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Beeswax Wraps as an Alternative to Single-Use Plastics

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Honors Research Project

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Executive Summary

Background and Approach

Single-use plastics are a staple in many homes for food storage in the form of plastic bags and plastic wrap, however most of these traditional food storage methods are single use, which can have a negative impact on the environment. However, a natural alternative to single-use plastics for food storage that is gaining popularity is beeswax food wraps. Beeswax wraps are composed of organic cotton, beeswax, plant oils, and tree resin that is advertised as a durable and pliable plastic wrap alternative. These beeswax wraps are also marketed as being reusable and exhibiting antimicrobial properties. A series of experiments were conducted to determine the efficacy of beeswax wraps compared to plastic sandwich bags and plastic wrap and also to compare new beeswax wrap to reused beeswax wrap. Percent spoilage was calculated for samples every other day to compare the storage methods.

Results

The spoilage of apple using beeswax and plastic wraps appeared to be faster than in plastic bags, with more signs of spoilage such as dark spots and shriveling of the sample. The average percent spoilage of apples on day 6 of the experiments was 54.08±4.97 for beeswax wrap, 41.19±2.38 for plastic sandwich bags and 63.92±4.64 for plastic wrap. Bread, however, spoiled faster inside the sandwich bags as compared to the beeswax wraps, having an average percent spoilage of 5.14±1.90 for beeswax wraps and 19.23±16.23 for plastic sandwich bags on day 6 of the experiment. The bread sample stored in the plastic wrap dried early in the experiment, so visible spoilage was not observed. For the apple samples in experiments 4-6, the reused beeswax performed significantly worse than the new beeswax, showing an average percent spoilage of 90.84±4.23 on day 4, compared to 27.02±2.51in the new beeswax wrap. However, the new and reused beeswax wraps performed similarly up to two days. The bread samples in experiment 4-6 showed similar results, with the reused beeswax sample spoiling quicker than the new beeswax sample. However, the reused beeswax wrap bread sample dried after 5 days, indicating that the reused beeswax has a weaker moisture barrier than the new beeswax wrap. It was also observed that the reused beeswax wrap showed visible creases after cleaning, which may have affected its moisture and air barrier properties.

Conclusions

Based on results, one can infer that while beeswax performs better than plastic wrap for food storage, plastic sandwich bags still prevent food spoilage the longest. Also, while beeswax wrap is marketed as reusable, experimental results show that the efficacy in preventing spoilage decreases significantly after just one use. Results from this study cannot determine the antibacterial properties of beeswax wrap.

By completing this research project, I have learned a variety of skills which I can apply as an entry-level engineer, including adaptation and collaboration. An initial approach to the project has to be adjusted, which was the kinds of food that was being used in the study, which were strawberries and white bread. The spoilage window for these foods were vastly different, so the decision was made to switch to apples and Italian bread to better observe changes in the samples. I also learned how to collaborate with my mentor, from the initial planning stage of the project to editing of the written report. As a result of this project, I feel more confident in my abilities to plan experiments and complete research projects successfully. This study could have a positive impact on environmental efforts, as single-use plastics are actively affecting wildlife and the atmosphere through accumulation of these materials and the burning of fossil fuels required to produce and distribute them. Although the beeswax wraps are not a perfect solution, they can be an effective alternative to a product that is harming the planet.

Recommendations

Further investigation about beeswax wraps should involve storage of the samples in a refrigerated environment, to imitate normal food storage methods more closely. Also, storing the samples in an environment with monitored humidity would prevent samples from drying out, allowing more data to be usable in the study. Finally, beeswax wraps should be utilized in the storage of different foods to further understand their capability as an alternative to single-use plastics.

The advice that I would give to students who wish to complete independent research is to choose a subject that they are passionate about. Because I am passionate about the environment and sustainability, I found it easy and interesting to research my topic. I would also advise having self-discipline in meeting personal deadlines, as the end of senior year is very busy and stressful, so it is better to complete work earlier in the semester.

Introduction

Single-use plastics are a staple in many homes for food storage in the form of plastic bags and plastic wrap. Most of these traditional food storage methods are single use, which can have a negative impact on the environment, both due to plastic waste that ends up in waterways and from harmful byproducts that are generated during the production of single use plastics. Low-density polyethylene (LDPE) is a commonly used plastic in both plastic wrap and plastic sandwich bags that is favored for food storage due to its properties of being lightweight, low cost, excellent oxygen and moisture properties, and bio-inertness (Das & Kumar, 2015). However, these positive properties also come with a variety of issues with the disposal of these single use plastics. Because these plastics have a long-term resistance to biodegradation, they are accumulating in the environment and affecting organisms of all ecosystems on earth. Although many look at recycling as a solution for how to dispose of these plastics, only around 9 percent of plastic waste has been recycled (*A Whopping 91 Percent of Plastic Isn't Recycled* 2018). In addition, production of non-degradable plastics, which ranges from 350 million to 400 million tons each year, uses fossil fuels, giving it a large carbon footprint estimated to be around 56 gigatons of carbon between 2019 and 2050 (Joyce, 2019). However, a natural alternative to single-use plastics for food storage that is gaining popularity is beeswax food wraps. Beeswax wraps are composed of organic cotton, beeswax, plant oils, and tree resin that is advertised as a durable and pliable plastic wrap alternative. These beeswax wraps are also marketed as reusable, which cannot be said for the more traditional plastic food storage methods. In addition, there is evidence suggesting that beeswax exhibits antimicrobial properties (Fratini et al., 2016). The goal of this study was to investigate the environmental impacts of single use plastics and to compare the efficacy of beeswax wraps for food storage when compared to food storage using single use plastics. This study also investigated the reusability of the beeswax wraps to see if they are effective for food storage after multiple uses.

Background

Polyethylene, shown in **Figure 1**, is a thermoplastic produced from the monomer ethylene. Polyethylene is produced through free radical polymerization, in which a free-radical initiator, such as an organic peroxide, attacks the double bond in the ethylene monomer. This polymerization detail is shown in **Figure 2**.

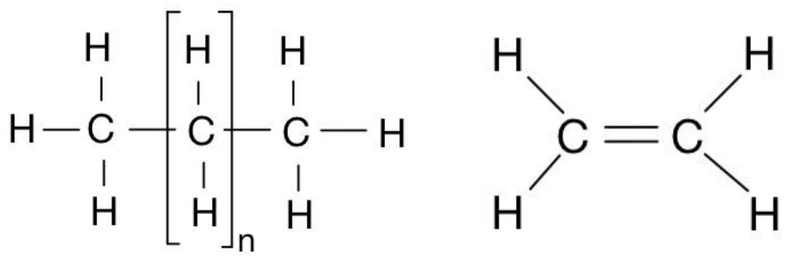

Figure 1 - Chemical structure of (left) polyethylene and (right) the monomer ethylene.

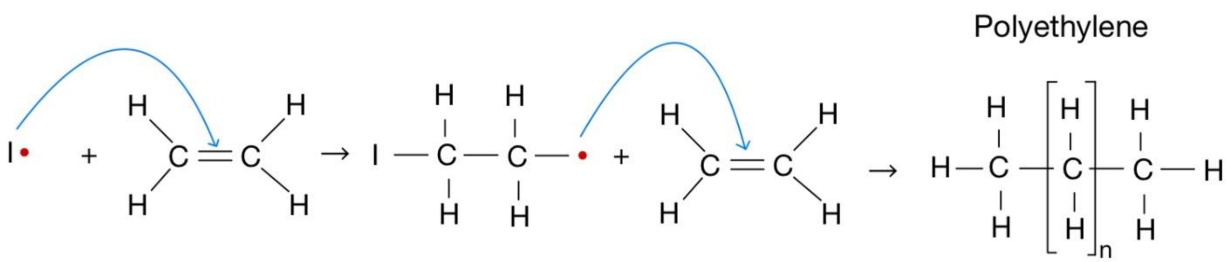

Figure 2- Mechanism for the polymerization of ethylene. The initiator is represented by the letter I, and the red dot represents the radical ion.

