Journal of
Emerging Investigators

Effectiveness of Biodegradable Plastic in Preventing Food Spoilage

Catherine R. Zhang[1] and Jill Carter[1]

[1]Shrewsbury High School, 64 Holden Street, Shrewsbury, MA 01545

Summary:

The purpose of this study was to compare 100% polylactic acid (PLA) biodegradable plastic with a low-density polyethylene plastic (LDPE) in terms of their effectiveness against food spoilage. The interests of this study were: 1) the type of plastic that is more effective in preventing food spoilage, and 2) the materials' properties, which are key factors in preventing food spoilage. Three trials were conducted testing the two plastics, in which an apple half was wrapped in either 100% biodegradable plastic, LDPE plastic, or no plastic at all (control). Over a period of 11 days, the daily mass of the apple was measured to determine the type of plastic that was more effective in preventing food spoilage. The results showed that in the long term (11 days), the LDPE plastic was more effective in preventing food spoilage than the biodegradable plastic. By day 11, the apples in LDPE plastic lost about 4.84% of their original mass, the apples in biodegradable plastic lost 18.25% of their mass, and the control apples lost about 56.11% of their mass. However, in the short term (1-3 days), both the apples in LDPE plastic and the apples in the biodegradable plastic lost a similar amount of their mass (2-4%) while the control apples lost about 20% of their mass. The results demonstrate that the biodegradable plastic can prevent food spoilage as effectively as the LDPE plastic in the short term. Hopefully, this will increase the appeal of biodegradable bags to consumers due to its ability to reduce the amount of trash in landfills.

Received: September 29, 2011; **Accepted:** November 1, 2011; **Published:** March 20, 2012

Introduction:

Packaging containers, bags, and wraps made up 56% of the total plastic waste and 31% of the total solid waste in 2005, and this percentage is annually increasing (1). Plastic packaging waste is a large contributor to the growing landfill problem. In the past, much research has been done to test the biodegradability of these types of plastics; however, comparisons between biodegradable plastics and generic plastics in their effectiveness in the prevention of food spoilage, which interests the consumer, has not been deeply examined. Hence, it is important to compare the effectiveness of a biodegradable plastic in preventing food spoilage with that of a generic plastic.

Food spoilage is when the original nutritional value, texture, or flavor of the food are damaged and the food becomes harmful to people and unsuitable to eat (2). Food spoils mainly because of moisture, oxygen, light, and microorganisms. Oxygen can have deteriorating effects on fats, food colors, vitamins, and flavors, and can create conditions suitable for the growth of microorganisms. Oxygen also causes oxidative spoilage, which is the main cause of quality loss in fats (2). Oxidation is the loss of electrons. Oxidation not only starts to degrade the apple's nutrients, but atmospheric oxygen can react with some food components which may cause rancidity or color changes (2). Certain enzymes in foods can speed up the chemical reactions between oxygen and food. In apples, the specific enzyme that causes the brownish color to appear is called polyphenol oxidase. Exposure to light can cause food spoilage through photodegradation (degradation by UV light) in the pigments, fats, proteins, and vitamins of food. In solid foods, photodegradation occurs where the light penetrates the outer layer of the food. In liquids, light penetration can be greater, but the light penetration depends on factors such as the light source strength and the type of light emitted (2).

In this study, the focus will be on examining the influence of moisture on food spoilage. Normally, barrier materials (such as non-biodegradable and biodegradable plastics) have the ability to restrict the passage of gases, vapors, and organic liquids through their boundaries. In simpler terms, barrier materials prevent substances inside the barrier from escaping, and outside substances from entering the barrier. Therefore, mass is the best indicator of the amount of substances moving in and out of the barrier. However, mass loss can be caused by many factors, including moisture loss and microbial degradation (3). Low-density polyethylene (LDPE) is gaining market share in food industrial applications and is now used in both Saran Wrap® and Glad® Cling Wrap. LDPE is flexible, transparent, resists tearing, and acts as a moisture barrier. It also has very good resistance to acids, bases, and vegetable oils. Because of this excellent combination of properties, it is widely used for packaging applications (4). The water vapor transmission rate (WVTR) is one of the key indicators for determining a plastic wrap's effectiveness in preventing food spoilage. It is defined as the rate at which water vapor can move from one side of the barrier to the other. The transmission rate of gases and vapors depends on both the solubility of the gases and their rate of diffusion through the barrier (which depends on the configuration of the barrier polymer) (3). Current biodegradable plastic wraps (ex. PLA) have a higher WVTR than LDPE plastic wrap (3).

