Modeling the Retention Rate of Water with Pineapple

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Abstract. The purpose of this experiment was to determine the effectiveness of salt as a preservative for perishable foodstuffs. Pineapple was used as the experimental unit. In order to prove the effectiveness of salt ($NaCl$), the water loss over time in the pineapple was measured as units of pineapple with varying levels of salt were left to sit in two levels of sunlight exposure over a period of 72 hours. The water loss was modeled as an interaction between the salt applied and the sunlight exposure the experimental units received. After conducting an experiment and culminating the data, we found a statistically significant effect of both salt and sunlight exposure on pineapple preservation. The most efficient combination of table salt and sunlight to optimize fruit preservation was extrapolated from this model, and was found to be the lowest level of salt applied combined with the highest level of sunlight exposure.

1. Introduction

Once exposed to air, food begins to spoil immediately. Because of this, food preservation has been around since early humans began hunting and gathering. Historians have found evidence of food preservation dating as far back as 12,000 B.C. [1]. It is a crucial development in how we were able to spend our time and expend our energy more efficiently. Now, with the implementation of food preservation, we can store our fruits, vegetables, and meat in a pantry for extended periods of time. Food preservation was soon globalized. No longer would ancient humans have to eat their meal immediately after harvesting or killing. This allowed humans to progress from a nomadic lifestyle to a more stationary one. They could settle in one place and form large communities, all the while building up a food surplus. Food preservation acted as a catalyst for human technological progress, pulling our species out of the stone age into modern society.

Food preservation hasn't changed much since its inception. Preservation methods include: curing, freezing, smoking pickling, jellying, canning, and more. In colder climates, humans froze their food by submerging it in snow, ice, cellars, caves, and cold water if the temperature was low enough. Eventually, humans grew smarter and built huts, or "ice houses" full of ice blocks, away from sunlight [3]. As time went on and technology advanced, we continued to innovate new ways to keep food. In the mid 1800s, the household refrigerator was invented by James Harrison [4]. This invention, as you know, has transformed the food business.

In warmer regions, people utilize the sun's heat and warm breeze to desiccate their meat and produce. The act of drying food with the intent to preserve it is often referred to as "curing." Fire pits, or "smoke houses," and salt were also used to dry out food, (e.g., fish, fruit, vegetables, game, etc.). The introduction of salts become very popular among the masses because of its beneficial effects on meat and poultry. Different kinds of salts, (e.g., sea salt, rock salt, kosher salt, spiced salt, etc.) have varying effects on odor, flavor, and color. Meat often turned a darkish green if salt wasn't added to preserve it. Also, salt was incredibly affordable, accessible, and abundant. It can be found in every corner of the world, and harvested with ease. Salt can be extracted from oceans and salt lakes, or mined from ancient underground sea beds that have dried up, leaving it ingrained in the rock [2]. Salt plays such a large role in modern society's food industry. Because of this, there has been a growing number of research in finding new ways to increase the longevity of foodstuffs' shelf life.

A team of scientists recently published an article discussing benefits of applying edible nanosystem coatings (i.e. nanoparticles, nanocomposites, and nanotubes) on nutriments [6]. In their studies, they found that utilizing nanotechnology can enhance shelf life while maintaining the natural freshness of produce; all the while acting as an environmentally friendly preservation agent. Another research project was conducted that utilized pressurized temperature-controlled chambers, similar to refrigerators, to regulate the effects of food storage. Instead of measuring the weight of each produce, (in this case whey cheese), to model water loss, the scientists measured a myriad of components including: yeast, mold, aerobic mesophiles, enterobacteriaceae, and lactic acid [7]. From this, we can see that having a more specific understanding of preservation techniques can be greatly beneficial to businesses and people all over the world.

2. Methods

2.1 Question. In modeling the effect salt and sunlight have on the water retention of pineapple, we are able to better understand and optimize food preservation techniques. With this research, we can maximize the shelf life of food and minimize the salt used. This, in turn, will prevent food waste, and thus save money. We will be able to find how much salt is needed to preserve a given amount of food the longest. This determines the supply for the salt miners, and demand for the food storage and transportation companies. Of course, all this is relevant information for public health reasons. Organizations such as the Food and Drug Administration (FDA) can use our findings to establish regulations and prevent foodborne illnesses [5]. Because we want to minimize food waste, it makes sense to always want to maximize a food's shelf life. Hence, we only care about the optimal combination of treatments, (salt and sunlight). What is the effect of salt on pineapple? What is the effect of sunlight on pineapple? What is the optimal combination of salt and sunlight to maximize the duration of pineapple shelf life? What is the most cost effective combination of salt and sunlight to maximize the duration of pineapple shelf life?