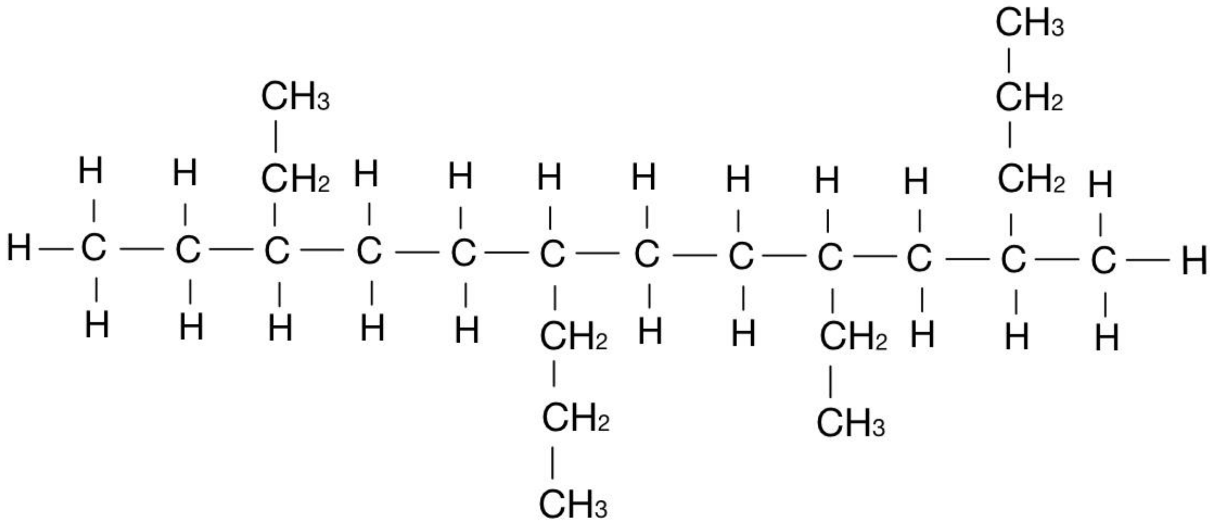

Figure 3 - Branched microstructure of LDPE.

Low density polyethylene (LDPE) is a branched polymer, meaning that it has chains that are attached to the polymer backbone, as shown in **Figure 3**. These side chains interfere in the packing of the polymer chains to each other, resulting in a less dense overall polymer structure. Due to its high molecular weight and low density, it is both tough and flexible, leading to it often being used for food storage applications such as plastic wrap and plastic sandwich bags. However, these products accumulate in the environment because they are not easily biodegradable, as their long carbon backbone and semi-crystalline structure keeps them stable in natural environments (Martínez-Romo et al., 2015). The polymer also lacks functional groups where microbial enzymes can attack to break down the structure (Dey et al., 2020). Also, the products are essentially non-recyclable, as they generally have small masses and are usually contaminated (Martínez-Romo et al., 2015). Because these plastics cannot be recycled and do not biodegrade, they accumulate in the environment, getting into waterways and harming the digestive systems of wildlife when they are consumed. Incineration reduces the number of plastics that directly pollute the environment, however even this method releases harmful air pollutants such as carbon monoxide and nitrogen oxides (Dey et al., 2020).

A possible alternative to plastic food storage methods is beeswax wrap, which is made of a thin fabric, often cotton, which is coated with a layer of beeswax. These wraps are marketed to be an option to replace single-use plastics due to their flexible and tacky surface, and they are marketed to be reusable unlike more traditional methods such as plastic wrap or plastic sandwich bags (Hubbert). Beeswax is a crystalline substance that is composed of over 284 different compounds, including long chain alkanes, acids, esters, polyesters, and hydroxy esters. Hentriacontane, which composes around 10% of beeswax, plays a major role in the stability and structure of beeswax. The chemical formula of hentriacontane is $CH_3(CH_2)_{29}CH_3$, and its structure is shown in **Figure 4** (Ouellette & Rawn, 2015).

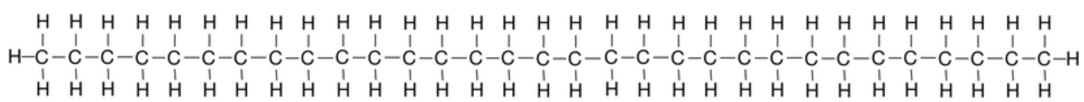

Figure 4- Molecular structure of hentriacontane

Beeswax is crystalline and insoluble in water, giving it similar properties to LDPE and a viable option for food storage (Grumezescu & Holban, 2018). While the composition of beeswax is dependent on the geographical origin of the bees that it is produced from, it is generally composed of hydrocarbons, free fatty acids, esters of fatty acids and fatty alcohol, diesters and exogenous substances. Some studies have also suggested that beeswax has antimicrobial qualities, however there are still few studies on the subject (Fratini et al., 2016). This study will investigate the efficacy of beeswax food wraps compared to the more traditional single-use plastic methods of plastic wrap and plastic sandwich bags. Because beeswax wrap is also marketed as reusable, this study will also investigate its reusability.

Experimental Methods

A set of experiments was designed to compare the efficacy of food storage in single use plastics compared to beeswax wraps. The plastics selected were plastic sandwich storage bags and plastic wrap. Foods initially selected for the study included American cheese, white bread, and strawberries. However, after one round of experiments, it was concluded that the American cheese and white bread contained additives that extended their shelf life to a length that was not reasonable for the scope of the project. Also, the strawberries posed the issue of spoiling too quickly, which created difficulties in comparing the efficacy of the different storage methods. The decision was then made to switch the food for the study to apple slices and Italian bread, which displayed a much more reasonable spoiling timeline for the project. The bread was sliced into approximately 1 cm thick slices using a serrated bread knife, and the apples were sliced into approximately 2 mm thick slices using a small mandolin slicer. To avoid contamination during the preparation process, gloves and an N95 mask were worn during all food handling. Three sets of both bread and apples were prepared for each of the three food storage methods: plastic wrap, plastic sandwich bags, and beeswax wrap. The same method was used for folding the plastic wrap and the beeswax wrap. The food item was placed on the upper half of the wrap, and the bottom of the wrap was folded up to meet the top edge. The top was then folded down twice, and each of the sides were folded in twice. The wrapped specimens were then set on paper plates and placed into a dark room kept between 68-72°F. Each day, the specimens were photographed against the white plate to observe changes using an Apple iPhone 14, and a ruler was included in each photograph as a reference so that the photos could be edited to the same size. Because the beeswax wrap is not translucent and needed to be completely unwrapped each day to be photographed, all specimens were opened each day so that all samples were exposed to the same conditions. Gloves and an N95 mask were worn for each part of the process to protect against contamination of the food and for the safety of the experimenter.

To determine the reusability of the beeswax wraps, a beeswax wrap used in the aforementioned procedure was cleaned using cool water and dawn dish soap and air dried. The same procedure was followed wrapping bread and apples and samples were stored and photographed in the same manner as mentioned previously.

Photographs taken were edited in Adobe Photoshop CS6, where a 10 x 10 grid was placed over each image. For the apple samples, the grid was scaled to be 2.5" by 2.5", while the grid was scaled to 4.0" by 4.0" for the bread samples. Because the bread samples only occupied the bottom 8 rows of the grid, the top two rows were disregarded. For each sample, the number of squares on the grid were counted for which ≥ 50% of the square was covered by the sample. Examples of this counting method are demonstrated in **Figure 5** and **Figure 6**.

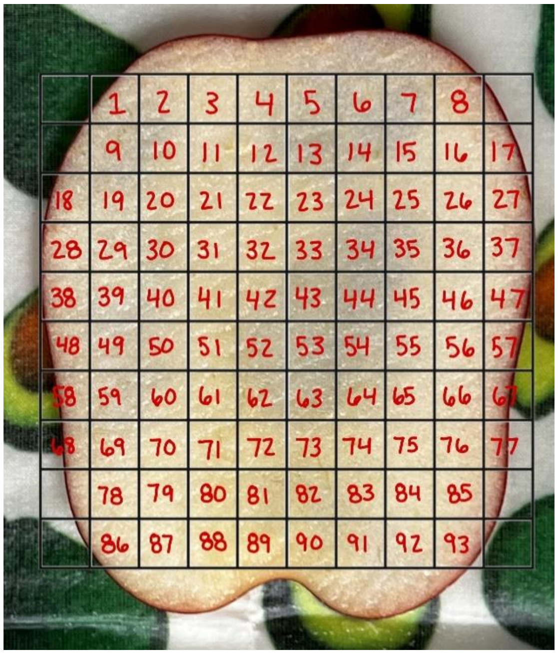

Figure 5 - Square counting method demonstrated on apple sample.