Permeability is a function of both the permeance and the thickness of the barrier material. Permeation, which includes the rate at which a gas passes through a barrier material, is affected by the characteristics of the polymer, such as its chemical makeup. Permeability is also affected by the molecular organization of the polymer, such as crystallinity: crystallites are impermeable, so a polymer with a higher degree of crystallinity will have a lower amount of permeation, resulting in it being a better barrier. Permeability is also affected by temperature, humidity, and pressure. For example, every 5oC increase in temperature can result in a permeability increase of 30-50%, making it a worse barrier (3).

The interests of this study were: 1) which type of plastic wrap is more effective in preventing food spoilage: a generic, non-biodegradable plastic wrap or a 100% biodegradable plastic wrap; 2) the material properties which prevent food spoilage; and 3) the average amount of time for each plastic wrap that it takes for the apple to spoil by measuring the average accumulated rate of mass loss over time. The purpose of this study was to compare the effectiveness of a 100% biodegradable plastic (BioMass®) with a low-density polyethylene (LDPE) plastic (Glad®) in preventing food spoilage. Three experimental trials were conducted to test the LDPE wrap and the biodegradable wrap in a controlled environment covering a Gala apple to evaluate their effectiveness in preventing food spoilage. Because LDPE has a lower WVTR than the biodegradable plastic, it was initially thought that the generic LDPE plastic would be more effective than the biodegradable plastic in preventing food spoilage. In the short term (3 days), the LDPE and biodegradable wrap performed similarly in preventing food spoilage, while in the long term (11 days), the LDPE wrap performed more effectively in preventing food spoilage than the biodegradable wrap.

Materials and Methods:

The apples used in the study were Gala apples. For the biodegradable plastic, BioMass® Bags (PLA Flat Bag with 1" Lip & Tape 5.5"X8") were used. For the LDPE plastic, Glad® Cling Wrap was used. The permeability of the LDPE plastic used in this study is 1.0-1.5 grams/100 sq. in/day at 20oC (3). The thickness of the biodegradable bag was measured using a digital

micrometer, and the thickness of the bag was found to be 56 microns. Because the thickness of the bag is 56 microns, the thickness of the biodegradable film was found to be 28 microns. The thickness of the LDPE plastic was measured using a digital micrometer and found to be 12 microns.

First, each apple was cut in half in order to accelerate the speed of apple spoilage and then using a permanent marker, each apple half was labeled with a number followed by a letter, where the number represents which of the five apples it is (1, 2, 3, 4, or 5) and the letter represents which half of the apple it is (one half of the apple is A and the other is B). The thicknesses of both plastic wraps were measured using a micrometer. The Glad® Cling Wrap was measured and torn at a length of 30 cm. One half of an apple was fully covered and wrapped in Glad® Cling wrap. The other half of the same apple was put into a BioMass® Bag in order to eliminate possible variation from apple to apple. The remaining apple halves were the control samples, and therefore did not have any packaging. There were 3 samples in each condition (and 4 for the control, as there were 10 apple halves).

