Nutrients in Your Plastic? A Novel Approach Towards Reaping the Benefits of Flavonoids from Fruit Peel Infused Bioplastics

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Abstract

The purpose of this project was to discover whether or not flavonoids could transfer from the fruit peels in bioplastic bowls to water kept in the bowls over four days (data recorded on days two, three and four). This has relevance to professionals in the medical field, as well as the common population, as using fruit-infused bioplastics in daily lives could increase nutrient intake just by drinking water, which would ultimately accumulate into multiple health benefits. This also has relevance to ecologists since fruit peels allow bioplastics to break down faster, causing a decrease in ocean pollution and death. The hypothesis that if fruit peels were added to the bioplastics, then lemon peels would allow the most transfer of flavonoids, as their acidic properties would be ideal to break the bonds of the plastic, allowing extraction of flavonoids (Hirashima, Takahashi & Nishinari, 2005).

The average results collected revealed that each water group had absorbed more flavonoids than distilled water: 0.071 Au (absorbance units) for lemon, 0.067 Au for banana, 0.073 Au for apple, and 0.067 Au for orange. This means that the lemon absorbed the most amount of light, meaning it had the most amount of flavonoids. The hypothesis was accepted. A possible error could be pushing the cuvette down too far in the spectrophotometer, leading to inaccurate measurements. Future research will focus on identifying different types of flavonoids in the water.

Keywords: **flavonoids, bioplastics, fruit peels, nutrients, pollution, lemon, banana, apple, orange**

Introduction

In 2017, the CDC approximated that an average of only 12% of adults meet the recommendations for daily fruit intake, with the percent being even lower in children. Fruits are an important part of every person's diet in the world, yet most people do not get enough of it. That is a problem, as fruits provide a variety of nutrients and vitamins that are essential for a healthy lifestyle, including vitamin C and antioxidants. One particular class of molecules that is essential for your health is flavonoids. Flavonoids are pigmented compounds that are known for their "anti-oxidative, anti-inflammatory, anti-mutagenic and anti-carcinogenic properties coupled with their capacity to modulate key cellular enzyme function" (Panche, Diwan & Chandra, 2016). By not eating fruits and vegetables, people across the world are not consuming enough of these natural nutrients, which can lead to adverse health effects, including heart disease and diabetes. The most common reasons as to why people do not eat enough fruit and vegetables is due to high cost, limited availability, lack of time for cooking, and distaste for them (the latter especially for kids) (CDC, 2017). Therefore, a major deficiency in the health of humans today is a steady supply of nutrients.

Although there are many brands and types of vitamin pills available for people to buy, not only are they expensive, but also can be harmful. The total amount of money spent on vitamins per year exceeds 12 billion dollars per year - money that could be better spent on vegetables and fruits. Furthermore, some vitamins, such as vitamin E and beta-carotene, have been proven to be harmful in high doses, and most vitamin pills heavily exceed daily values recommended for most people (Johns Hopkins, 2020). Nonetheless, people across the world have continued buying vitamins for years now, and would prefer this easier method rather than cooking their own vegetables. Therefore, there is a severe need for a solution that allows humans to gain their nutrients and vitamins in a healthy, easy, and all-natural way. One method of gaining these nutrients is through fruit peels.

Fruit peels have been proven to have a variety of healthy nutrients and vitamins, and are sometimes healthier than the actual fruit itself. For instance, "there are about 6000 flavonoids that contribute to the colourful pigments of fruits, herbs, vegetables and medicinal plants," making fruit peels such as orange peels and apple peels rich with them (Panche, Diwan & Chandra, 2016). In fact, there have been studies in which citrus flavonoids have been quantified in traditional Chinese medicinal foods, proving their beneficial effects. Therefore, fruit peels can be an excellent source of flavonoids.

Not only that, but billions of kilograms of fruit peels are wasted per year in the US, despite their many health benefits. According to the United Nations Food and Agriculture Organization, fruit and vegetable losses make up 60% of all food waste, of which 25 to 30% are peels, rinds, and seeds (Sagar et al, 2018). Additionally, EU (European Union) households waste over 17 billion kg of fresh fruit and vegetables a year (EU Science Hub, 2018). As a result, it is imperative that these otherwise wasted fruit peels be used to nourish people that are not gaining enough nutrients from their diets.