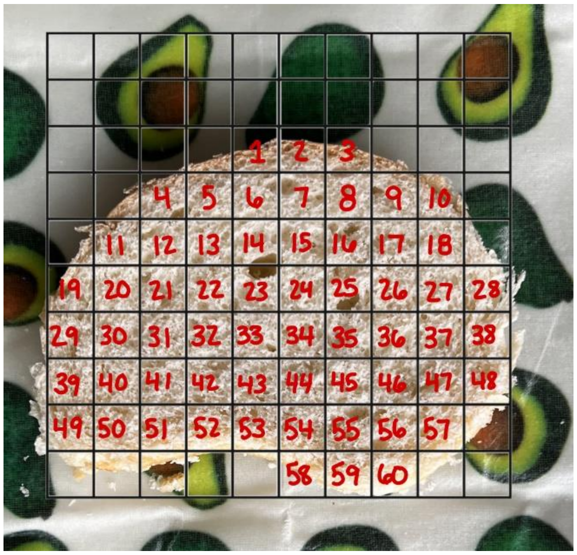

Figure 6 - Square counting method demonstrated on bread sample.

This counting method was then used on each sample to count spoilage of the sample, counting each square that was covered ≥ 50% with signs of spoilage indicated by discoloration or mold growth. The % spoilage for each day was then calculated by dividing the number of squares with spoilage by original number of squares counted for the sample. The % spoilage was plotted against time in days for the three storage methods (beeswax wrap, plastic wrap, and plastic sandwich bags) for both apples and bread for three sets of experiments using Microsoft Excel.

Data and Results

Experiments 1 through 3 investigate the efficacy of beeswax food storage wraps compared to plastic wrap and plastic sandwich bags. Some of the representing images of the apple and bread samples using the three storage means are shown in **Figures** 7 and 10. The spoilage of apple using beeswax and plastic wraps appeared to be faster, with more signs of spoilage such as dark spots and shriveling of the sample, as compared to those stored inside the sandwich bags. Bread, however, spoiled faster inside the sandwich bags as compared to the beeswax wraps.

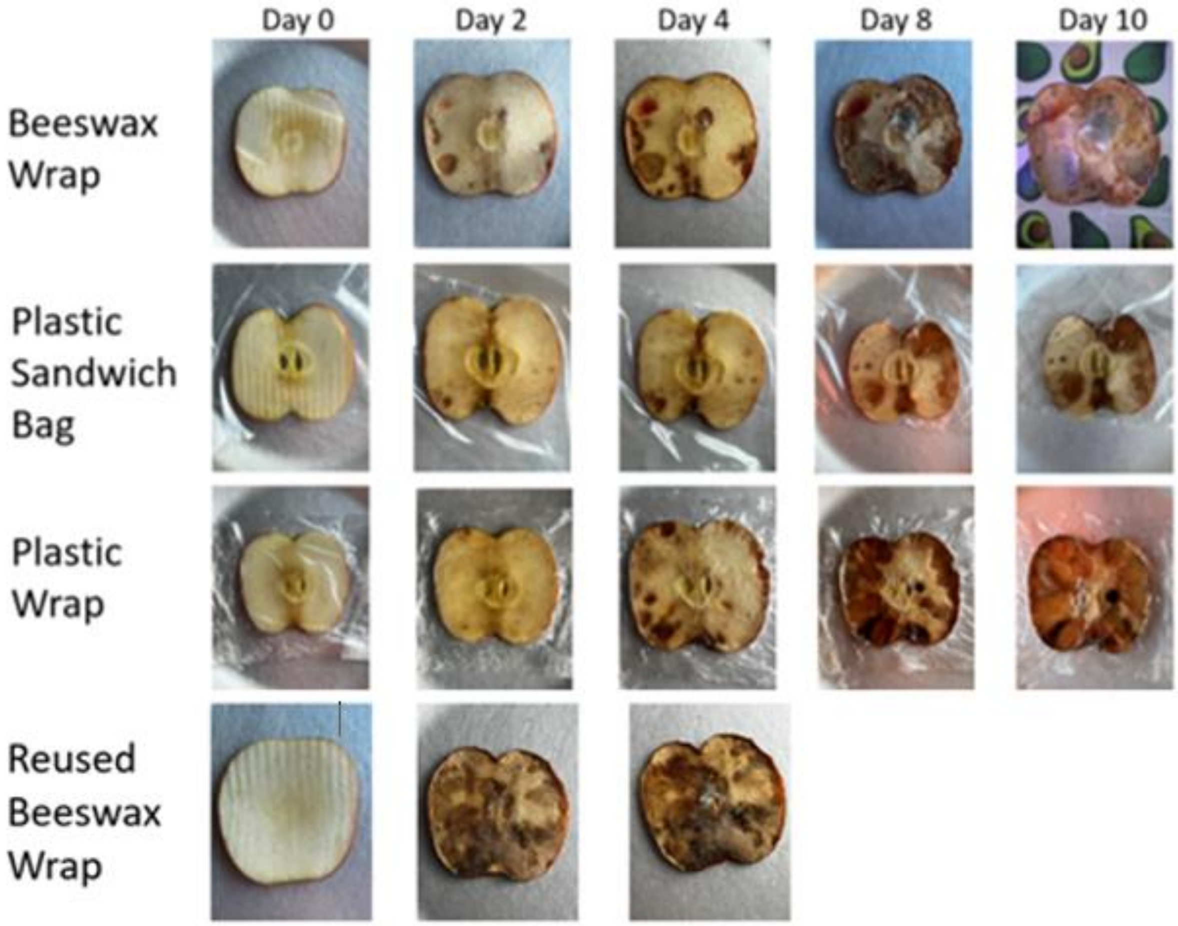

Figure 7- Range of photos of apple samples stored in beeswax wrap, plastic sandwich bag, and plastic wrap (raw 1, 2 and 3, respectively) for experiment 1 and those (row 4) stored in reused beeswax wrap for experiment 4. The days 8 and 10 photos for the samples stored using reused beeswax wrap were not taken on the paper plate because the rotted apples were stuck to the beeswax wraps.

Plots for bread and apple samples for the average % spoilage for all three experiments are shown in **Figure 8** and **Figure 9**, while plots for the individual experiments are included in the appendix, along with data tables for all three sets of experiments with calculated standard deviation values.

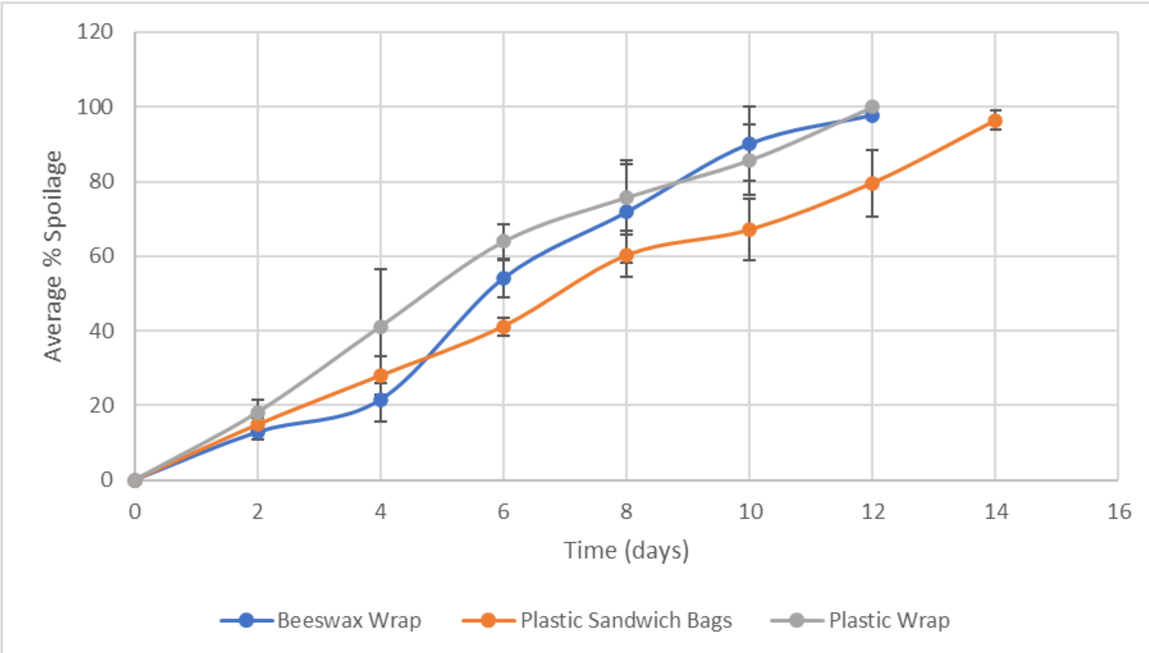

Figure 8 - Average values of % spoilage vs. time in days for experiments 1-3 of apple samples wrapped in beeswax wrap, plastic sandwich bags, and plastic wrap.