A picture was taken of both the skin side and the flesh side of each apple half. Using a digital balance, the mass of each apple (including the bag/wrap) was recorded on a chart. On the following day, another picture was taken of each apple half (both sides) and the mass was recorded. Using a vegetable peeler, an extremely thin slice of each apple was sliced and placed on a slide with a cover slip to be observed (sketched and observations recorded) under a microscope. Each apple slice was then returned to each apple and each apple half was rewrapped. For the next 11 days, the process of taking a picture, recording the mass, and observing each apple half under the microscope was repeated. After the 11 days, the apples were disposed of. In the analysis, the raw data of the mass of the apple every day was first changed to the accumulated mass loss each day by calculating the difference between the current mass and the original mass. Then the mass loss was changed into the rate of mass loss by dividing the original mass by the accumulated mass loss at that day and then converting the decimal into a percentage. Microsoft Excel was used to calculate the change in the mass of the apples, to determine the average rate of accumulated mass loss, and to create graphs.

Results:

The independent variable of this experiment was the type of plastic: a generic LDPE plastic versus a biodegradable BioMass® plastic, while the dependent variable was the effectiveness of the plastic in preventing

Table 1

Apple Mass and Average Mass Loss (in grams)

		Day 0	Day 1	Day 2	Day 3	Day 4	Day 7	Day 8	Day 9	Day 10	Day 11
Control	4A	98.654	87.202	80.162	75.913	70.309	58.216	53.678	49.690	46.552	43.345
	4B	93.314	81.595	75.931	69.752	64.577	54.038	50.572	46.648	43.234	39.954
	3A	119.314	107.793	102.257	94.626	88.254	78.593	75.025	70.908	65.818	61.246
	3B	102.367	90.898	84.071	76.648	70.368	57.705	52.705	47.116	42.755	38.363
	Average Mass Loss	0.000	11.540	17.807	24.178	30.035	41.274	45.417	49.822	53.823	57.685
Glad	1A	103.522	102.823	101.673	101.935	101.849	101.538	101.241	100.759	100.349	99.946
	2A	99.031	98.752	96.421	95.902	95.647	95.133	94.598	93.849	93.629	93.038
	5A	88.521	88.359	86.404	86.047	85.936	84.623	85.796	84.038	83.742	84.085
	Average Mass Loss	0.000	0.380	2.192	2.397	2.547	3.260	3.146	4.143	4.451	4.668
Bio	1B	101.983	100.730	98.763	97.191	95.385	92.267	91.094	89.341	88.402	86.046
	2B	84.192	82.875	81.126	79.413	77.864	74.776	73.239	71.491	69.485	67.640
	5B	97.431	96.436	93.073	90.936	88.993	85.020	83.590	82.835	80.601	78.466
	Average Mass Loss	0.000	1.188	3.548	5.355	7.121	10.514	11.894	13.313	15.039	17.151

Table 1: Daily mass of each apple and average accumulated mass loss of three conditions tested (apples wrapped in Glad® plastic, apples wrapped in biodegradable plastic, and the control apples)

food spoilage (specifically measured by the average rate of accumulated mass loss). The control was an apple with no barrier, which was used to compare the results of the apples wrapped in the plastics to an apple with no barrier. The sample size was half of an apple and 3 samples in each condition (and 4 for the control, as there were 10 apple halves). The purpose of using half an apple for experiments was to accelerate the apple spoilage because the skin protects the apple from exposure to light and oxygen and thus slows its spoilage process. Multiple trials were conducted at once to make sure the conditions (temperature and air moisture) were the same and to reinforce the accuracy of the experimental results.

Two criteria were used for determining which barrier material was better in preventing food spoilage: 1) quantitative method—mass loss, measured by taking the mass of the apples daily (Table 1); and 2) qualitative method—visual observations (which includes changes in apple texture, color, and odor), measured by drawing and taking pictures of the apples. More mass loss demonstrates a poorer barrier material. When color and texture begin to change, it shows that the quality of the apples is starting to degrade, due to food spoilage because of oxidation and photodegradation.

There were 2 outliers in the data, but these outliers did not affect the data consistency too dramatically. On Day 3, Apple 1A increased in mass from the day before by 0.262 grams and on Day 8, Apple 5A increased in mass from the day before by 1.173 grams. Both the outliers were apples in LDPE.