Therefore, the proposed solution to this problem that is being investigated in this experiment is infusing bioplastic bowls with fruit peels, with the expectation that the flavonoids from the bowls would transfer to water or food contained by them, therefore giving the food or water a nutritive boost. Hypothetically, when fruit peels are blended up, their sealed skins are broken, releasing a variety of chemicals and pigments (flavonoids) that can be beneficial to your health. When this fruit pulp is therefore added to the inside of bioplastics, it is essentially infusing the pigments into the plastic. Additionally, bioplastics are water sensitive, meaning that though they are meant to be durable like normal petroleum-based plastics, they can be weakened by water diffusing into the plastic and making it more fragile (Reddy, Reddy & Gupta, 2013). They are made this way so that they can easily degrade in the ocean if they are thrown in there (Santana et al., 2018). Therefore, if water were to be placed on the plastic, the water would slightly break down the surface of the plastic, enough to release flavonoids that could possibly transfer to the water, adding health benefits to the water.

This would make it so that fruit peels would no longer be wasted by being sent to a landfill, and people could gain nutrients as if they are eating the fruits, even though all they are doing is drinking water. This would make use of a by-product that is normally wasted, but has the potential to improve human health, all while making it easier for humans to take advantage of this potential. Additionally, another benefit of this idea is that the addition of fruit peels in bioplastic helps degrade it, lowering pollution.

The Science for Environmental Policy estimates 230 million tons of plastic to have been created in 2009, and though the number dropped a bit a few years ago, it will continue to increase in the near future (Science for Environmental Policy, 2011). Since normal plastic is not biodegradable, it ends up in places that subsequently causes environmental pollution by releasing toxins (Andrews, 2018). Therefore, scientists have created bioplastics, which are similar to plastics except that most of the ingredients used in making the bioplastics are biodegradable, hence making the plastic more eco friendly. However, further research has shown that fruit peels can make excellent biodegradable films, and can even help degrade bioplastics. For example, one experiment had information about the effect of prickly pear peels in bioplastics on their solubility, flexibility, and other aspects (Gheribi, Habibi, & Khwaldia, 2018). There is also a study on the effects of passion fruit rinds on bioplastic degradation, which states that passion fruit bioplastics degrade when exposed to nitrogen-fixing symbiotic bacterium (Munhoz et al., 2018). From these sources, one can conclude that many fruit peels can degrade bioplastic faster, including apple peels, banana peels, or lemon peels. Banana peels can aid in degradation because of certain chemicals in it, such as serotonin and lutein, while lemon peels and apple peels can do so because of its acid that weakens and breaks the bonds inside of the bioplastics (Hiroshima, Takahashi & Nishinari, 2005).

Therefore, by adding fruit peels to bioplastic containers, not only would humans gain nutritive benefits, but the earth would also be a healthier place. However, no experiments involving the transfer of flavonoids from plastic to water have been previously performed, making these conclusions only backed by separate pieces of evidence, rather than one cohesive piece of evidence connecting the ideas and proving them. This gap in research is what this experiment is filling - it will test whether or not flavonoids can actually transfer from the plastic to water. By completing this experiment, scientists can determine which fruit peels, if any, can transfer their flavonoids to the water contained by fruit-infused bioplastic bowls. This can lead to a greater application of the production of bioplastic bowls and spoons and cups that can transfer nutrients to the consumer just by consumption of the liquid contained by them. Then, by extension, not only would human health improve while the product is being used, but environmental health will also improve because of the easily degradable material, preventing increased pollution. These two facets of this concept make it worth investigating.

Moving on to the investigation process itself, the manner in which this idea will be tested is using a spectrophotometer. A spectrophotometer is a machine that shines light at a specific wavelength through a liquid sample and detects how much light the sample absorbs and transmits. As flavonoids are pigments, a positive absorption value would mean that flavonoids are present, as they would be absorbing light. There is no chance that any other sort of molecule is absorbing the light instead, as only flavonoids can be seen at 415nm (Do et al., 2013). Therefore, *any positive spectrophotometric values in the data would be a proof of concept for the passive transfer of flavonoids from fruit-infused bioplastic bowls to water*. After much research, it is hypothesized that if flavonoids can passively diffuse from fruit-peel infused bioplastics to water, then out of the four fruit peel bioplastics tested for flavonoid transfer (apple, banana, lemon, and orange), the lemon peel added bioplastic will transfer the most flavonoids by passive diffusion compared to the others because the plastic broken down by the lemon's acid would expose more of the fruit to the water, leading to more pigmented flavonoids reaching the water (Hiroshima, Takahashi & Nishinari, 2005).