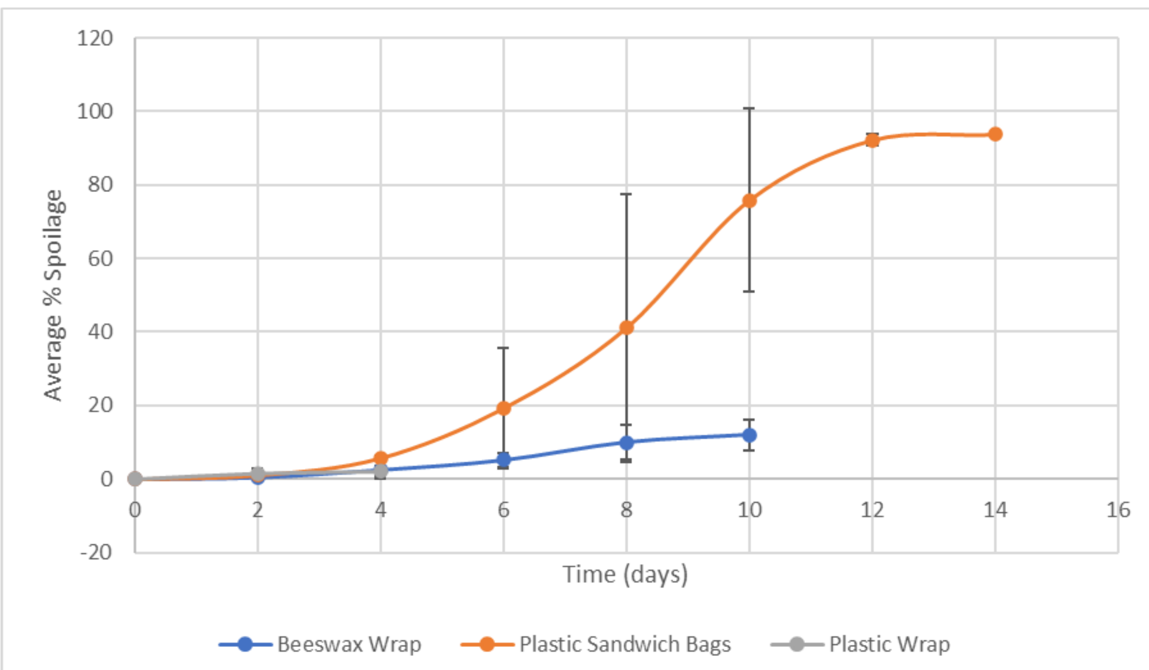

Figure 9 - Average values of % spoilage vs. time in days for experiments 1-3 of bread samples wrapped in beeswax wrap and plastic sandwich bags. Values for plastic wrap were excluded because the samples dried early in the course of the experiments.

For the apple samples in experiments 1-3 (**Figure 8**), all storage methods performed comparatively, with the apple stored in the plastic sandwich bag taking the longest to spoil.

However, it is notable that while the sample stored in the beeswax wrap was quicker than the plastic sandwich bags to spoil, it performed well early in the experiment, having the lowest % spoilage from days 0 through 4 of the experiment, indicating that it may be a good option for short-term food storage.

For the bread samples in experiment 1-3 (**Figure 8**), the plastic wrap sample was not considered, as the sample dried out early in the experiment and therefore did not show visible signs of spoilage, indicating that the plastic wrap does not provide a good moisture barrier for the sample. The beeswax wrap appears to have performed better than the plastic sandwich bag with less than 20% spoilage after 10 days; however, the bread sample dried after 10 days which indicates that the beeswax also does not provide a good moisture barrier when compared to the plastic sandwich bag.

Experiments 4 through 6 investigate the reusability of beeswax food wraps. Photographs were taken and analyzed using the same method as in experiments 1 through 3, and some of the representing images of the apple and bread using new and reused beeswax wraps are shown in **Figure 7 & 10**.

Figure 10- Range of photos of bread samples in stored in beeswax wrap, plastic sandwich bag, and plastic wrap (rows 1, 2, and 3, respectively) for experiment 1 and those (row 4) stored in reused beeswax wrap for experiment 4. The day 10 photos were not taken on the paper plate because the sample was stuck to the plastic wrap or the reused beeswax wrap.

Plots for the average % spoilage values for bread and apple samples for experiments 4-6 are shown in **Figure 11** and **Figure 12**.

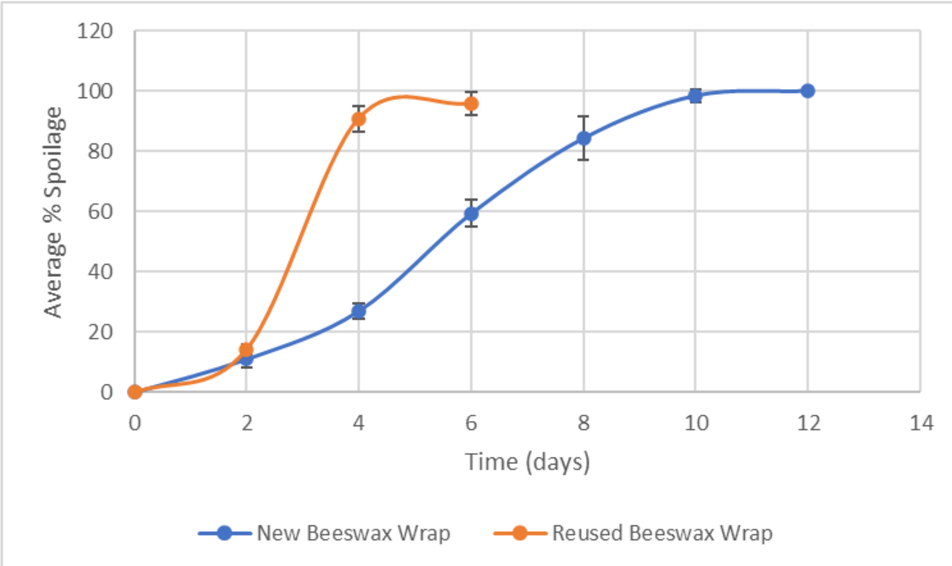

Figure 11 - Average values of % spoilage vs. time in days for experiments 4-6 of apple samples wrapped in a new beeswax wrap and a reused beeswax wrap.

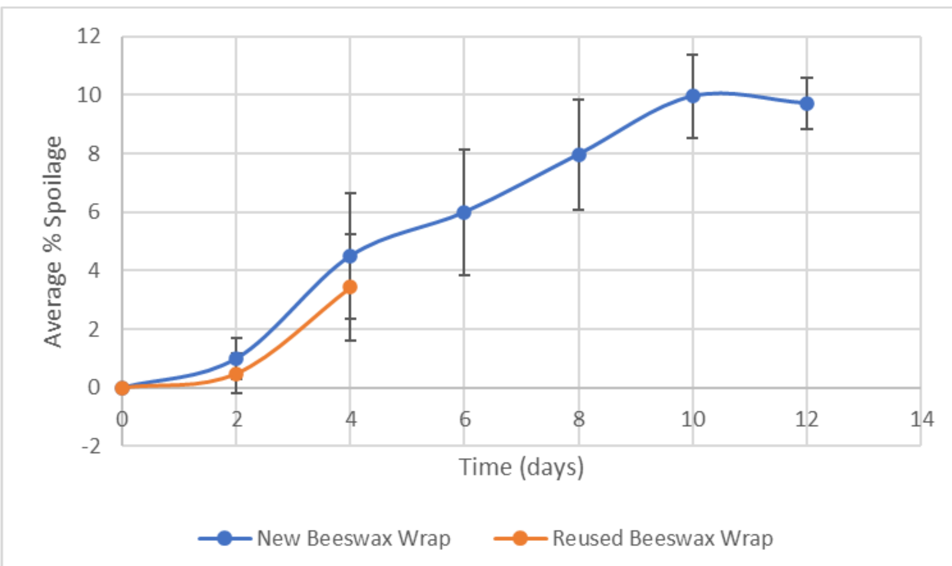

Figure 12 - Average values of % spoilage vs. time in days for experiments 4-6 of bread samples wrapped in a new beeswax wrap and a reused beeswax wrap.