2.2 Hypothesis. The goal is to desiccate the pineapple. Drying out the fruit and extracting all the water from it will allow for a much longer edible time span than if it were allowed to retain the water. From this, we predict that sunlight will have a significant effect on the rate of water loss of pineapple. Sunlight drastically increases evaporation. Hence, the more sunlight exposure, the less water retained. We predict salt to act in a very similar manner. The salt ($NaCl$) will draw out the water (H_2O), leaving less water in the pineapple. This, we expect, will draw more water out towards the surface, allowing the sunlight to have a greater effect (see Figures 9 & 10). Thus, we believe the combination of high sunlight exposure and high salt will maximize shelf life.

2.3 Experimental Method. This experiment tests the effectiveness of salt and sunlight in the preservation of pineapples. To execute the experiment, two pineapples must be diced in such a way that 30 pieces of pineapple are produced with dimensions 2 in x 2 in x 0.25 in. Each piece of pineapple is weighed after being lightly dabbed with a paper towel, then the pineapples are randomly assigned a treatment. To do so, use a random number generator (range of values from 1-30) to randomly assign each piece a number from 1 to 30, where the first 15 slices are given the full sun exposure treatment and the last 15 are given the no exposure treatment. Next, for the salt treatments, use a random number generator to generate numbers 1, 2, and 3 (which correlate to the amount of salt in treatments). Go through the first 15 pieces of pineapple with the random number generator until you have assigned 5 pieces to each number, and repeat this step for the last 15 pieces. Once the treatments are assigned, apply corresponding levels of salt to the pineapple squares. Pack the salt around each piece to encapsulate them entirely by the salt. After the salt treatments are applied to all 30 pieces of pineapple, place the full exposure group in front of a window where sunlight is concentrated, and the no exposure group in an area with no sunlight. Every 12 hours ,(9am. and 9pm.), weigh each bowl and record the data. After exactly 3 days, take the final measurements and discard the materials. We will assume the following: perfect sunlight for 12 hours each day, perfect measurements were taken, constant temperature throughout the duration of the experiment. Pictures of the experimental setup are provided below.

Figure 1. (left) Sunlight-exposed pineapple slices were placed on top of a desk beside a window. (middle) The pineapples randomly selected to be hidden from sunlight were placed inside a dresser drawer. (right) An example of how we recorded weight measurements every 12 hours.

2.4 Model. The way we set up our experiment resulted in a relatively simple model. We knew precisely how much salt that would be added, and assumed perfectly constant sunlight over each time period, for whichever treatment. We also knew with certainty that water would be the only output leaving the pineapple and the system (through evaporation). Thus, we obtain the following diagrammatic model:

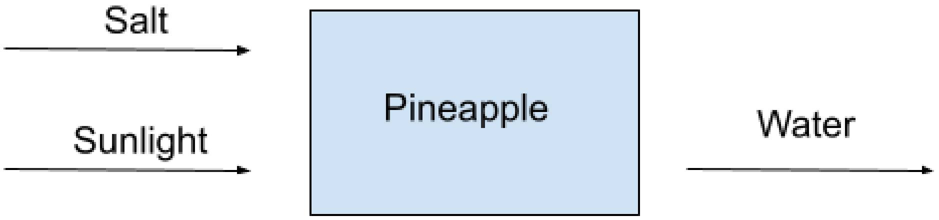

Figure 2. Shows the diagrammatic model used throughout the research. This depicts the two inputs (salt & sunlight), and the one output (water) of the pineapple.

2.5 Analytics. The data collected bests fits an exponential decay model. This makes sense when you consider the properties of evaporation. The more water that is in the pineapple, the more water that will be evaporated. As time increases, the less water there is; hence, the less water that will be available to evaporate. Such characteristics follow that of an exponential decay function, (shown below).

