the amount of plastics thrown out into the environment has also significantly increased. In 2010, 270 million tonnes of plastic were produced annually, however 275 million plastics were wasted, exceeding its annual production (Ritchie, 2018).

Plastic pollution is a problem that society is still facing. It arises when people carelessly throw away these plastic materials that hardly ever degrade into the public. When this happens, these plastic materials can spread all around the environment via heavy winds, floods, rivers, and etc. Most of the highest concentration of plastics will end up in the ocean as well as in natural environments like forests causing habitat losses and unnourished soils.

The amount of plastics thrown into the wild has been a major problem towards the environment and its ecosystems. These common plastics do not completely decompose which is a major factor in its harmful element. Normal plastics take up to nearly 1,000 years to completely degrade (Chamas, 2020). However, when plastics do break down, they cannot degrade completely and are broken down into microplastics that can contaminate local ecosystems causing habitat destruction and the release of toxins.

There are two main problems with plastic waste and its impact on the environment. First, with its rate of decomposition, plastics have had a major negative impact on animal habitats in the ocean. Empirically, At least 14 million tons of plastic end up in the ocean every year as well as being 80% of all marine debris found from surface waters to deep-sea sediments. This has caused many marine wildlife to accidentally ingest these plastics resulting in their death. Some wildlife animals have mistaken plastics as food, and this causes them to eat the plastic waste. With plastics inside of the organism, it may cause internal damages, starvation, and infections. (IUCN, 2021).

The second problem is that the molecules in the plastic are extremely toxic. Plastics are made using PVC or polyvinyl chloride which is the reason why microplastics residue can release toxic chemicals into the environment. Plastics containing PVC became one of the most widely-used types of plastics. These plastics can be found in packaging, home furnishings, children's toys, products, and many more. PVC contains chlorine which is the basic building blocks to infamous toxic problems that occur in the environment. (PVC, 2003). A study estimates that one third of all plastic waste ends up in soils or freshwater. The main problem is that these plastics are entering the food chain. Microplastics have intoxicated local natural organisms like earthworms and any organism that drinks a plastic polluted water ultimately leading to deaths caused by intoxications (UNEP, 2021).

This problem leads to questions about a possible solution to fix the effects of plastics thrown into the environment. Scientists today have found a solution to mitigate plastic pollution which is the usage of biodegradable plastics. Biodegradable plastics are similar to normal plastics besides the fact that they are environmentally friendly. Biodegradable plastics are made using compounds such as starches, cellulose, glycerin and more. These compounds are organic (carbon based) which means that the ingredients are not toxic to animals and habitats. These ingredients also benefit organisms because if eaten, the starches would be digested as food for the organism. Thus, using biodegradable plastics, the slow rate of degradation and toxic chemicals released from plastics would be mitigated as a result of the biodegradable plastics degrading significantly faster than typical plastics as well as containing safe ingredients.

These biodegradable plastics are a first step towards a possible solution. However, the goal is to find the most efficient biodegradable plastics. There have been many controversies about which starch is the best for biodegradability in biodegradable plastics. Different starches have their own unique property that may alter the rate of degradation. Therefore this project will answer the question of “which starch is best for the biodegradability in biodegradable plastics?”

Starch is the most commonly used ingredient in making biodegradable plastics. The purpose of starch in biodegradable plastics is to fill in the role of binding the plastic together through starch gelatinization, as well as having the ability to dissolve in water because of hydrolysis. Starch gelatinization is a process of breaking down the intermolecular bonds of starch molecules in the presence of water and heat, allowing the hydrogen bonding sites to engage more water. The heat will cause starch granules to swell which thickens the substance(IFST 2017). The reason why starch degrades is because starch is a carbohydrate that bonds with multiple monomers through dehydration synthesis. When water is bonded to the starch it undergoes hydrolysis, and the molecule will remove existing bonds that keep polymers together causing the starch to dissolve. The more gelatinization, the more hydrolysis may occur in the starch because more water is implemented into the starch.

A project by Loannis in 2022, tested the gelatinization of different starches using heat. The project found that oat starch required the least heat with 50 degrees celsius needed to gelatinize which indicates that oat starch bonds are weaker. On the other hand, Corn starch requires more heat with 67 degrees celsius to gelatinize, which hence that corn starch bonds are much stronger (Loannis, 2022).