For the apple samples in experiments 4-6, the reused beeswax performed significantly worse than the new beeswax, showing an average percent spoilage of 90.84±4.23 on day 4, compared to 27.02±2.51in the new beeswax wrap. However, the new and reused beeswax wraps performed similarly up to two days. The bread samples in experiment 4-6 showed similar results, with the reused beeswax sample spoiling quicker than the new beeswax sample. However, the reused beeswax wrap bread sample dried after 5 days, indicating that the reused beeswax has a weaker moisture barrier than the new beeswax wrap. It was also observed that the reused beeswax wrap showed visible creases after cleaning, which may have affected its moisture and air barrier properties. Plots and data tables for experiments 4-6 with calculated standard deviation values are included in the appendix.

Discussion/Analysis

A t-test with paired comparison was performed to determine if there were differences between the storage methods. Performance of the beeswax wraps were compared to the plastic bags, plastic wrap, and the reused beeswax wrap. Because the samples dried early in the experiment, the beeswax wrap was not compared to plastic wrap for the bread samples due to insufficient data points to compare. Hypothesized mean difference was assumed to be zero, and t-test results are available in the appendix. Every comparison resulted in a P-value greater than 0.05, meaning that we fail to reject the null hypothesis, and the data sets are not significantly different, and that the beeswax wrap performed similarly to plastic bags, plastic wrap, and reused beeswax wrap.

The goal of this study was to investigate the environmental impacts of single use plastics and to compare the efficacy of beeswax wraps for food storage when compared to food storage using single use plastics. This study also investigated the reusability of the beeswax wraps to see if they are effective for food storage after multiple uses. While beeswax wraps do not appear to be a suitable long term storage solution compared to plastic sandwich bags, they are comparable to plastic wrap and may even be desirable for short term food storage, especially considering the environmental impact of single-use plastics. While beeswax wraps are marketed to have antimicrobial properties, more evidence is needed to support this claim. Beeswax wraps are also marketed as reusable; however, this study suggests that the efficacy of these wraps after cleaning is much lower compared to when they are new.

Further investigation about beeswax wraps should involve storage of the samples in a refrigerated environment, to imitate normal food storage methods more closely. Also, storing the samples in an environment with monitored humidity would prevent samples from drying out, allowing more data to be usable in the study. Finally, beeswax wraps should be utilized in the storage of different foods to further understand their capability as an alternative to single-use plastics.

Literature Cited

Das, M.P., Kumar, S. An approach to low-density polyethylene biodegradation by *Bacillus amyloliquefaciens*. *3 Biotech* **5**, 81–86 (2015). https://doi.org/10.1007/s13205-014-0205-1

Dey, A. S., Bose, H., Mohapatra, B., & Sar, P. (2020). Biodegradation of unpretreated low-density polyethylene (LDPE) by Stenotrophomonas sp. and Achromobacter sp., isolated from waste dumpsite and drilling fluid. *Frontiers in Microbiology*, *11*. https://doi.org/10.3389/fmicb.2020.603210

Fratini, F., Cilia, G., Turchi, B., & Felicioli, A. (2016). Beeswax: A minireview of its antimicrobial activity and its application in medicine. *Asian Pacific Journal of Tropical Medicine*, *9*(9), 839–843. https://doi.org/10.1016/j.apjtm.2016.07.003

Grumezescu, A. M., & Holban, A. M. (2018). Chapter 5 - Report on Edible Films and Coatings. In *Food Packaging and preservation* (pp. 177–212). essay, Academic Press, an imprint of Elsevier.

Hubbert, J. (n.d.). *What is beeswax food wrap (and does it really work?)*. Tru Earth. Retrieved April 11, 2023, from https://www.tru.earth/What-is-Beeswax-Food-Wrap-And-Does-it-Really-Work

Joyce, C. (2019, July 9). *Plastic has a big carbon footprint - but that isn't the whole story*. NPR. Retrieved April 11, 2023, from https://www.npr.org/2019/07/09/735848489/plastic-has-a-big-carbon-footprint-but-that-isnt-the-whole-story

Martínez-Romo, A., González-Mota, R., Soto-Bernal, J. J., & Rosales-Candelas, I. (2015). Investigating the degradability of HDPE, LDPE, PE-Bio, and pe-oxo films under UV-B radiation. *Journal of Spectroscopy*, *2015*, 1–6. https://doi.org/10.1155/2015/586514

natgeo.com. (2018, December 20). *A Whopping 91 Percent of Plastic Isn't Recycled*. National Geographic Education. Retrieved April 11, 2023, from https://education.nationalgeographic.org/resource/whopping-91-percent-plastic-isnt-recycled/

Ouellette, R. J., & Rawn, J. D. (2015). *Principles of organic chemistry*. Elsevier.

Appendix

Photos

Figure 13 - Example of apple sample spoilage throughout course of experiment from day 0 (left) to day 10 (right)

Figure 14 - Example of bread sample spoilage throughout course of experiment from day 0 (left) to day 10 (right).

Experimental Data

Table 1 - Experimental data for apple samples for experiment 1.

Beeswax			
Time (days)	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	91	0	0.00
2	91	9	9.89
4	91	15	16.48
6	91	44	48.35
8	91	54	59.34
10	91	73	80.22
12	91	89	97.80

Plastic Sandwich Bags			
Time (days)	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	92	0	0.00
2	92	16	17.39
4	92	25	27.17
6	92	41	44.57
8	92	48	52.17
10	92	51	55.43
12	92	64	69.57
14	92	91	98.91

Plastic Wrap			
Time (days)	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	93	0	0.00
2	93	21	22.58
4	93	36	38.71
6	93	54	58.06
9	93	64	68.82
10	93	71	76.34
12	93	93	100.00

Table 2 - Experimental data for bread samples for experiment 1.

Beeswax			
Time (days)	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	61	0	0.00
2	61	0	0.00
4	61	0	0.00
6	61	3	4.92
8	61	10	16.39
10	61	11	18.03

Plastic Sandwich Bags			
Time (days	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	64	0	0.00
2	64	0	0.00
4	64	3	4.69
6	64	27	42.19
8	64	59	92.19
10	64	64	100.00

Plastic Wrap			
Time (days	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	65	0	0
2	65	0	0
4	65	0	0

Table 3 - Experimental data for apple samples for experiment 2.

Beeswax			
Time (days	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	88	0	0.00
2	88	13	14.77
4	88	26	29.55
6	88	47	53.41
8	88	80	90.91

Plastic Sandwich Bags			
Time (days	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	81	0	0.00
2	81	11	13.58
4	81	28	34.57
6	81	32	39.51
8	81	52	64.20
10	81	60	74.07
12	81	74	91.36

Plastic Wrap			
Time (days	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	85	0	0.00
2	85	15	17.65
4	85	52	61.18
6	85	59	69.41
8	85	75	88.24
10	85	84	98.82
12	85	85	100.00

Table 4- Experimental data for bread samples for experiment 2.

Beeswax			
Time (days)	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	68	0	0.00
2	68	0	0.00
4	68	1	1.47
6	68	2	2.94
8	68	4	5.88
10	68	6	8.82
12	68	6	8.82

Plastic Sandwich Bags			
Time (days	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	64	0	0.00
2	64	1	1.56
4	64	4	6.25
6	64	5	7.81
8	64	13	20.31
10	64	55	85.94
12	64	60	93.75

Plastic Wrap			
Time (days	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	60	0	0.00
2	60	2	3.33
4	60	2	3.33

Table 5- Experimental data for apple samples for experiment 3.