$$W = W_0 e^{-k_i t} \quad where\ i\ represents\ extreme\ treatments \tag{1}$$

$$\Rightarrow k_i = \frac{-ln(W)}{tW_0} \tag{2}$$

$$k_{natural} = 0.0095177445 \quad \text{(1 tbsp. \& no sun)}$$

$$k_{salt} = 0.0048494541 \quad \text{(3 tbsp. \& no sun)}$$

$$k_{sunlight} = 0.062963472 \quad \text{(1 tbsp. \& sun)}$$

$$k_{2tbsp} = 0.0032290382 \quad \text{(2 tbsp \& no sun)}$$

Sun + 1 tbsp. Salt: $\frac{dW}{dt} = -W[(k_{natural} + k_{salt} + k_{sunlight}) + k_{sunlight}]$

Sun + 2 tbsp. Salt:

$$\frac{dW}{dt} = -W[(k_{natural} + k_{salt} + k_{sunlight}) + k_{2tbsp} + k_{sunlight}]$$

Sun + 3 tbsp. Salt:

$$\frac{dW}{dt} = -W[(k_{natural} + k_{salt} + k_{sunlight}) + k_{salt} + k_{sunlight}]$$

No Sun + 1 tbsp. Salt: $\frac{dW}{dt} = -W(k_{natural} + k_{salt} + k_{sunlight})$

No Sun + 2 tbsp. Salt: $\frac{dW}{dt} = -W[(k_{natural} + k_{salt} + k_{sunlight}) + k_{2tbsp}]$

No Sun + 3 tbsp. Salt: $\frac{dW}{dt} = -W[(k_{natural} + k_{salt} + k_{sunlight}) + k_{salt}]$

To find the effect of each treatment, we found modeling the extremes provided us with a more useful perspective. This process is shown in the above formulations. Each k_i represents an extreme, (specified above). By taking the natural log of our generic equation (1), and solving for k_i, we were able to obtain each value for the extremities. Then, we determined a k_{2tbsp} corresponding to the data from the pineapples with no sunlight exposure and 2 tbsp. of salt applied. With these k values , we were able to formulate differential equations for each of the six treatment groups.

3. Results

3.1 Final Experiment Data

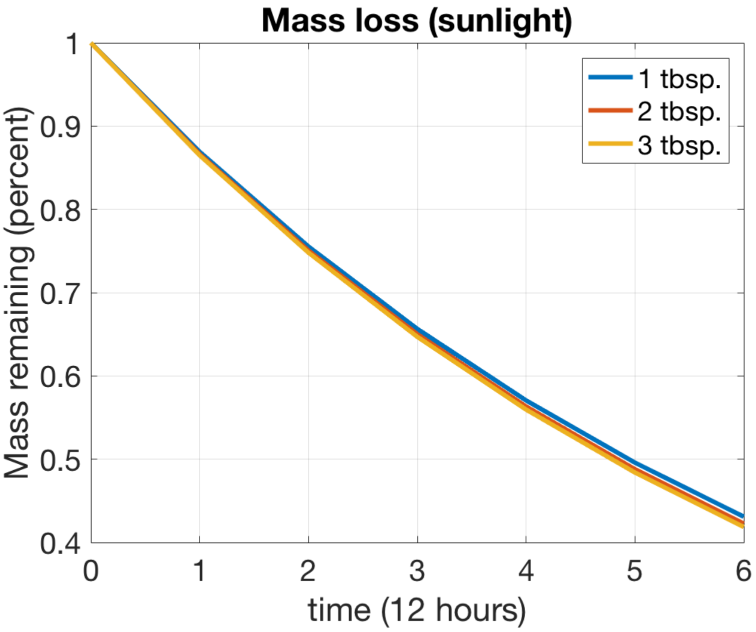

Figure 3. The average proportion of mass remaining of the pineapples exposed to sunlight. Each line represents one of the three salt treatments applied.