Methods

Independent Variable

The independent variable is the different types of fruit peels (apple peels, banana peels, lemon peels, and orange peels) added to the bioplastics.

Dependent Variable

The amount of flavonoids diffused to the water (measured in absorption and transmission values of light recorded from a spectrophotometer).

Standardized Variables

The constant variables include the:

- type of starch used to make bioplastics
- amount of starch used to make plastics
- amount of fruit peels added to each experimental group (40g each)
- type of water poured in bioplastic bowls (distilled water)
- brand of bananas used (Chiquita)
- type of apples used (Gala)
- brand of oranges used (Cuties)
- type of lemons used (Lisbon)

Control Groups

The cuvette filled with plain distilled water is a baseline control, to which the experimental samples will be compared to to see if they absorb more light and, therefore, contain more pigments (or flavonoids).

Replication/Sample Size

Each day, 5 3.5 mL cuvettes were filled for each experimental group, meaning a replication size of five trials.

Materials

- 260 grams of cornstarch
- 788 mL of tap water
- 48 grams of glycerin
- 100 grams of vinegar
- 40g of orange peels
- 40g of apple peels
- 40g of banana peels
- 40g of lemon peels
- 1 non-stick pot
- Stove
- Plastic wrap (as needed)
- 213.5 mL of distilled water
- 4 weigh boats
- 1 spectrophotometer
- 1 cuvette holder
- 20 3.5 mL cuvettes and their caps
- Tape (as needed to label)
- 12 disposable pipettes
- Parafilm (as needed to cover plastic bowls)
- Fan (optional; speeds up drying process)

Procedure

Bioplastics making procedure.

1. Hands were washed with soap and warm water for at least 30 seconds.
2. The needed ingredients were prepared to make the bioplastics (260 grams of cornstarch, 788 mL of tap water, 48 grams of glycerin, 100 grams of vinegar, and peels of 2 small oranges). For example, the banana peels were chopped and the insides were peeled off.
3. 40 grams of orange peels were blended with 98 mL of tap water to form a pulp.
4. 65 grams of cornstarch, 25 grams of vinegar, and the orange pulp were added to the non stick pot. They were mixed together with the silicon spatula until a smooth paste formed.
5. The stove was turned on to approximately 91 degrees Celsius (or 195 degrees Fahrenheit) and the ingredients were mixed in the pot on the stove until it turned dry and hot.
6. The paste was allowed to cool down for three minutes. Once cooled down, the paste was shaped into two bowls (one extra in case of breakage). The pot was rinsed, making sure all plastic residue was removed.
7. Steps 2-5 were repeated, while making sure to add and mix in fruit peels (first 40 grams of apple peels, then 40 grams of banana peels (insides only), and finally 40 grams of lemon peels) to the ingredients mix each time before putting them over the heat.
8. The bioplastics were allowed to cool down and harden overnight. A fan was directed towards the plastic to speed up the drying process. The bowls were firm when finished.

Flavonoid diffusion procedure.

1. Each bowl from each experimental group was filled with 52.5 mL of distilled water and covered with para film. (One extra bowl was kept for each experimental group in case of mishap. The bowls were placed in weigh boats to keep them stable.) The water was left in there for two days.

Figure 1. The image above shows a bowl made out of orange bioplastic that is filled with distilled water.

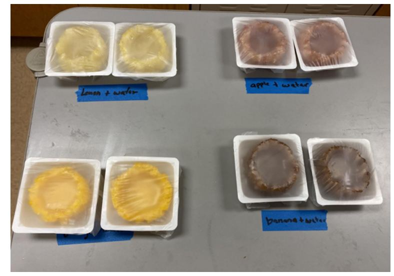


Figure 2. The image above shows the lemon, apple, orange, and banana bowls (left to right) with distilled water filled in them.

2. After two days, five cuvettes were filled to the top with water from the apple bowl. The same step was repeated for the banana, lemon, and orange bowls as well. The cuvettes were immediately capped after being filled to prevent possible spillage.
3. 3.5 mL of distilled water was added to one more cuvette.