Another research project created by Gael Neighbors (Neighbors, 2019) has already experimented with different starches for biodegradable plastics, however the project was done to find out which starch created the strongest biodegradable plastics instead of focusing on how well the biodegradable plastics can dissolve. The results concluded that Corn starch had a really thick texture, and the strongest. Oat starch was found to be the weakest as well.

This experiment will have multiple varieties of carbohydrate polymers tested such as corn flour, potato starch, oat flour, and rice flour. Based on the two other experiments, the hypothesis of the research is that if oat flour is used, the bioplastic will degrade the most due to the oats' hydrophilic characteristics, low energy bonds, and weakness in strength. Oatmeal is a perfect example of a hydrophilic food. Oats are low-fats which means there are less non-polar bonds which could be a contributing factor of biodegradability.

Methodology

This experiment to test the best starches for biodegradability was done at home in a kitchen. The ingredients used to make all of the biodegradable plastics were ordered online and bought at a local pharmacy. First, to make the control biodegradable plastic which is the plastic using cornstarch, 120 mL of water were poured in a cooking pot. Next, 2 tablespoons of cornstarch were added into the pot and stirred for a minute to let it spread around. Then, 2 teaspoons of vinegar and glycerin were added in the pot, and the stove was turned on to medium heat (temperature of 375℃). The glycerin was added to make the plastic move fluidly instead of hardening after drying, and the heat allows the starch to gelatinize, making the solution thicker during the cooking process. The mixture in the pot was stirred using a whisk for 6-7 minutes. When the mixture became thicker, using a spoon for aid, the mixture was spreaded in a mold containing the dimensions of 5½” x 4¼”. Flattening the mixture in a specific dimension reduces any factors that could cause inaccurate results during the degrading process. After spreading the substance, it was dried in room temperature (~20℃) for 24 hours. The same steps were used to create the other biodegradable plastics. The only change was the type of starch added into the pot. After all of the biodegradable plastics were created and dried, they were weighed to identify whether they had the same mass. This is because if the plastics had different masses, the degradation results may be inaccurate. The plastics were weighed to be 0.3 grams for all which makes mass a constant. Next the biodegradable plastics were placed in a 100 mL graduated cylinder. The graduated cylinder was filled up with water until the 100mL mark. After filling up the graduated cylinders, the whole process was repeated 3 times to create 3 trials for each biodegradable plastic. The reason why the biodegradable plastics were submerged under water in a graduated cylinder was to measure the degradation of the biodegradable plastic. When the biodegradable plastics degrade, smaller particles will break off causing the surface area to change. This causes the water level to decline in the graduated cylinder. The biodegradable plastics were submerged under water for 4 weeks. Every 3 days, the water level changes were measured and recorded on a table chart. The method used to find the change in water level was taking the initial water level (100mL) and subtracting to the current water level. Once the table chart was completed, the biodegradable plastics degradation speed was calculated using the slope of the line of best fit in a line graph. The biodegradable plastic's total degradation was measured using the water level change on the last day of the experiment. Then it was formatted into a graph to visualize the results. When the experiment was completed, the remaining trash was disposed of and all tools were put back into their designated areas.

Data and Results

Table 1: *Change in volume of water (mL) after degradation*

Days:	Rice Starch	Oat Starch	Potato Starch	Corn Starch (Control)
0	0.00	0.00	0.00	0.00
3	0.40	0.53	0.07	0.10
6	1.33	0.83	0.70	0.57
9	1.33	2.10	0.90	0.77
12	1.97	2.67	1.13	1.13
15	2.37	3.40	1.50	1.27
18	2.80	3.80	1.73	1.47
21	3.17	4.33	1.87	1.77
24	3.70	4.67	2.07	2.30
27	3.93	4.87	2.07	2.43
30	3.90	5.27	2.23	2.70
33	4.23	5.50	2.43	2.80

Figure 1:

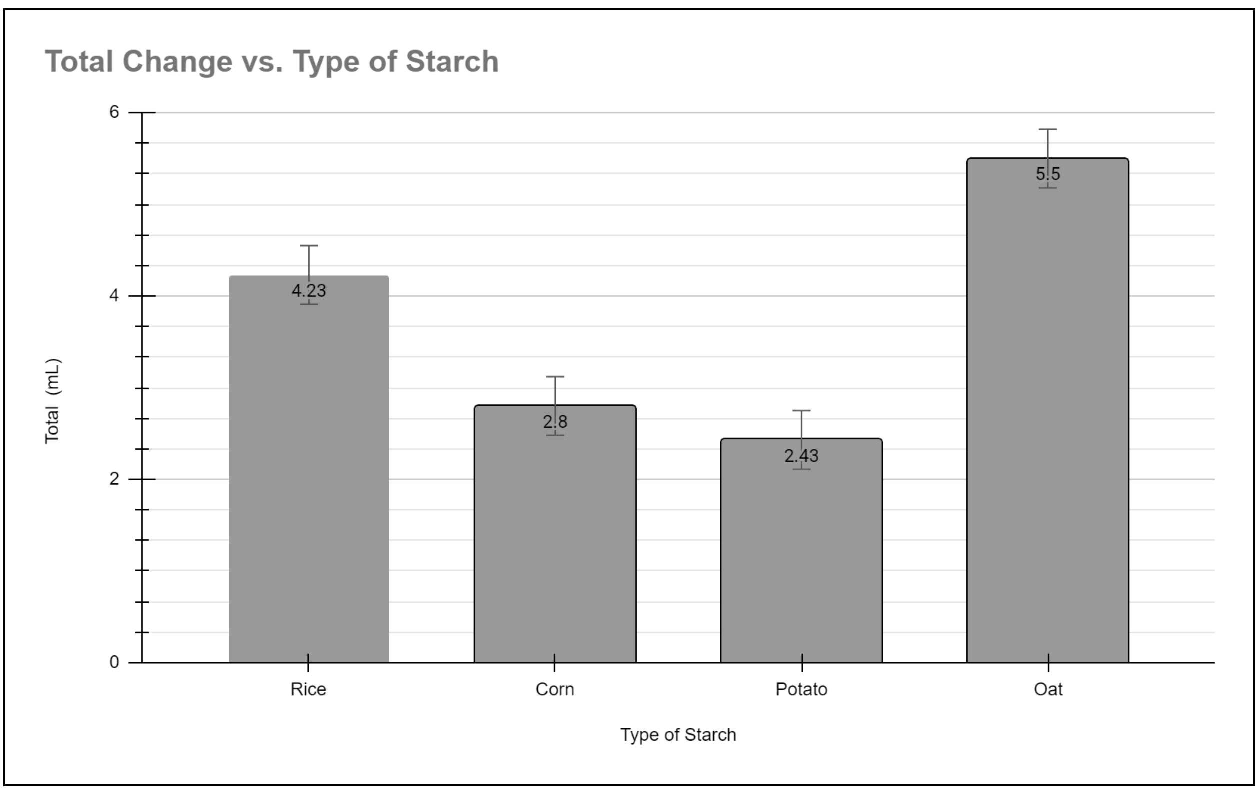


Table 1 consists of the average change in volume after the biodegradable plastics degraded inside of the graduated cylinder. The table consisted of 12 checkups with one check up being three days which is 33 days in total for the experiment. The change in volume was measured by taking the initial volume (100mL) and subtracting to the current volume. In figure 1, the graph showcased the results of the experiment. The x-axis represents the type of starch, and the y-axis represents the total volume change after the 33 days of the experiment. It was found that oat starch degraded the most compared to the other 3 independent variables including the control variable (corn starch). The oat starches caused a change in the volume of water by an average of 5.5 mL after 33 days. The volume change was significantly greater than the other starches. Thus, it proves the hypothesis that “The biodegradable plastic that uses oat starch will degrade the most.” Based on Figure 1, the standard deviation line for the oat starches did not overlap other variables which means oat starch had a significant difference in biodegradability compared to all other 3 independent variables.

Figure 2:

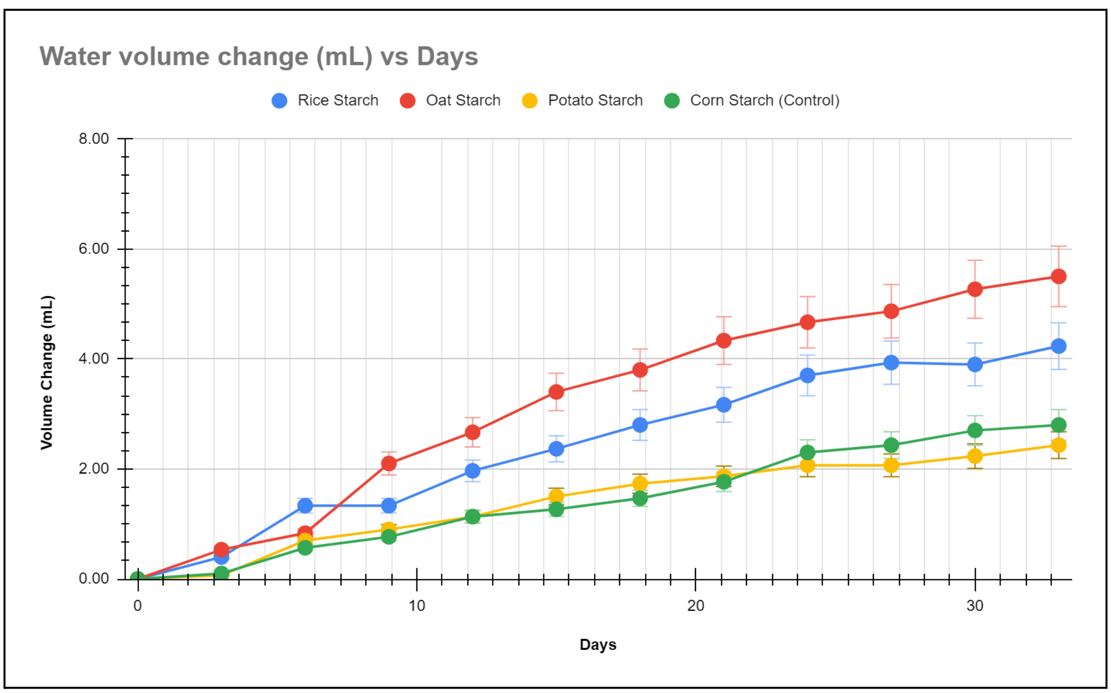
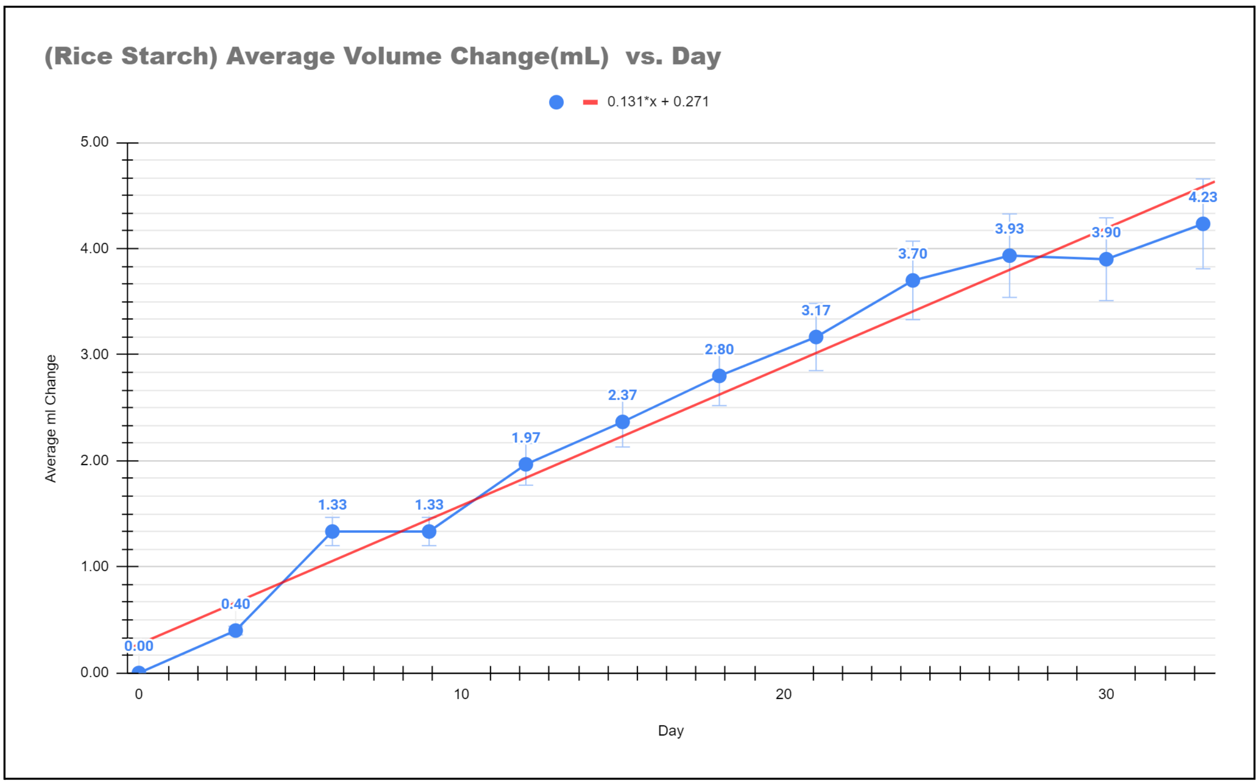