In the analysis, the raw data of the mass of the apple every day was first changed to the accumulated mass loss each day by calculating the difference between the current mass and the original mass. Then the mass loss was changed into the rate of mass loss by dividing the original mass by the accumulated mass loss at that day and then converting the decimal into a percentage. The average rate of accumulated mass loss for each experimental group was determined (Table 2) and then plotted on a graph (Figure 1). The data shows that on average, by Day 11 (the end of the experiment), the control apples lost 56.11% of their mass, the apples in Glad® lost 4.84% of their mass, and the apples in the BioMass® bags lost 18.25% of their mass.

Furthermore, oxidation also played a role in the experiment. This starts to promote food spoilage as the original nutrient value starts to break down. For example, by Day 4 (Figure 2B), the food spoilage has even begun to occur on the apples wrapped with the generic non-biodegradable LDPE plastic and it shows that the color change occurred most severely in the apples in the control group, followed by the biodegradable and the generic groups. On Day 8 (Figure 2C), the apples are spoiling even more. At the end of the experiment, Day 11 (Figure 2D), all tested apples spoiled. Slices of the apples were also observed daily under the microscope. By Day 3, microorganisms were observed on the control

Table 2

Average Rate of Accumulated Mass Loss

	Duration (Day)								
Storage Method	Day 0 to 1	Day 0 to 2	Day 0 to 3	Day 0 to 4	Day 0 to 7	Day 0 to 8	Day 0 to 9	Day 0 to 10	Day 0 to 11
Control	11.26%	17.39%	23.53%	29.20%	40.21%	44.26%	48.55%	52.39%	56.11%
Glad	0.38%	2.27%	2.50%	2.65%	3.42%	3.25%	4.32%	4.64%	4.84%
Biodegradable	1.27%	3.76%	5.68%	7.55%	11.15%	12.63%	14.15%	16.02%	18.25%

Table 2: Comparison of calculated average of the rate of accumulated mass loss of each category of apple (apples wrapped in Glad® plastic, apples wrapped in biodegradable plastic, and the control)

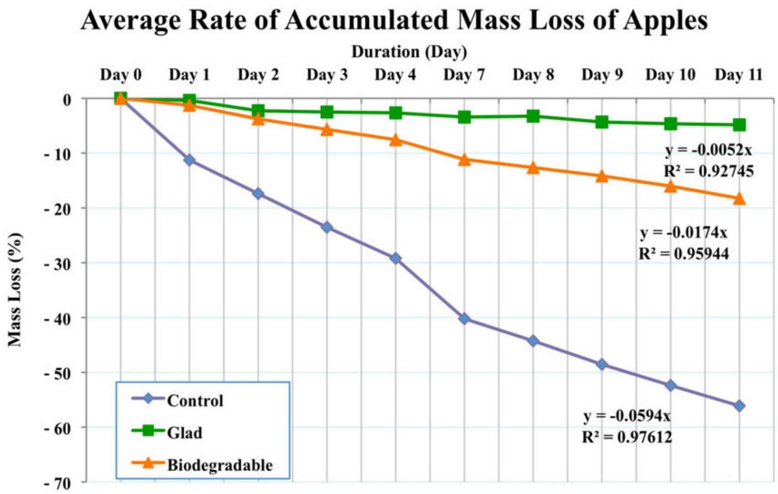

Figure 1: A plot of the average rate of accumulated mass loss with values on the plot which represent the WVTR (y, slope of best fit lines not depicted here).

apples. By Day 4, microorganisms were also observed on the apples wrapped in both Glad plastic as well as the apples wrapped in biodegradable plastic, suggesting that both plastics are similar in preventing this aspect of food spoilage.