Beeswax			
Time (days)	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	86	0	0.00
2	86	12	13.95
4	86	16	18.60
6	86	52	60.47
8	86	56	65.12
10	86	86	100.00

Plastic Sandwich Bags			
Time (days)	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	81	0	0.00
2	81	11	13.58
4	81	18	22.22
6	81	32	39.51
8	81	52	64.20
10	81	58	71.60
12	81	63	77.78
14	81	76	93.83

Plastic Wrap			
Time (days)	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	84	0	0.00
2	84	12	14.29
4	84	20	23.81
6	84	54	64.29
8	84	59	70.24
10	84	69	82.14
12	84	84	100.00

Table 6- Experimental data for bread samples for experiment 3.

Beeswax			
Time (days	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	66	0	0
2	66	1	1.515151515
4	66	4	6.060606061
6	66	5	7.575757576
8	66	5	7.575757576
10	66	6	9.090909091
12	66	7	10.60606061

Plastic Sandwich Bags			
Time (days	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	65	0	0
2	65	1	1.538461538
4	65	4	6.153846154
6	65	5	7.692307692
8	65	7	10.76923077
10	65	27	41.53846154
12	65	59	90.76923077
14	65	61	93.84615385

Plastic Wrap			
Time (days	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	65	0	0
2	65	1	1.538461538
4	65	2	3.076923077

Table 7- Experimental data for apple samples for experiment 4.

Beeswax			
Time (days)	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	88	0	0.00
2	88	13	14.77
4	88	26	29.55
6	88	47	53.41
8	88	80	90.91
10	88	88	100.00

Reused Beeswax			
Time (days)	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	89	0	0.00
2	89	11	12.36
4	89	80	89.89
6	89	81	91.01

Table 8- Experimental data for bread samples for experiment 4.

Beeswax			
Time (days)	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	68	0	0.00
2	68	0	0.00
4	68	1	1.47
6	68	2	2.94
8	68	4	5.88
10	68	6	8.82
12	68	6	8.82

Reused Beeswax			
Time (days)	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	68	0	0.00
2	68	0	0.00
4	68	4	5.88

Table 9- Experimental data for apple samples for experiment 5.

Beeswax					Reused Beeswax			
Time (days	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage		Time (days	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	86	0	0.00		0	84	0	0.00
2	86	8	9.30		2	84	12	14.29
4	86	24	27.91		4	84	81	96.43
6	86	55	63.95		6	84	84	100.00
8	86	64	74.42					
10	86	82	95.35					
12	86	86	100.00					

Table 10- Experimental data for bread samples for experiment 5.

Beeswax					Reused Beeswax			
Time (days	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage		Time (days	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	66	0	0.00		0	69	0	0.00
2	66	1	1.52		2	69	1	1.45
4	66	4	6.06		4	69	2	2.90
6	66	5	7.58					
8	66	5	7.58					
10	66	6	9.09					
12	66	7	10.61					

Table 11- Experimental data for apple samples for experiment 6.

Beeswax					Reused Beeswax			
Time (days)	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage		Time (days)	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	89	0	0.00		0	87	0	0.00
2	89	8	8.99		2	87	14	16.09
4	89	21	23.60		4	87	75	86.21
6	89	54	60.67		6	87	84	96.55
8	89	78	87.64					
10	89	89	100.00					

Table 12- Experimental data for bread samples for experiment 6.

Beeswax					Reused Beeswax			
Time (days)	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage		Time (days)	# of squares total (50% or more covered)	# of squares spoiled (50% or more spoiled)	% spoilage
0	67	0	0.00		0	67	0	0.00
2	67	1	1.49		2	67	0	0.00
4	67	4	5.97		4	67	1	1.49
6	67	5	7.46					
8	67	7	10.45					
10	67	8	11.94					

Plots

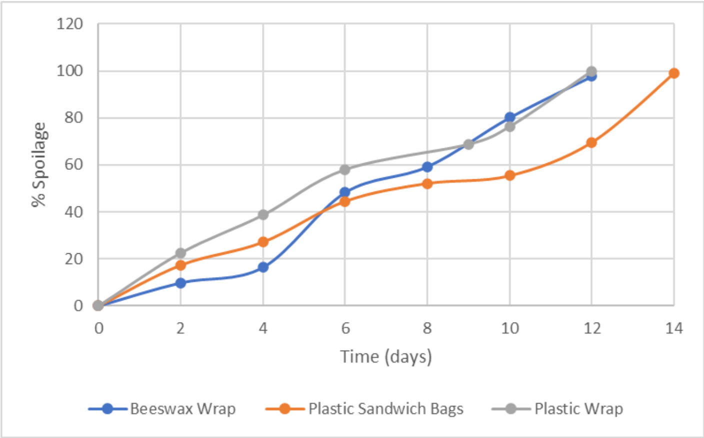

Figure 15 - % spoilage vs. time in days for apple samples of experiment 1.

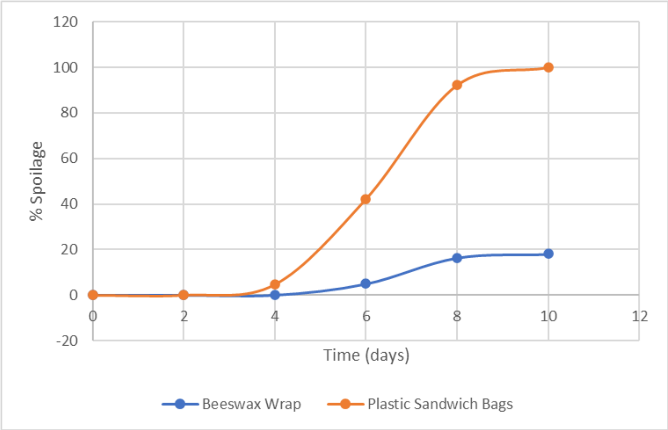

Figure 16 - % spoilage vs. time in days for bread samples of experiment 1.

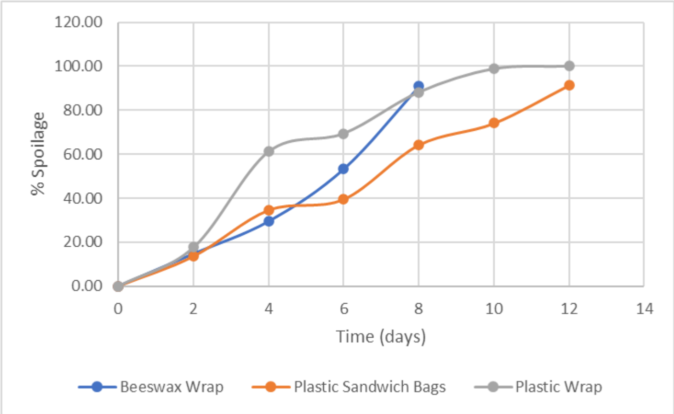

Figure 17- % spoilage vs. time in days for apple samples of experiment 2.

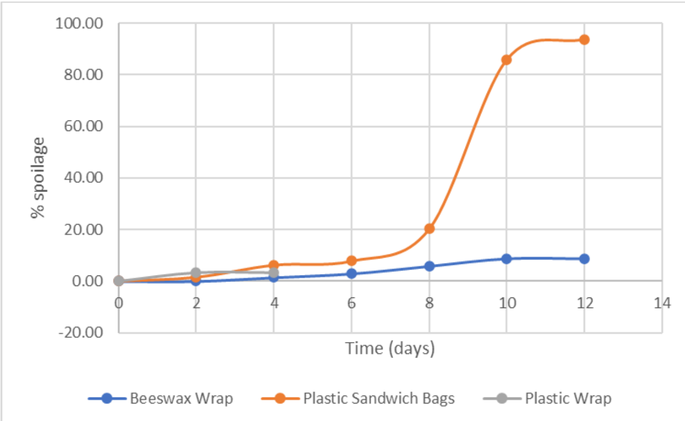

Figure 18- % spoilage vs. time in days for bread samples of experiment 2.