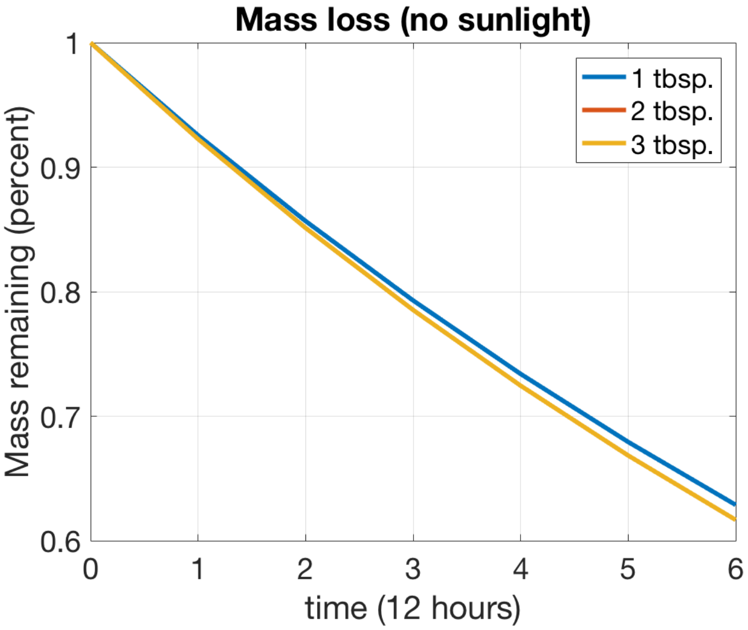

Figure 4. The average proportion of mass remaining of the pineapples not exposed to sunlight. Each line represents one of the three salt treatments applied.

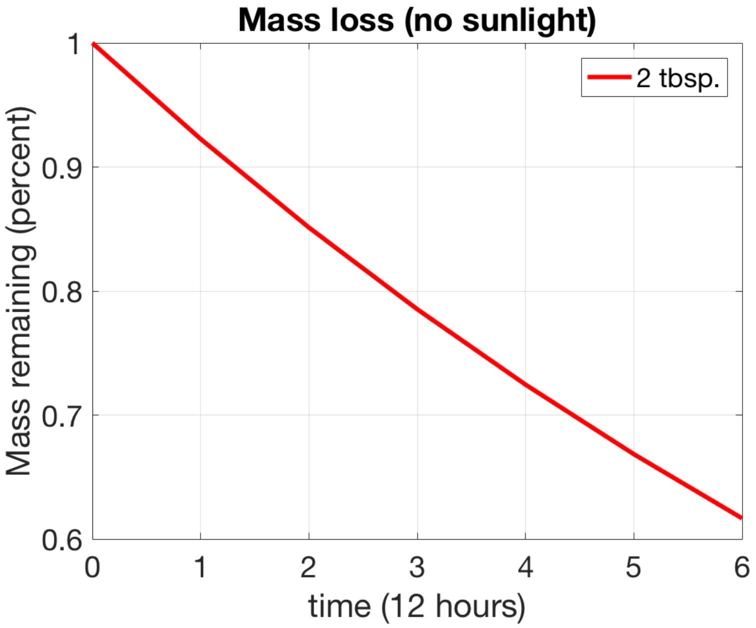

Figure 5. The average proportion of mass remaining of the pineapples not exposed to sunlight, and received the 2 tbsp salt treatment. It is difficult to see in Figure 3, so it was presented in its own graph as well.

	9 am day 1	9 pm day 1	9 am day 2	9 pm day 2	9 am day 3	9 pm day 3
Sunlight & 1 tbsp.	91.74%	85.32%	82.57%	79.82%	78.44%	77.06%
Sunlight & 2 tbsp.	93.09%	87.83%	86.18%	83.88%	81.91%	81.58%
Sunlight & 3 tbsp.	96.05%	93.68%	91.58%	90.00%	88.42%	88.16%
No sunlight & 1 tbsp.	99.13%	98.26%	97.39%	95.65%	94.78%	94.78%
No sunlight & 2 tbsp.	100.00%	99.36%	99.04%	98.39%	97.75%	97.43%
No sunlight & 3 tbsp.	99.74%	98.96%	98.18%	98.18%	97.40%	96.88%

Table 1. The average mass remaining for all 6 treatments per 12 hours. The initial mass was 100% at 9 pm day 0, and the final mass is seen at 9 pm day 3.