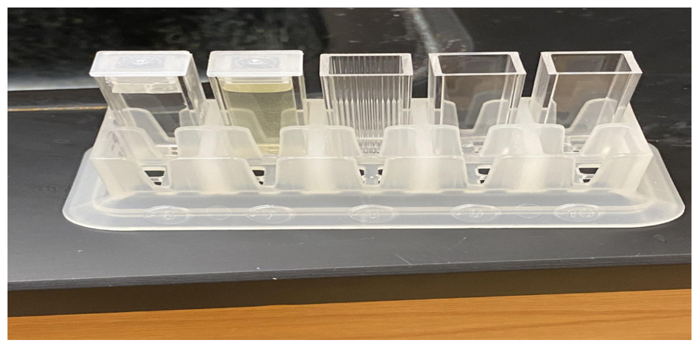


Figure 3. The image above shows cuvettes first filled with a distilled water blank and then the lemon water from day 4. There is an evident presence of pigments in the lemon sample.

4. A spectrophotometer was turned on, allowed to warm up for 15 minutes, and set at a wavelength of 415nm.
5. The cuvette filled with distilled water was inserted in the cuvette holder and in the spectrophotometer. The absorption value for it was recorded. The spectrophotometer was zeroed out to set this value as a baseline for the following measurements.
6. Each cuvette from each experimental group was inserted into the spectrophotometer, and their absorbance values were recorded.
7. The next day (three days after the water was added in the plastic bowls), steps 2-6 were repeated.
8. The next day (four days after the water was added in the plastic bowls), steps 2-6 were repeated.
9. Analyze all results.

Results

Statistical Methods

The first statistical method used for the data was averaging. Since averages are important to every science experiment, and since they can show the effect of outliers on the data, the scientist used averages to represent the data by adding up all of the raw data from all five trials for each experimental group and dividing it by the total number of numbers added together. Since there were outliers in this experiment, though, the scientist deemed it appropriate to include median in the statistical analysis so the middle numbers would be displayed so that there would be some analysis in the experiment that would not be skewed by a few outliers. Standard deviation in the data was also determined so the scientist could figure out how close the data was to the mean, therefore allowing the scientist to see the spread of the data and possibly detect some outliers.

Data Tables

Passive Diffusion of Flavonoids from Fruit Peel Infused Bioplastic Bowls to Water				
Trials	Absorption of Light (Au) of the Water in the Bowls After 2 Days			
	Type of Fruit Peels			
	Lemon	Apple	Orange	Banana
1	-0.009	0.1	-0.012	-0.03
2	-0.012	0.012	0.003	0.002
3	-0.019	-0.009	-0.004	-0.027
4	-0.013	-0.017	-0.012	-0.026
5	-0.001	0.006	-0.015	-0.012
Mean	-0.011	0.018	-0.008	-0.019
Standard Deviation	0.007	0.047	0.007	0.013
Median	-0.012	0.006	-0.012	-0.026
Standard Error of the Mean	0.003	0.021	0.003	0.006

Table 1. The table above shows the absorption values for the water kept in the different fruit plastic bowls for two days.

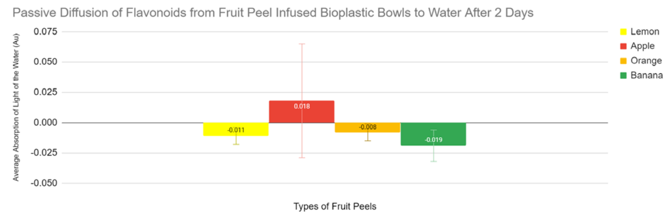
Passive Diffusion of Flavonoids from Fruit Peel Infused Bioplastic Bowls to Water				
Trials	Absorption of Light (Au) of the Water in the Bowls After 3 Days			
	Type of Fruit Peels			
	Lemon	Apple	Orange	Banana
1	0.052	0.067	0.103	0.055
2	0.077	0.15	0.077	0.073
3	0.053	0.089	0.075	0.059
4	0.061	0.076	0.05	0.057
5	0.073	0.157	0.056	0.076
Mean	0.063	0.108	0.072	0.064
Standard Deviation	0.011	0.043	0.021	0.010
Median	0.061	0.089	0.075	0.059
Standard Error of the Mean	0.005	0.019	0.009	0.004

Table 2. The table above shows the absorption values for the water kept in the plastic bowls for three days. The positive absorption values indicate a higher presence of pigments, and therefore flavonoids, in the sample.