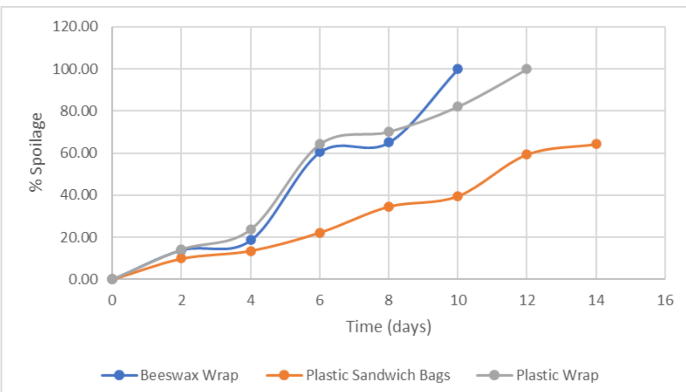

Figure 19- % spoilage vs. time in days for apple samples of experiment 3.

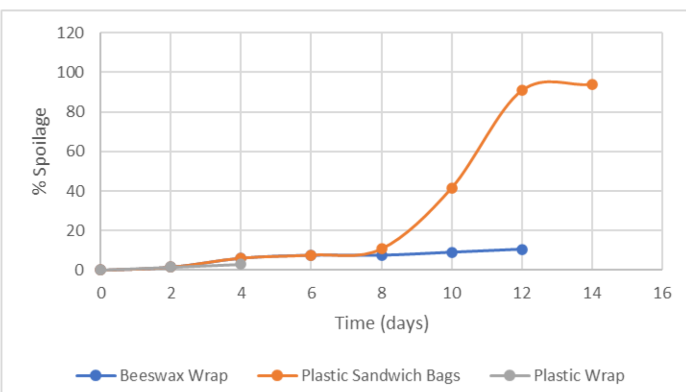

Figure 20- % spoilage vs. time in days for bread samples of experiment 3.

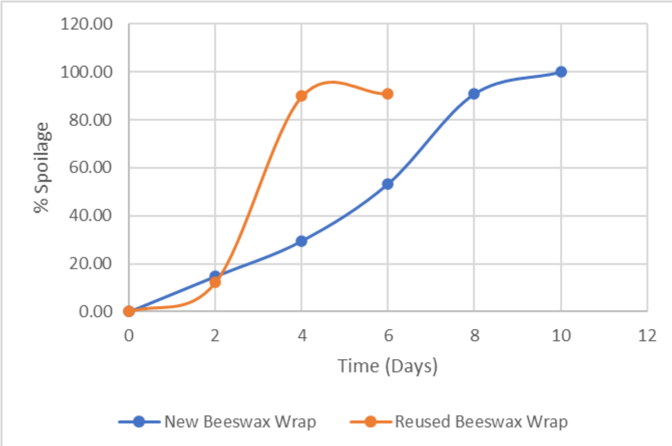

Figure 21- % spoilage vs. time in days for apple samples of experiment 4.

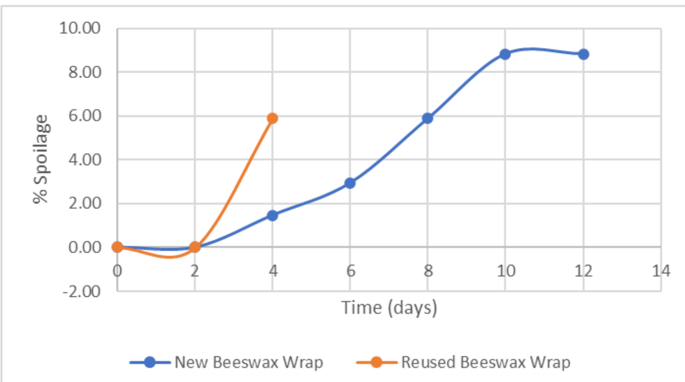

Figure 22- % spoilage vs. time in days for bread samples of experiment 4.

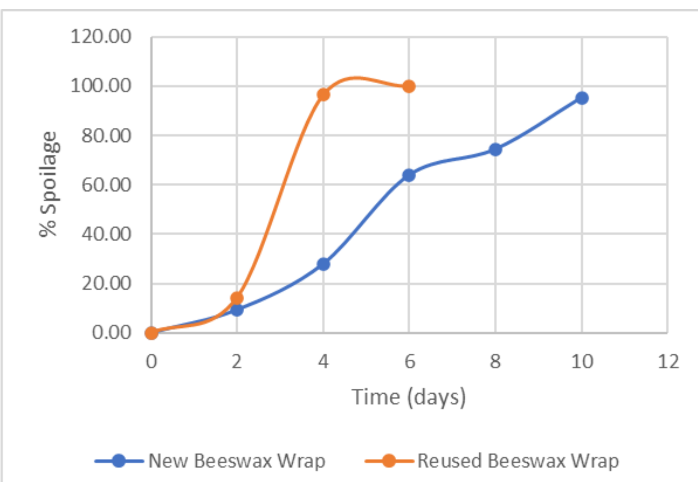

Figure 23- % spoilage vs. time in days for apple samples of experiment 5.

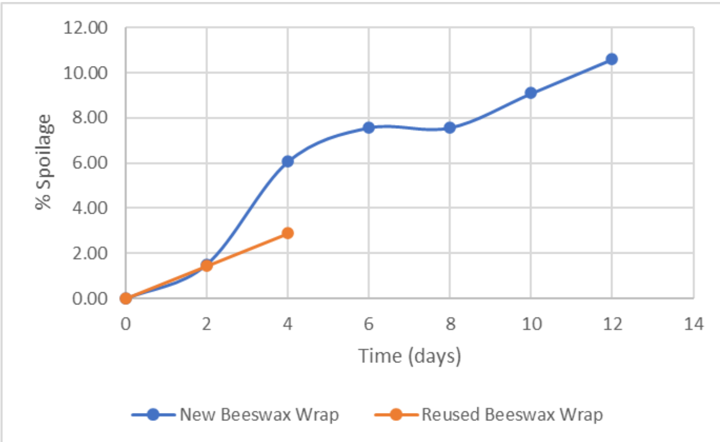

Figure 24- % spoilage vs. time in days for bread samples of experiment 5.

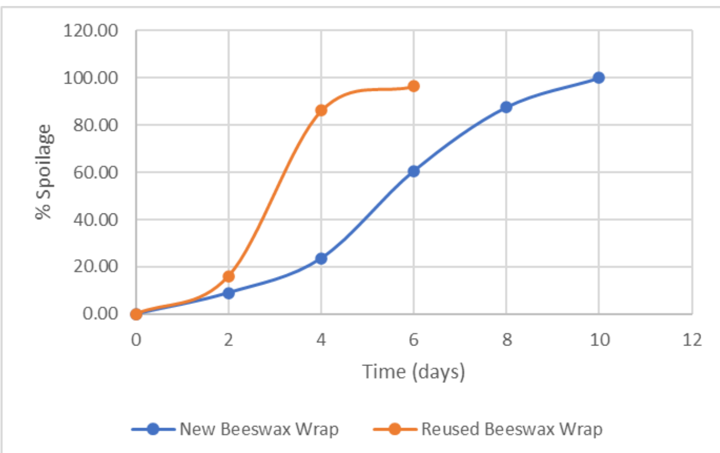

Figure 25- % spoilage vs. time in days for apple samples of experiment 6.

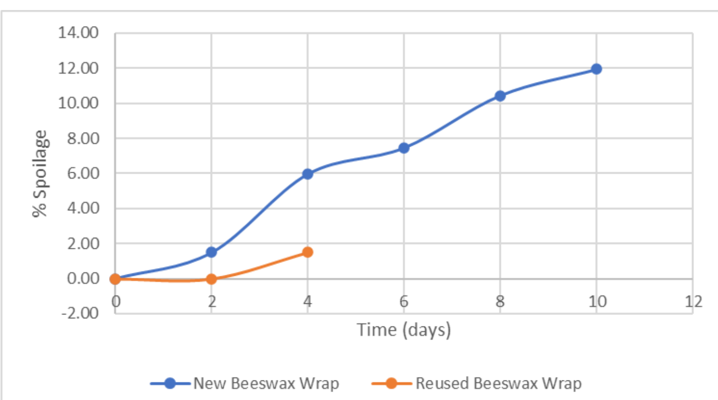

Figure 26- % spoilage vs. time in days for bread samples of experiment 6.