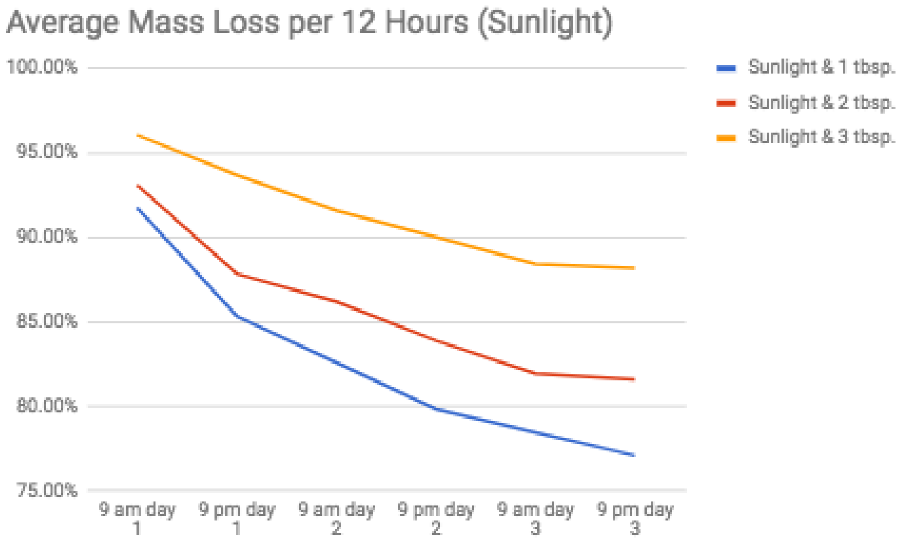

Figure 6. Graph corresponding to the first three (sunlight) rows of Table 1. The x-axis is time (6 x 12 hour periods), the y-axis is mass remaining, and the three functions correspond to the three salt treatments.

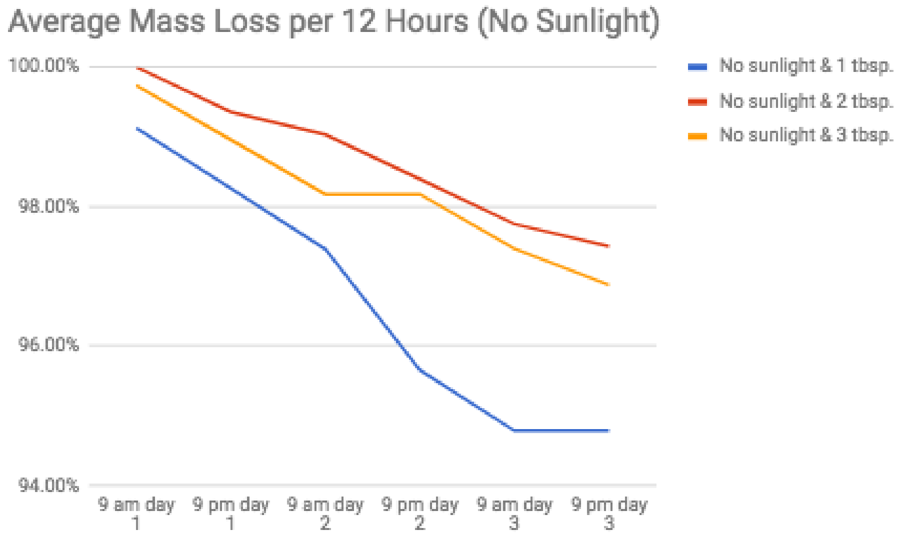

Figure 7. Graph corresponding to the last three (no sunlight) rows of Table 1. The x-axis is time (6 x 12 hour periods), the y-axis is mass remaining, and the three functions correspond to the three salt treatments.

Source	**SS**	**DF**	**MS**	**F**	**p-value**
Sunlight Exposure	0.147	1	0.147	490	0.00000000000
Salt Amount	0.019246666	2	0.00962333333	32.077777778	0.00000016578
Interaction	0.01154	2	0.00577	19.233333333	0.00001034558
Error	0.0072	24	0.0003	-	-
Total	0.184986667	29	-	-	-

Table 2. Full model analysis of variance (ANOVA) table. The p-values are less than 0.01, which indicates statistically significant effects and a statistically significant interaction between the effects.

Sunlight Exposure	**1 tbsp**	**2 tbsp**	**3 tbsp**	$y_{i\cdot}$	a_i
Full Exposure	23%	18%	12%	18%	7%
No Exposure	5%	3%	3%	4%	-7%
$y_{\cdot j}$	14%	11%	8%	11%	-
b_j	3%	0%	-3%	-	-

Table 3. Shows the average deviation of each treatment from the averaged effects. This table was mostly used to derive Table 2.

3.2 (Failed) First Attempt Data. This data is from our first attempt at the experiment. The mass of the pineapples was weighed at the beginning and end of the 3 day period only. The salt was removed from the pineapples before recording the final mass. This data is referenced in the discussion, but is not part of our model because two time periods is not enough data to determine a differential function modeling the rate of water loss.