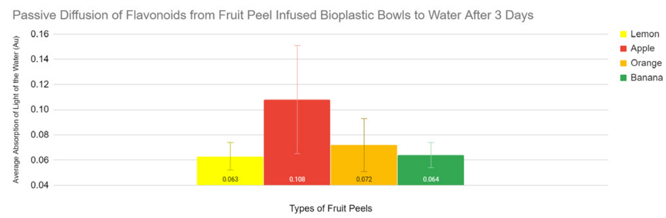
Passive Diffusion of Flavonoids from Fruit Peel Infused Bioplastic Bowls to Water				
Trials	Absorption of Light (Au) of the Water in the Bowls After 4 Days			
	Type of Fruit Peels			
	Lemon	Apple	Orange	Banana
1	0.063	0.064	0.081	0.073
2	0.077	0.066	0.063	0.039
3	0.059	0.062	0.066	0.074
4	0.079	0.057	0.077	0.079
5	0.075	0.084	0.076	0.072
Mean	0.071	0.067	0.073	0.067
Standard Deviation	0.009	0.010	0.008	0.016
Median	0.075	0.064	0.076	0.073
Standard Error of the Mean	0.004	0.005	0.003	0.007

Table 3. The table above shows the absorption values of the water kept in the fruit-infused plastic bowls after four days.

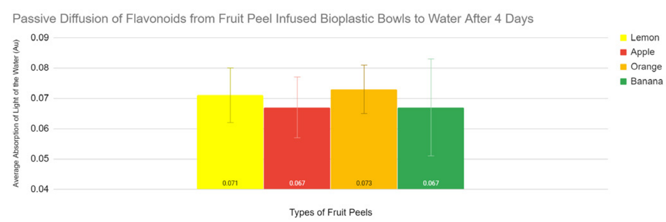
Graphs



Graph 1. The bar graph above displays the average absorption values of the water kept in the fruit-infused bowls for two days, with error bars depicting the standard deviation from the mean.



Graph 2. The bar graph above displays the average absorption values of the water kept in the fruit-infused bowls for three days, with error bars depicting the standard deviation from the mean.



Graph 3. The bar graph above displays the average absorption values of the water kept in the fruit-infused bowls for four days, with error bars depicting the standard deviation from the mean.

ANOVA (Analysis of Variance) Calculations

Day two.

	degrees of freedom	Fs	p
among groups	3.	1.229	0.3586811
within groups	8.331		

Table 4. The table above shows the results from a Welch's ANOVA test done on the data recorded two days after the water was poured in the fruit-infused plastic bowls. This will determine whether or not the data from each experimental group was significantly different from each other or not.

Day three.

	degrees of freedom	Fs	p
among groups	3.	1.662	0.2486622
within groups	8.350		

Table 5. The table below shows a Welch's ANOVA test done on the data recorded three days after the water was poured in the fruit-infused plastic bowls.

Day four.

	degrees of freedom	Fs	p
among groups	3.	0.364	0.7808463
within groups	8.698		

Table 6. The table below shows a Welch's ANOVA test done on the data recorded four days after the water was poured in the fruit-infused plastic bowls.

Discussion

Main Findings

The main purpose of this experiment was to determine whether or not flavonoids from fruit peels infused in bioplastic bowls could transfer to water after a few days. Lemon peels, apple peels, orange peels, and banana peels were the variables that were investigated.

Two days after pouring the distilled water into the bowls, a majority of the absorbance values were negative (-0.011 Au, 0.018 Au, -0.008 Au, and -0.019 Au for lemon, apple, orange and banana, respectively), meaning the samples were absorbing less light that the distilled water blank. This may have occurred due to error in using the spectrometer, although consistent values of this nature even after restarting the procedure diminishes the likelihood of error. This is further discussed in the "Limitations and Errors" section. Regardless, from the means collected from this data, it is evident that apple absorbed the most amount of light, followed by orange, lemon and finally banana.