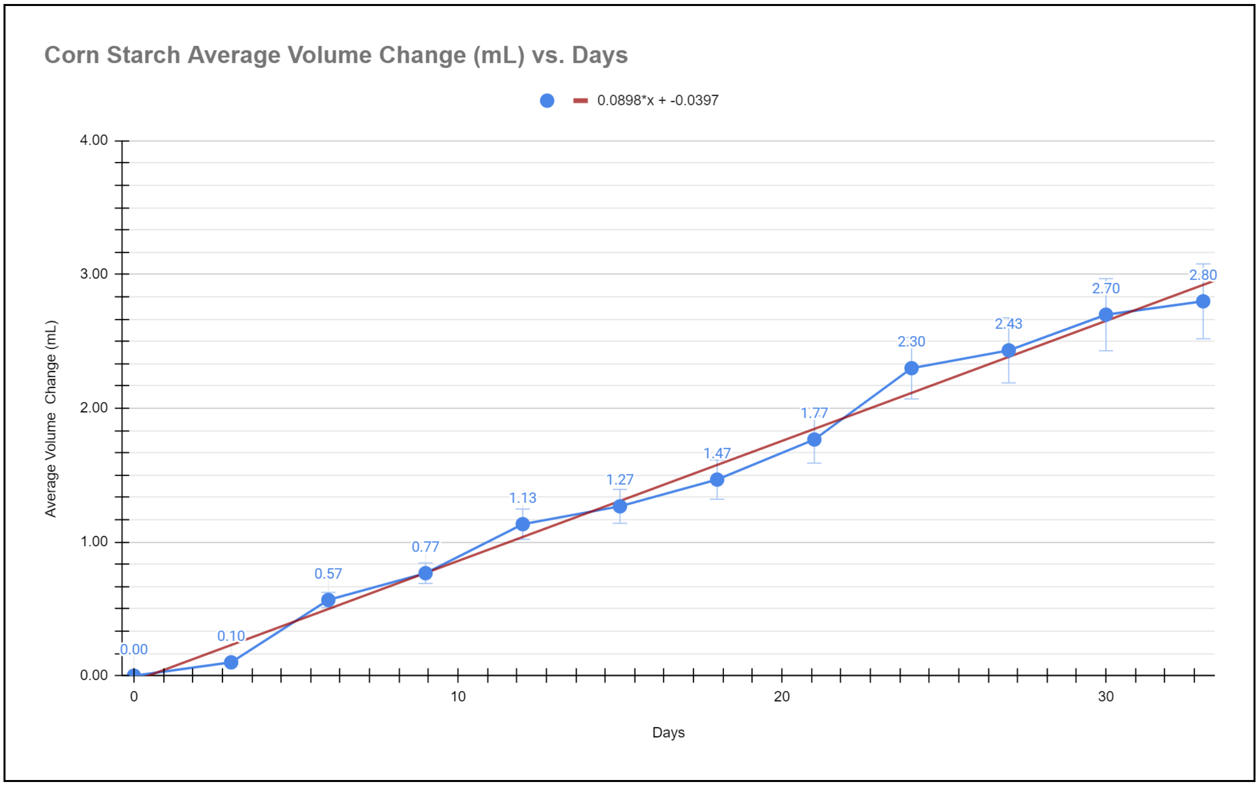
Figure 2 shows the timeline of the volume change in the graduated cylinder with the biodegradable plastics. The x-axis represents the days throughout the experiment. The Y-axis represents the volume change. The line graph also contains error bars. The error bars in potato starch and cornstarch overlap indicating that the volume change for both starches have no significant difference when compared together. On the other hand, oat starch had a significant difference compared to the other starches in the change of volume.