3.2.1 Sunlight

Bowl / pineapple #	Starting mass (g)	Treatment (tbsp)	Ending mass (g)	Change in mass (g)
1	29	4	14	-15
2	36	3	20	-16
3	27	2	17	-10
4	35	2	23	-12
5	30	3	17	-13
6	28	2	18	-10
7	32	2	22	-10
8	31	3	18	-13
9	35	4	18	-17
10	28	4	15	-13
11	32	3	17	-15
12	38	4	21	-17

Table 4. Shows the data resulting from our first attempt at the experiment. Unlike the second attempt, only the initial and final masses of each pineapple were recorded. This table is for the bowls receiving the sunlight treatment.

3.2.2 No sunlight

Bowl / pineapple #	Starting mass (g)	Treatment (tbsp)	Ending mass (g)	Change in mass (g)
13	36	4	19	-17
14	30	2	18	-12
15	32	4	19	-13
16	31	3	19	-12
17	36	3	24	-12
18	32	4	18	-14
19	32	2	22	-10
20	30	2	19	-11
21	33	3	19	-14
22	36	4	22	-14
23	30	2	18	-12
24	32	3	18	-14

Table 5. Shows the data resulting from our first attempt at the experiment. Unlike the second attempt, only the initial and final masses of each pineapple were recorded. This table is for the bowls receiving ‘no sunlight’ treatment.

3.2.3 Table averages

	Initial mass	Final mass	Change in mass
Sunlight + 2 tbsp.	30.5	20	-10.5
Sunlight + 3 tbsp.	31.75	20	-14.25
Sunlight + 4 tbsp.	30.75	18.75	-15.5
No sunlight + 2 tbsp.	30.5	20	-11.25
No sunlight + 3 tbsp.	33	20	-13
No sunlight + 4 tbsp.	34	18.75	-14.5

Table 6. The averages of the 4 replicates for each treatment for our first attempt at the experiment.

3.2.4 Change in mass

	2 tbsp.	3 tbsp.	4 tbsp.
Sunlight	-10.5	-14.25	-15.5
No sunlight	-11.25	-13	-14.5

Table 7. The average changes in mass for each treatment for our first attempt at the experiment (taken from Table 6).

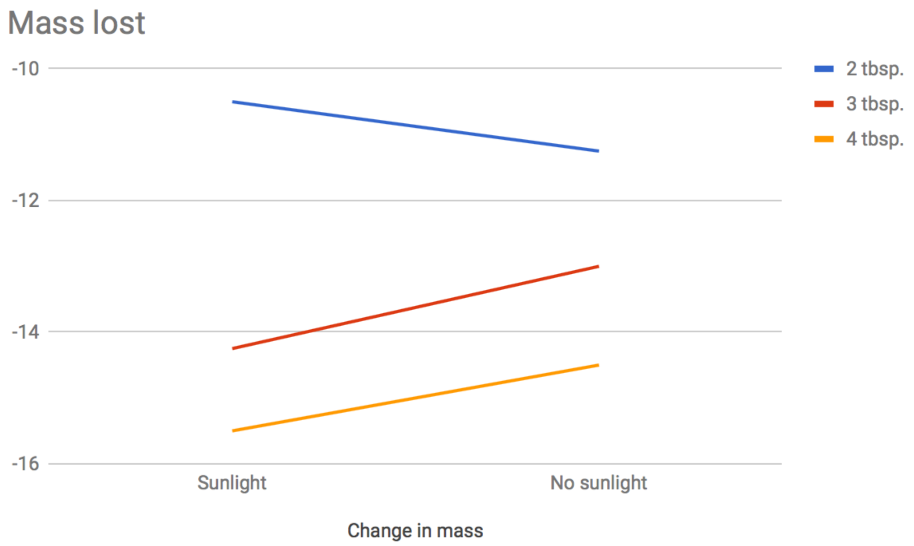

Figure 8. The graph corresponding to Table 7, showing the average changes in mass for each treatment for our first attempt at the experiment.

4. Discussion

Our hypothesis regarding sunlight exposure was proven to be true. By comparing Figure 3 with Figure 4, we can see that the pineapples that were exposed to sunlight lost significantly more mass over time than the ones that were not exposed to sun. Looking closer at Figure 3, the pineapples, when exposed to sunlight, experienced an inverse relationship between water loss and salt applied. This means that the effect of adding more salt to pineapples actually prevented more water from evaporating. Looking at Figure 4, the effect of adding more salt to the pineapples not exposed to sunlight is less clear. The effect appears to be similar to that observed in Figure 3, but the 2 tbsp. and 3 tbsp. lines have notably traded places. Although it is possible some strange interaction is occurring with moderate levels of salt, we determined that experimental or precision error are more likely to explain this change. The scale we used to weigh the pineapples was accurate only to the nearest gram, giving us only two significant digits. This, combined with the small y-scale (when compared to the scale in Figure 3) in Figure 4, makes small errors and changes in mass more noticeable, and seem bigger than they really are. Assuming that the switching of position between the 2 and 3 tbsp. lines in Figure 4 are due to error, the effect of adding salt observed in both Figure 3 and Figure 4 is the opposite of what we predicted.