A day after these readings, new samples were taken from each group and read by the spectrophotometer, resulting in the following means: 0.063 Au, 0.108 Au, 0.072Au and 0.064 Au for lemon, apple, orange, and banana samples, respectively. Evidently, these results drastically changed from the previous day, with numbers being in the 0.06 range, except for apple being in the 0.1 range. (Further analysis showed that the higher mean in the apple samples was due to outliers, which will be discussed in later sections.) All of the readings were positive, meaning they absorbed more light than the distilled water baseline. *This alone is a proof of concept that passive diffusion of flavonoids does occur between the fruit peels in bioplastic bowls and the water contained by the bowls, since flavonoids are pigmented molecules that absorb light, and the absorbance of light by the samples has been narrowed down through research to only possibly being due to flavonoid activity.* (Flavonoids are the only molecules present in the bioplastic bowls that are visible at a wavelength of 415 nm, which is what the spectrophotometer was set at.) According to the means, the apple fruit peels transferred the most flavonoids to the water, followed by orange and finally banana and lemon (which were extremely close with a difference of 0.001). The accuracy of these means will be discussed later.

In the final day of testing (the fourth day), the following means were achieved: 0.071, 0.067, 0.073 and 0.067 from lemon, apple, orange, and banana samples, respectively. The values are once again positive, meaning that the samples consistently show that more light is being absorbed by them than the baseline, further proving that flavonoids are present in the samples. (Figure 3 also corroborates this conclusion, as the pigments in the lemon sample to the right is easily visible, as that sample is evidently more yellow than the distilled water blank.) As for the individual levels of the experimental group, the mean values of absorption began to visibly plateau by day 4, with all groups having a mean of about 0.06 to 0.07 Au. (More specifically, orange had the highest mean, followed by lemon and banana and apple.)

Overall, by the end of the experiment, means indicate that the orange peels transferred the most amount of flavonoids, although the true statistical significance of the differences between the means will be discussed in the "ANOVA" section. Regardless, just from the means, the hypothesis is seemingly refuted, which may have occurred because orange peels contain more flavonoids than lemon peels (Sir Elkhatim, Elagib & Hassan, 2018). Moreover, however, this experiment has proven that flavonoids can indeed passively diffuse from fruity bioplastic bowls to water; the application of this groundbreaking research will be later discussed in the "Application" section of the discussion.

Median. As outliers can easily skew means, the scientist deemed it necessary to investigate the medians as well, which are the middle values in each range of values collected for an experimental group on a specific day. On day 2, the lemon and orange groups had a median of -0.012 Au, the banana group had a median of -0.026, and the apple group had a median of 0.006. Apple is once again the only group that had a positive Au result for day 2, however the value is three times as much lower than the mean value of 0.018. Evidently, the apple group had an outlier that caused this jump in the mean. Nonetheless, according to the median, the ranking between all of the groups is the same as the ranking found with the means.

On day 3, the following medians were found for the lemon, apple, orange, and banana groups, respectively: 0.061, 0.089, 0.075 and 0.059. Although the apple median is less than the mean by 0.02 Au, apple is still ranked first, followed by orange, lemon, and banana. Therefore, the ranking is still the same as the one with the means. Although the medians were closer to the means this time, there is still a possible indication of an outlier in the apple group, with the 0.02 difference between the median and mean.

On the final day, the following medians were found for the lemon, apple, orange, and banana experimental groups, respectively: 0.075, 0.064, 0.076 and 0.073. The medians and means on this day are in the same range of 0.06 and 0.07 for each experimental group, with a similar ranking (except in this case the banana has a higher median than the apple, instead of being tied as it was with the means). Therefore, there were little to no outliers on this day as well (in addition to day 3), as the medians and means were similar. Additionally, according to the median, the orange still transferred more flavonoids to the water compared to the other groups.

Standard deviation. Standard deviation is a statistical method used to determine the range of values differing from the mean. This can be used to see the range in which the mean can vary in order to still give accurate data, which can be skewed with outliers. On day 2, the standard deviations were somewhat similar for the lemon, orange and banana groups (0.007-0.013); however, the apple group had a much higher and different deviation of 0.047. This was likely the result of an outlier (0.1), as the rest of the values were relatively close to each other. As for the other groups, the seemingly high deviations of 0.007 and 0.013 was likely due to the variable nature of the spectrophotometer (described further in the "Limitations and Errors" section of the discussion).

On day 3, the lemon, orange and banana groups had once again had relatively similar deviations in the range of 0.011 to 0.02 Au. However, the apple reached another high deviation of 0.043 (more than double than the next highest value among the other groups), meaning that an outlier was possibly present in the apple group (most likely the two 0.15 values), as the other values were relatively close to each other as well.