Since the WVTR of the biodegradable plastic is unknown, an attempt to determine the water vapor permeability of the biodegradable plastics based upon the experimental data has been carried out. Since the WVTR (W) is represented by the water vapor loss (G) in a unit of time (t) through a unit area (A) of body, $W=G/(t\cdot A)$. Therefore, all plots in Figure 1 can be fit as straight lines with $G=(A\cdot W)\cdot t$; in other words, the slope of the plot is $k=(A\cdot W)$. Water vapor permeability (h) is defined as the rate of water vapor transmission through a material of thickness (d) induced by the unit vapor pressure difference (ΔP) between two specific surfaces i.e., $h=W\cdot d/\Delta P$. Therefore, the slope of the plot in the Figure 1 described above can be further presented as $k=(A\cdot W)=A\cdot h\cdot \Delta P/d$. The thickness of LDPE wrap is measured as $d1=12$ micron and the biodegradable bag has a thickness of $d2=28$ micron. In the present study, we have the same packaging area (A) and same vapor pressure ΔP, thus the permeability of the biodegradable bag (h2) can be determined from the two plot slopes displayed in Figure 1 (for Glad® $k1=-0.0052$, and biodegradable bag $k2=-0.0174$) and the known water vapor permeability value of LDPE ($h1=1.0$ grams/100 sq. in/day) (6). With $k1/k2=h1\cdot d2/h2\cdot d1$, substituting the known values of parameters gives $h2=k2\cdot d2\cdot h1/k1\cdot d1=(-0.0174 \times 28 \times 1)/(-0.0052 \times 12)=7.8$ grams/100 sq.in/day, which means that the water vapor permeability is almost 8 times higher for the biodegradable bag than the one made of LDPE. Despite the thicker film of the biodegradable bag, which can better slow water vapor loss, the much higher water permeability of the biodegradable film leads to higher water loss in the apple.

Discussion:

The study demonstrated that the generic LDPE Cling Wrap performed better than the biodegradable plastic in terms of preventing overall food spoilage. The experimental results show that by Day 11, on average, the control apples lost about 56.11% of their mass, the biodegradable apples lost about 18.25%, and the Glad® apples only lost 4.84% of their mass. This result implies that the biodegradable plastic wrapped apples lost more water than the LDPE wrapped apples because biodegradable plastics have higher water vapor transmission rates than Glad Cling Wrap and LDPE plastics (as described above). Due to the fact that the apples in the biodegradable plastic lost more mass than the apples in the generic LDPE plastic, the biodegradable plastic was not as effective of a barrier material as the generic LDPE, and therefore is not as effective in the prevention of food spoilage. However, the experimental results also show that in the short term (days 1-3), the LDPE plastic and biodegradable plastic performed very similarly, and only in the long term (days 4-11) does the LDPE plastic begin to perform better than the biodegradable plastic (Figure 1). Most consumers are likely looking for a plastic that can protect their food in the short term (1 to 3 days). As a result, biodegradable plastics can be as suitable for short-term conditions as a generic plastic, which can hopefully increase their appeal to consumers.

Secondly, the experimental observations in changes of apple color and texture also demonstrated that the generic LDPE has the better barrier property to resist the discoloration and oxidation of the food in the long term. In Figure 2, oxidation is shown to be the worst in the control apple, however it is very similar in the LDPE wrapped apple and the biodegradable plastic wrapped apple. However, by day 8, all of the apples are spoiled, displaying that though LDPE and the biodegradable plastic are very similar in preventing oxidation in the