To explain what might have caused this, we compared our data for the experiment to our data from our first attempt. For our first attempt at the experiment, the results confirmed both of our hypotheses, as can be seen in Figure 8. For the second attempt, only the sunlight hypothesis was confirmed, while the salt hypothesis was proven false. So, we determined that the change in the results must have been a result of a change we made in the experimental design. In the first experiment, we diligently brushed the salt off of the pineapples, and then weighed the dried out pineapple squares individually at the end of the experiment, and we weighed the pineapple squares by themselves at the beginning of the experiment. The values we recorded gave us our initial and final masses. In our second attempt, we weighed the combined system of pineapple, salt, and bowl for each of the 30 experimental units, and then weighed the complete system every 12 hours for 3 days.

Initially, we thought that changing the experimental procedure in this way would not affect the results. However, upon reflection, this difference in procedure created a fundamental difference in the experiment. In the second experiment, the change in mass we recorded could only be attributed to the amount of water that evaporated since the salt stayed in the system. When we removed the salt at the end of the first experiment, it had caked together around the pineapple. It was not stuck to the pineapple, but had formed a kind of rigid dome around it. For this to happen, we believe that a significant mass of water had become trapped between the salt crystals, so when we removed the salt, the water that had been drawn out by the salt but had not evaporated was removed as well, and factored into the change in mass values. If we had removed the salt, we might have actually found that more water was lost for higher amounts of salt added, as we observed in our original data in Figure 8. As for the effect of adding salt lowering the rate of evaporation, we believe that the salt prevents water from evaporating from the pineapple from direct exposure by acting as a barrier to the sunlight. When we removed the salt in the first experiment, the outside of the dome was hard and dry, but the side that was closer to the pineapple and not exposed to the sun was more damp and pliable. While the salt did draw water out of the pineapple, not all of it was made to be directly exposed to the sun, so the water that remained beneath the outside layer of salt never evaporated.

We also note that we made sunlight a binary variable, with only two levels: ‘sunlight’ and ‘no sunlight’. Obviously, the sunlight intensity varies throughout the day and night, but we tried to minimize the effect of this by recording every 12 hours, around sunrise and sunset. Still, the pineapples exposed to sunlight were only exposed around half of the time (during the day), and you can see their behavior is similar to the ‘no sunlight’ pineapples during the 12 hour night time period. This effect is especially notable in the yellow and red lines of Figure 6. During the night time periods, the slopes (rate of water loss) decrease, and increase again during the daytime period.

We could not fit a singular model to describe the behavior of pineapples when treated with varying levels of salt and sunlight, because the salt and sunlight levels do not change over time, while the water levels did. Our solution was to simply fit a line comparing water loss over time for each treatment, and to identify the treatment that experienced the highest rate of water loss. However, we did develop a system of 6 differential equations, one modeling each treatment. From examining the data, we determined that it resembled experimental decay, and the solved functions can be seen in Figures 3, 4, and 5. These graphs tell a similar story to Figures 6 and 7. Another change that would improve our model would be if we created a control group of pineapples that were exposed to zero salt and no sunlight, and a group with zero salt and full sunlight. This would improve our accuracy for $k_{natural}$ and $k_{sunlight}$. Since we did not do that, our best option was to use the data from the 1 tbsp. and ‘no sun’ group for $k_{natural}$and the 1 tbsp. and ‘sun’ group for$k_{sunlight}$.

Our conclusions from the two experiments are that more water is drawn out of the pineapple for larger amounts of salt applied, but less water is lost from evaporation. Therefore, the effectiveness of sunlight for drying out the pineapples diminishes for larger amounts of salt applied. Conversely, more salt draws out more water from the pineapples. Since our experimental design was inherently flawed, we found the ideal treatment to be the lowest amount of salt and the highest amount of sunlight. If we had weighed the pineapples after taking off the salt for the second experiment as we had done in the first, we might have found that there is an optimal combination of salt and sunlight. It is also possible that only applying salt might be the most time-efficient treatment, without bothering with sunlight at all. Sunlight is free, however, and salt is not, so depending on the circumstances it may be a better choice to use sunlight. Also, salt may be a good choice for preserving meats, but very salty fruit is not desirable. While salting grapes may turn them into raisins faster, they would be unbearably salty so sunlight would be the better option.