Figure 3: *Independent Variable's Individual Graph*

A)

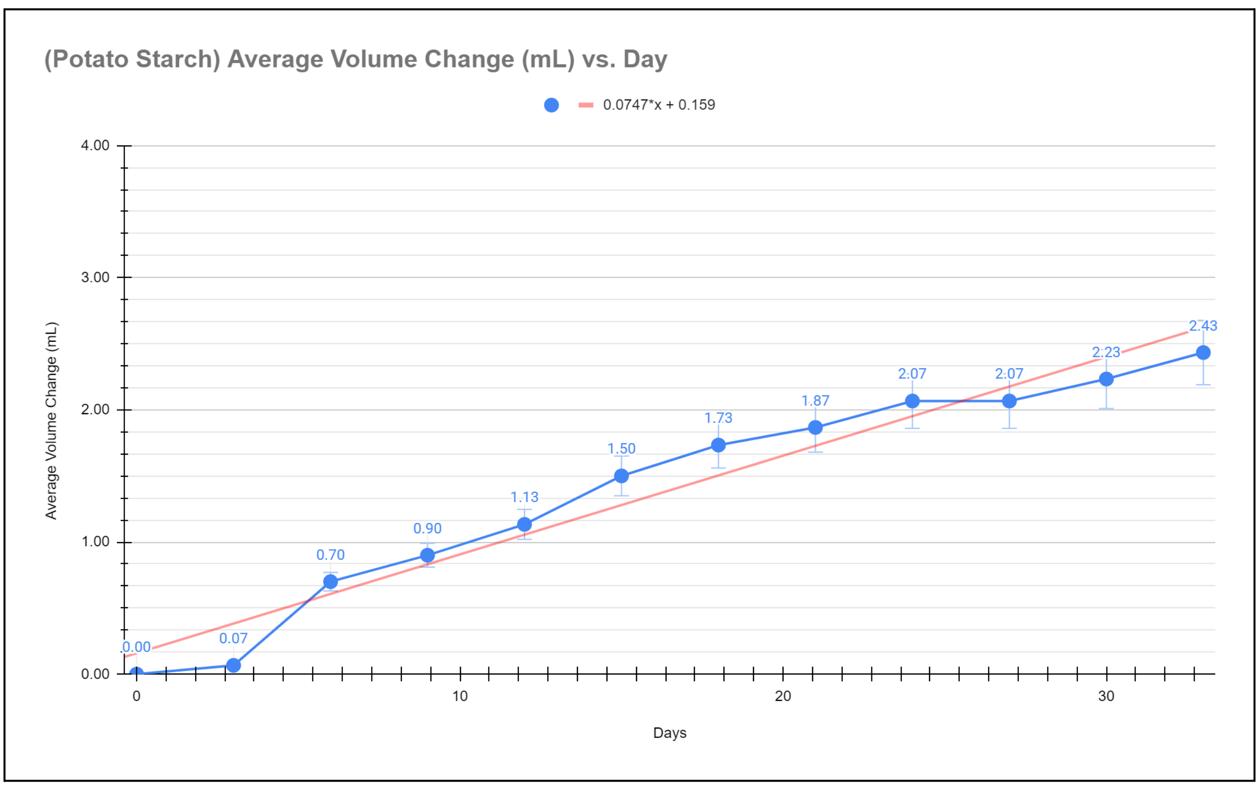


B)



Corn Starch Average Volume Change (mL) vs. Days
0.0898*x + -0.0397
Average Volume Change (mL)
Days
0.00
0.10
0.57
0.77
1.13
1.27
1.47
1.77
2.30
2.43
2.70
2.80

C)



(Potato Starch) Average Volume Change (mL) vs. Day
0.0747*x + 0.159
Average Volume Change (mL)
Days
0.00
0.07
0.70
0.90
1.13
1.50
1.73
1.87
2.07
2.07
2.23
2.43

D)