On day 4, the following standard deviations were found for the lemon, apple, orange and banana groups, respectively: 0.009, 0.010, 0.008 and 0.016. These deviations seem fairly similar (although the banana deviation may be slightly too different); this shows that the values found in each group were in a similar range and spread, ruling out outliers. The last day seems to have the most accurate data, as many outliers were avoided.

Standard error of the mean. The standard error of the mean is a statistical analysis method to determine how different the sample mean is from the true population mean. This can help analyze the precision of the achieved means.

On day 2, the following standard errors were achieved for the lemon, apple, orange, and banana groups, respectively: 0.003, 0.021, 0.003, 0.006. Evidently, the apple group had the highest standard error due to outliers. The experimental groups, however, were much more precise. All experimental groups had overlapping (or close to overlapping) intervals, therefore proving that their means were rather similar and the treatments had rather similar effects on the dependent variable, which will be solidified with the ANOVA.

On day 3, the following standard errors were achieved for the lemon, apple, orange, and banana groups, respectively: 0.005, 0.019, 0.009, 0.004. The apple once again had a rather high standard error (though not as high as the previous day's data). The lemon, orange, and banana groups have overlapping intervals in terms of standard error, meaning the means are similar. However, the apple mean remained much higher and never overlapped with the other groups, making it seem like the apple mean should be higher, though whether or not the difference between the groups is statistically significant will be determined by the ANOVA.

On day 4, the following standard errors were achieved for the lemon, apple, orange, and banana groups, respectively: 0.004, 0.005, 0.003, 0.007. This time all four groups had relatively precise means, all of them being in the similar or same range. This indicates that at the end all four treatments had similar effects on the flavonoid transfer, which will be verified by the ANOVA.

Welch's ANOVA. Although the median and standard deviation tests hinted at outliers in the apple groups on days two and three, these outliers do not always cause such a grand effect on the means so that the differences between the means are statistically significant. Therefore, it was deemed important to complete an ANOVA analysis to see if the means for each experimental group were significantly different. If the ANOVA proves that there is no significant difference, then it is concluded that the means are similar, meaning the different levels of the independent variable did not have a significant effect on the dependent variable. If there is a statistically significant difference, then that difference could either be caused by outliers or the treatment by the different levels of the independent variable. A post-hoc test is then done to further investigate where the difference occurred.

In this experiment, as the standard deviations of each experimental group were different from each other (especially the apple group on day two and day three), it was decided that Welch's ANOVA would be used rather than an one-way classic ANOVA, as Welch's ANOVA is not affected by heteroscedasticity, but the classic ANOVA is. (Heteroscedasticity occurs when standard deviations, or the scatter, of data for experimental groups are different.)

For days two, three and four, the following p-values were found using Welch's ANOVA test: 0.36, 0.25 and 0.78. As all of these values are higher than 0.05, the data from the different groups did not have statistically significant differences between them. This shows that the data was statistically similar, meaning that the different levels of the independent variable did not have statistically significant effects on the dependent variable. Although by the end the orange group still had the most absorption according to means and medians, all of the other groups also have a near equal capability of transferring flavonoids, meaning all of the fruit peels have a good potential for application, as will be described later on in the discussion.

Connections to Other Research

As of now, no other scientist has specifically researched the transfer of flavonoids from fruit-infused bioplastic bowls to water, making this research a breakthrough for the medical and environmental fields. However, there have been separate studies involving fruits degrading bioplastic and fruits having high amounts of flavonoids.

In terms of fruit and plastic degradation, there have been studies in which films and plastic have been made using fruit. In 2018, a few scientists effectively used prickly pears to form a stable, yet biodegradable film (Gheribi, Habibi & Khwaldia, 2018). Additionally, in 2018, Munhoz et al. created films using yellow passion fruit, and Santana et al. created films with jackfruit seeds. It has therefore been investigated that fruit can be used to make biodegradable films that are stable, yet can break down easier.

As for fruits and flavonoids, it has been a known fact for quite a while that fruits and their peels contain a variety of antioxidants and other molecules, many of which are flavonoids. In fact, the colors in the actual peels of fruits come from the flavonoids themselves. There have been many studies investigating the flavonoid content of orange peels, including the study by Ghasemi, Ghasemi & Ebrahimzadeh in 2009. There has also been an investigation of the use of such peels in Chinese herbal medicine due to their reported health benefits, which were corroborated by the study's results (Lu et. al, 2006). Evidently, fruit peels contain flavonoids that provide many health benefits in humans when consumed.