Figure 2

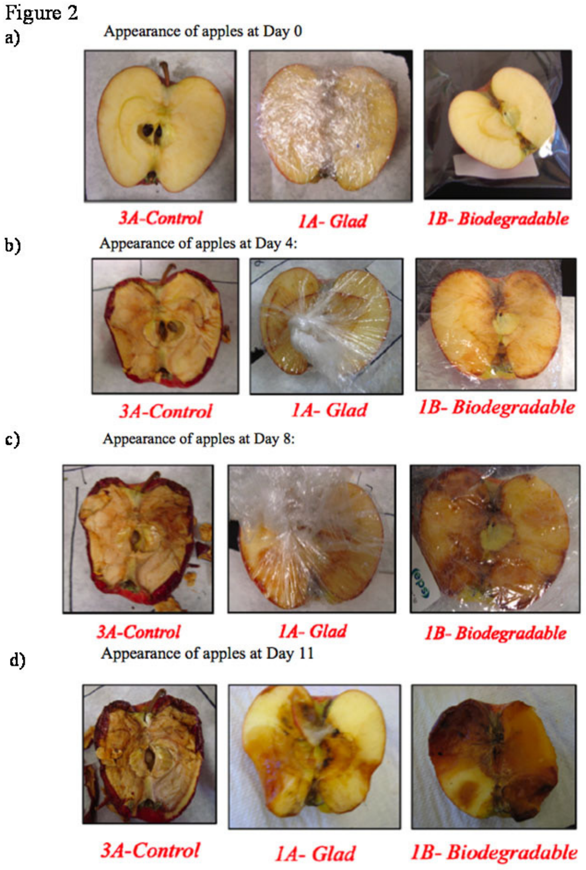

Figure 2: Pictures of the apples in the 3 testing conditions at: a) Day 0; b) Day 4; c) Day 8; d) Day 11.

short term, in the long term, oxidation affected all of the tested apples. However, although the BioMass® plastic did not prevent the passage of vapors and organic liquids through their boundaries as well as the Glad® Cling Wrap (LDPE), BioMass® does slow down the apple spoilage speed compared with the unwrapped apples, which is demonstrated in the experimental results that the control apples lost about 56.11% of their mass, while the biodegradable apples lost about 18.25%. Hence, the conclusion is that the BioMass® biodegradable plastic is not as effective as preventing food spoilage compared with non-biodegradable generic Glad® in the long term, but it is as effective as preventing food spoilage compared with a generic wrap in the short term, and can still reduce the speed of food spoilage in the long term.

The WVTR of the biodegradable bag was nearly eight times higher than that of the LDPE wrap. The WVTR calculation could be affected by other factors besides moisture loss. The mass loss, which was used in the WVTR calculation, also could have been caused by microbial degradation, the daily unwrapping of the apples, or other factors.

In summary, the experimental results show that the Glad® Cling Wrap is more effective in preventing food spoilage compared with the BioMass® Bag. However, the BioMass® Bag was still sufficient in preventing food spoilage in the short term. Hopefully, this will increase the appeal of biodegradable bags to consumers due to its ability to reduce the amount of trash in the landfill. Meanwhile, hopefully, more scientific breakthroughs in replicating the molecular structure of LDPE will allow for more effective biodegradable plastics solutions.

There are a few areas that could be further improved upon in future study. More types of plastics could be used in future studies. Another area to investigate is the influences of temperature and humidity on the permeability of LDPE and BioMass® Plastic. It is clear that there are many improvement opportunities for biodegradable plastics, specifically how to replicate the molecular structure of LDPE or using coatings in order to maximize the effectiveness in preventing food spoilage.

Acknowledgments

I would like to thank Mrs. Jill Carter for supervising my experiment. I would also like to thank Shrewsbury High School for allowing me to perform my experiment in their classrooms. Finally, I would like to thank Mr. Allen King from BioMass® Packaging for donating free samples of their PLA biodegradable plastic for my experimentation.

References

1. “Plastic 101.” Earth 911. N.p, 2010. Web. 11 Oct. 2010.
2. “Describe Why Food Spoils.” Food Safety Organization. Department of Food Science and Human Nutrition of Clemson University, n.d. Web. 1 Oct. 2010.
3. Massey, Liesel K. Permeability Properties of Plastics and Elastomers - A Guide to Packaging and Barrier Materials. Norwich, NY: William Andrews Publishing, 2003. Print.
4. Castellion, Mary. “Plastics and Other Polymers.” The New Book of Popular Science. Ed. Jerry Bennis. 2000 Edition. Vol. 6. Danbury, CT: Grolier International Inc., 1998. 201-203. Print.
5. Deacon, Jim. “Apple Rot and Other Fruit Rot Fungi.” The Microbial World. Institute of Cell and Molecular Biology. n.d. Web. 7 Jan. 2011.
6. Shogren, Randal. Water Vapor Permeability of Biodegradable Polymers. Journals of Polymers and the Environment. 5 (1997): 91-95. Print.