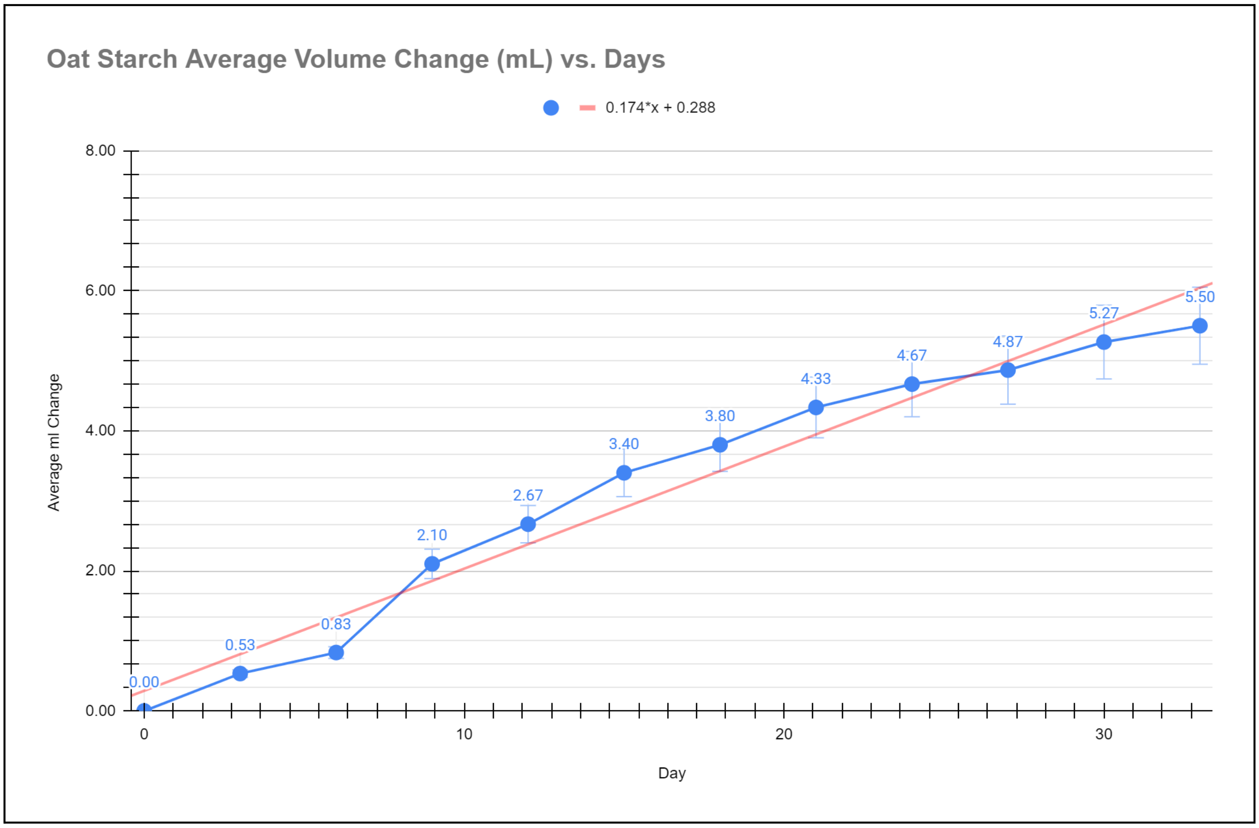


Figure 3 shows all of the individual starch's average water volume change inside of the cylinder. The x-axis of all graphs represents the days, and the y-axis represents the average volume change (mL). The graphs show the slope of the line of best fits for all of the independent variables. Based on the graphs, the oat starch (Figure 3D) had the most rate of change with the slope being 0.174 mL change / days compared to the other variables. For Figure 3A, the slope of the line of best fit is 0.131 ml change / days. For Figure 3B, the slope of the line of best fit is 0.0898 ml change / days. Lastly, for Figure 3C, the slope of the line of best fit is 0.0747 ml change / days

<u>**Table 2**</u>: *Statistic Table including T-tests*

IV Level	Rice Starch	Potato Starch	Oat Starch	(Control) Corn Starch
Mean	4.23	2.43	5.5	2.8
Standard Deviation	0.38	0.33	0.22	0.16
SD 1	3.85 - 4.61	2.1 - 2.76	5.28 - 5.72	2.64 - 2.96
SD 2	3.47 - 4.99	1.77 - 3.09	5.06 - 5.94	2.48 - 3.12
SD 3	3.09 - 5.37	1.44 - 3.42	4.84 - 6.16	2.32 - 3.28
Trials	3	3	3	3
Results of t-test (a=.05)	t=4.93244, p =0.00393	t=1.40841, p= 0.115893	t =14.10029. p = 0.000073.	
	Significant	Not Significant	Significant	