By adding the fruit peels to the plastic bowls, not only would the fruit peels make the bowl more easily biodegradable, but the flavonoids would also seep through the container to water or food, giving those additional nutrients and health benefits to the food or water that a person could then consume, making them healthier without requiring them to consume more fruits or vitamins.

Limitations and Errors

Although this experiment gave fairly accurate results, there are still some limitations and errors involved with it. One limitation is the lack of certain lab equipment to further expand this project and make it more accurate. Although a spectrophotometer allowed the scientist to see and detect the pigments in the water, a HPLC machine (a machine that separates, identifies, and quantifies the amount of each component in a mixture) would have allowed the scientist to not only more accurately quantify the amount of flavonoids in the water, but also identify which types of flavonoids are present. However, the scientist did not have access to such equipment.

As for errors, an error may have occurred on day two during the spectrophotometer readings. Although the machine was tested previously, and the machine was reset repeatedly, the machine consistently gave negative results on day two. Such results are highly improbable, and usually only occur if an error has occurred. Although the scientist checked everything to make sure that no errors were occurring, something may have caused inaccurate values to show up, such as the machine overheating. Nonetheless, the results on day three and four showed sensible results and proved the hypothesis to be correct, meaning the problem did not affect the later results, which can be trusted. Another possible error that may have led to a few outliers in the data is that the spectrophotometer results can be variable. Pushing in the cuvette just a millimeter lower or higher than usual can lead to outliers. Although samples were checked twice or thrice before data was recorded, such errors may have caused outliers, though it is highly unlikely.

Nonetheless, the experiment's results show a positive transfer of flavonoids from the bowl to the water, which is a proof of concept.

Future Research

In order to prevent the aforementioned results earlier, the machine will be checked for accuracy, as will all samples twice or thrice to prevent any inaccurate data. As for other future research, one area of interest is using the HPLC machine. The use of this technology could present more refined and detailed data that would identify different flavonoids as well, which would be useful in confirming the presence of certain flavonoids in the water. Another area of future research could be investigating with other fruit peels or super foods (such as watermelon peels or chia seeds), diversifying the data being received. Additionally, the plastic can be shaped into other utensils, such as spoons or cups to investigate whether or not the flavonoids would still transfer and how long it would take for them to transfer. Finally, in the future, more trials will be done to certify that all data is accurate, and so that outliers do not heavily affect the data.

Application

The passive transportation of nutritious flavonoids from utensils to food and water could be applied in the real-world to make the earth and people healthier. By adding fruit peels to the containers, the plastic is not only biodegradable but also easier to break down. Additionally, by adding fruit peels to the containers, food or water contained by the containers can absorb the nutrients in the container, leading to more nutritious food, which is important, as a majority of people across the world lack a nutritious diet full with fruits and vegetables. Additionally, by using fruit peels, the waste that is usually sent to the landfill would actually have a beneficial effect on people across the world by providing them more nutrients, just by eating with a fruity bowl and spoon! This application can lead to healthier people and less pollution, which would benefit both humans and the land they live on. By creating spoons and bowls with fruity bioplastics, the earth can be healthier, as can the human population.

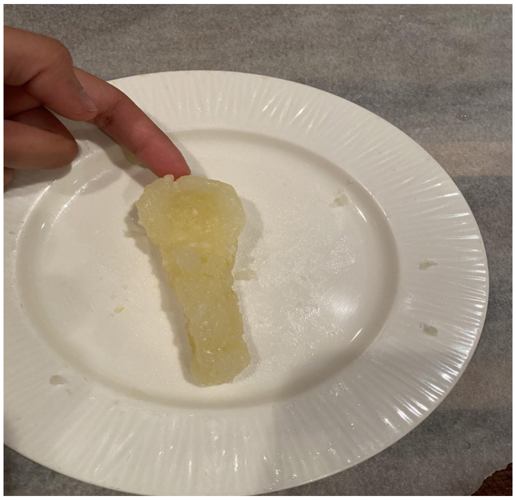


Figure 4. The image above shows a very rough spoon made out of lemon-infused bioplastics, one of the many applications of the bioplastic bowls used in this experiment.

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