Averages and Standard Deviation

Table 13- Average calculated % spoilage of apple samples and standard deviation for beeswax wrap for experiments 1-3.

	% Spoilage				
Time (days)	Exp1	Exp2	Exp3	Average % Spoilage	Std Dev
0	0.00	0.00	0.00	0.00	0.00
2	9.89	14.77	13.95	12.87	2.13
4	16.48	29.55	18.60	21.54	5.72
6	48.35	53.41	60.47	54.08	4.97
8	59.34	90.91	65.12	71.79	13.72
10	80.22		100.00	90.11	9.89
12	97.8021978			97.8021978	0

Table 14- Average calculated % spoilage of apple samples and standard deviation for plastic sandwich bags for experiments 1-3.

	% Spoilage				
Time (days)	Exp1	Exp2	Exp3	Average % Spoilage	Std Dev
0	0.00	0.00	0.00	0.00	0.00
2	17.39	13.58	13.58	14.85	1.80
4	27.17	34.57	22.22	27.99	5.07
6	44.57	39.51	39.51	41.19	2.38
8	52.17	64.20	64.20	60.19	5.67
10	55.43	74.07	71.60	67.04	8.27
12	69.57	91.36	77.78	79.57	8.99
14	98.91		93.83	96.37	2.54

Table 15- Average calculated % spoilage of apple samples and standard deviation for plastic wrap for experiments 1-3.

	% Spoilage				
Time (days)	Exp1	Exp2	Exp3	Average % Spoilage	Std Dev
0	0.00	0.00	0.00	0.00	0.00
2	22.58	17.65	14.29	18.17	3.41
4	38.71	61.18	23.81	41.23	15.36
6	58.06	69.41	64.29	63.92	4.64
8	68.82	88.24	70.24	75.76	8.84
10	76.34	98.82	82.14	85.77	9.53
12	100.00	100.00	100.00	100.00	0.00

Table 16- Average calculated % spoilage of bread samples and standard deviation for beeswax wrap for experiments 1-3.

	% Spoilage				
Time (days)	Exp1	Exp2	Exp3	Average % Spoilage	Std Dev
0	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	1.52	0.51	0.71
4	0.00	1.47	6.06	2.51	2.58
6	4.92	2.94	7.58	5.14	1.90
8	16.39	5.88	7.58	9.95	4.61
10	18.03	8.82	9.09	11.98	4.28
12		8.82	10.61	9.71	0.89

Table 17- Average calculated % spoilage of bread samples and standard deviation for plastic sandwich bags for experiments 1-3.

	% Spoilage				
Time (days)	Exp1	Exp2	Exp3	Average % Spoilage	Std Dev
0	0.00	0.00	0.00	0.00	0.00
2	0.00	1.56	1.54	1.03	0.73
4	4.69	6.25	6.15	5.70	0.71
6	42.19	7.81	7.69	19.23	16.23
8	92.19	20.31	10.77	41.09	36.34
10	100.00	85.94	41.54	75.83	24.91
12		93.75	90.77	92.26	1.49
14			93.85	93.85	0.00

Table 18- Average calculated % spoilage of bread samples and standard deviation for plastic wrap for experiments 1-3.

	% Spoilage				
Time (days)	Exp1	Exp2	Exp3	Average % Spoilage	Std Dev
0	0.00	0.00	0.00	0.00	0.00
2	0.00	3.33	1.54	1.62	1.36
4	0.00	3.33	3.08	2.14	1.51

Table 19- Average calculated % spoilage of apple samples and standard deviation for new beeswax wrap for experiments 4-6.

	% Spoilage				
Time (days)	Exp4	Exp5	Exp6	Average % Spoilage	Std Dev
0	0.00	0.00	0.00	0.00	0.00
2	14.77	9.30	8.99	11.02	2.66
4	29.55	27.91	23.60	27.02	2.51
6	53.41	63.95	60.67	59.35	4.41
8	90.91	74.42	87.64	84.32	7.13
10	100.00	95.35	100.00	98.45	2.19
12		100.00		100.00	0.00

Table 20- Average calculated % spoilage of apple samples and standard deviation for reused beeswax wrap for experiments 4-6.

	% Spoilage				
Time (days)	Exp4	Exp5	Exp6	Average % Spoilage	Std Dev
0	0.00	0.00	0.00	0.00	0.00
2	12.36	14.29	16.09	14.25	1.52
4	89.89	96.43	86.21	90.84	4.23
6	91.01	100.00	96.55	95.85	3.70

Table 21- Average calculated % spoilage of bread samples and standard deviation for new beeswax wrap for experiments 4-6.

	% Spoilage				
Time (days)	Exp4	Exp5	Exp6	Average % Spoilage	Std Dev
0	0.00	0.00	0.00	0.00	0.00
2	0.00	1.52	1.49	1.00	0.71
4	1.47	6.06	5.97	4.50	2.14
6	2.94	7.58	7.46	5.99	2.16
8	5.88	7.58	10.45	7.97	1.88
10	8.82	9.09	11.94	9.95	1.41
12	8.82	10.61		9.71	0.89

Table 22- Average calculated % spoilage of bread samples and standard deviation for reused beeswax wrap for experiments 4-6.

	% Spoilage				
Time (days)	Exp4	Exp5	Exp6	Average % Spoilage	Std Dev
0	0.00	0.00	0.00	0.00	0.00
2	0.00	1.45	0.00	0.48	0.68
4	5.88	2.90	1.49	3.42	1.83

T-test Data

Table 23- t-test results comparing beeswax wraps to plastic sandwich bags for apple and bread samples.

Apples		
t-Test: Paired Two Sample for Means		
	Variable 1	*Variable 2*
Mean	49.74	41.55
Variance	1512.16	844.28
Observations	7.00	7.00
Pearson Correlation	0.99	
Hypothesized Mean Difference	0.00	
df	6.00	
t Stat	1.95	
P(T<=t) one-tail	0.05	
t Critical one-tail	1.94	
P(T<=t) two-tail	0.10	
t Critical two-tail	2.45	

Bread		
t-Test: Paired Two Sample for Means		
	Variable 1	*Variable 2*
Mean	5.69	33.59
Variance	23.94	1409.10
Observations	7.00	7.00
Pearson Correlation	0.90	
Hypothesized Mean Difference	0.00	
df	6.00	
t Stat	-2.22	
P(T<=t) one-tail	0.03	
t Critical one-tail	1.94	
P(T<=t) two-tail	0.07	
t Critical two-tail	2.45	

Table 24- t-test results comparing beeswax wraps to plastic wrap for apple samples. Bread samples were not included because the drying of the sample in the plastic wrap led to an insufficient data set to compare.

Apples		
t-Test: Paired Two Sample for Means		
	Variable 1	*Variable 2*
Mean	49.74	54.98
Variance	1512.16	1342.24
Observations	7.00	7.00
Pearson Correlation	0.98	
Hypothesized Mean Difference	0.00	
df	6.00	
t Stat	-1.79	
P(T<=t) one-tail	0.06	
t Critical one-tail	1.94	
P(T<=t) two-tail	0.12	
t Critical two-tail	2.45	

Table 25- t-test results comparing new beeswax wraps to reused beeswax wraps for apple and bread samples.

Apples		
t-Test: Paired Two Sample for Means		
	Variable 1	*Variable 2*
Mean	24.35	50.24
Variance	667.46	2516.25
Observations	4.00	4.00
Pearson Correlation	0.88	
Hypothesized Mean Difference	0.00	
df	3.00	
t Stat	-1.71	
P(T<=t) one-tail	0.09	
t Critical one-tail	2.35	
P(T<=t) two-tail	0.18	
t Critical two-tail	3.18	

Bread		
t-Test: Paired Two Sample for Means		
	Variable 1	*Variable 2*
Mean	1.83	1.30
Variance	5.58	3.44
Observations	3.00	3.00
Pearson Correlation	1.00	
Hypothesized Mean Difference	0.00	
df	2.00	
t Stat	1.71	
P(T<=t) one-tail	0.11	
t Critical one-tail	2.92	
P(T<=t) two-tail	0.23	
t Critical two-tail	4.30	