The results of Table 2 contain descriptive statistics of the total average change in volumes of water using the data from the final checkup. The means of the total change in volume of water of all independent variables were not all similar. The oat starch had the highest mean of 5.5 mL change, while the potato starch had the lowest mean of 2.43 mL change. The oat starch's volume change mean was more than 2x the volume change of the Potato starch. There were 3 trials for each independent variable to make sure the data was accurate. Based on Table 2, When comparing the Rice starch to the Corn starch (Control), the degradation was significantly different. Statistically, the P-value was equal to 0.00393 which is less than 0.05 which means that the rice starch's degradation compared to the Control's degradation (Cornstarch) has a significant difference. This rejects the null hypothesis that Rice starch wouldn't have a significant difference compared to corn starch. When comparing potato starch to corn starch, the degradation was not significantly different. The P-value was equal to 0.115893 which is greater than 0.05, meaning that potato starch's volume change was statistically insignificant. This accepts the null hypothesis that potato starch wouldn't be significantly different compared to cornstarch. When comparing oat starch, the results determined that the volume change of oat starch compared to the volume change of cornstarch is significantly different. The P-value of the oat starch result is

7.3x10^-5 which is less than 0.05 which means that the change of volume of the oat starch plastic compared to corn starch, is statistically significant. This rejects the null hypothesis that oat starch wouldn't have a significant difference compared to corn starch. The results of the project shows that oat starch has the highest volume change which indicates that it is the best starch for biodegradable plastic's biodegradability which proves the research's hypothesis to be correct.

Conclusions

The main purpose of this project was to identify the best starch to use for biodegradable plastic's biodegradability. This is because there are controversies about the best starch for biodegradable plastic's biodegradability. To answer the question, four different biodegradable plastics were created in which all of the biodegradable plastics had the same ingredients besides the type of starch. The experiment used 4 different starches: potato starch, corn starch, rice starch, and oat starch. These starches were chosen because they were the most controversial in how effective they degrade. After the creation of the 4 different biodegradable plastics, they were submerged underwater to test their biodegradability. The bioplastics were submerged underwater for 33 days and the results were visible.

The hypothesis of this experiment was that "the biodegradable plastic that used oat starch would degrade the most after the 33 days." The results of the experiment supported the hypothesis. The oat starch when compared all variables showed statistical significant differences. At the end of the 33 days, the bioplastic that used oat starch caused the water volume inside of the graduated cylinder to decline by an average of 5.5 mL. When the oat starch's degradation was also compared to the control starch (corn starch), it was also significantly different. The bioplastic with rice starch also had similar effects to the bioplastic with oat starch, however the oat starch's degradation still significantly surpassed the rice starch's degradation. The bioplastic with the potato starch degraded the least compared to the 3 starches. At the end of the 33 days, the bioplastic with potato starch only caused the volume of water to change by an average of 2.43 mL. The potato starch's volume change compared to the control starch showed no significant difference as well.

These results perfectly line up to the hypothesis, and there may be a few reasons. First, a study made by Gael Neighbors (Neighbors, 2019) experimented with the same starches for the biodegradable plastics used in this experiment, to test the strength of the bioplastic. The results concluded that corn starch and potato starch had the thickest texture, and was one of the strongest bioplastics. On the other side, oat starch was found to be the weakest in terms of strength. This may be the sole reason for why oat starch degraded the most. This shows that the bonds in the oat starch are weaker compared to the other 3 starches making it easier to degrade. Another research from Loannis in 2022, may explain why oat starch is generally weaker. This is because the gelatinization of the oat starch required the least amount of energy to break the bonds inside of it, which further proves its terms of being weak in strength.

There are some recommendations to improve the project's experiment. First, although the experiment tried to prevent evaporation from occurring, the ceramic wrap may not prevent evaporation as a whole. This is why adding in a cylinder with only water would be another option to control evaporation. If the cylinder with only water declined in volume, it shows that evaporation has occurred. This will further enhance the accuracy of the experiment, as well as determining if another variable has occurred. Another recommendation is to use a different method to measure. A spectrophotometer is a machine that shines protons into a given sample solution and identifies how much the light gets absorbed to determine the total degradation. This can further enhance the accuracy of the biodegradable plastic's biodegradability because its sole function is to identify how much residue is in the solution as a result of degradation.

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