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Appendix

Bowl / pineapple #	Starting mass of bowl + salt (g)	Starting mass of pineapple (g)	Total mass initial (g)	Total mass 9 am day 1 (g)	Total mass 9 pm day 1 (g)	Total mass 9 am day 2 (g)	Total mass 9 pm day 2 (g)	Total mass 9 am day 3 (g)	Total mass 9 pm day 3 (g)	Change in mass (g)	Salt level (tbsp)	Sun / no sun
1	46	17	63	59	56	55	53	53	53	-10	2	sun
2	44	14	58	53	50	49	49	48	47	-11	2	sun
3	43	19	62	57	54	52	51	50	50	-12	2	sun
4	45	17	62	57	54	53	51	50	50	-12	2	sun
5	46	13	59	57	53	53	51	48	48	-11	2	sun
6	46	13	59	59	59	59	59	59	58	-1	2	no sun
7	46	24	70	70	70	69	69	68	68	-2	2	no sun
8	46	18	64	64	63	63	63	62	62	-2	2	no sun
9	41	21	62	62	62	62	61	61	61	-1	2	no sun
10	44	12	56	56	55	55	54	54	54	-6	2	no sun
11	61	15	76	72	70	68	67	66	66	-10	3	sun
12	61	13	74	71	69	68	67	66	66	-8	3	sun
13	57	17	74	69	67	66	65	64	64	-10	3	sun
14	62	14	76	73	71	70	69	68	68	-8	3	sun
15	61	19	80	80	79	76	74	72	71	-9	3	sun
16	61	16	77	77	77	76	76	75	75	-2	3	no sun
17	59	15	74	74	74	73	73	73	72	-2	3	no sun
18	58	19	77	77	76	75	75	75	74	-3	3	no sun
19	59	19	78	77	76	76	76	75	75	-3	3	no sun
20	59	19	78	78	77	77	77	76	76	-2	3	no sun
21	26	14	40	38	35	34	33	32	32	-8	1	sun
22	27	16	43	39	37	35	35	34	34	-9	1	sun
23	28	11	39	36	34	33	32	32	31	-8	1	sun
24	28	20	48	44	40	39	37	36	35	-13	1	sun
25	31	17	48	43	40	39	37	37	36	-12	1	sun
26	29	18	47	47	46	45	45	44	44	-3	1	no sun
27	27	24	51	51	51	51	50	49	49	-2	1	no sun
28	30	17	47	45	45	45	44	44	44	-6	1	no sun
29	28	14	42	42	41	40	39	39	39	-3	1	no sun
30	26	17	43	43	43	43	42	42	42	-1	1	no sun

Table 8. Data collected during the experiment. A total of 180 data points were recorded.

$$\frac{dw}{dt} = -(\alpha)(su)(t) - (\beta)(sa)(t)$$

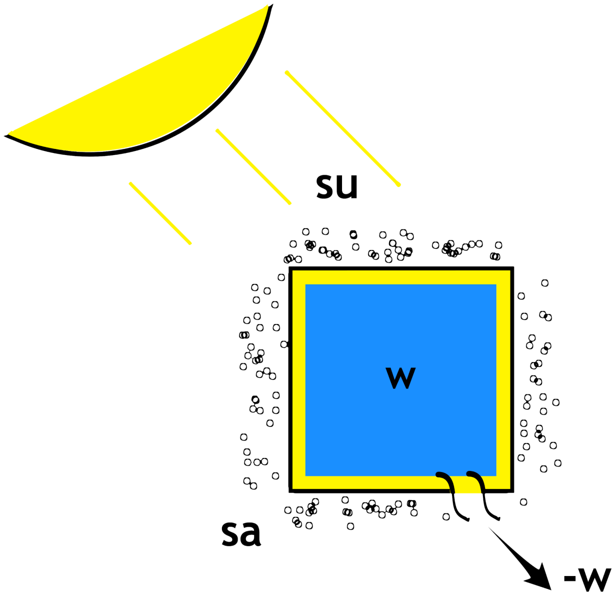

Figure 9. Basic overview of the experimental design.

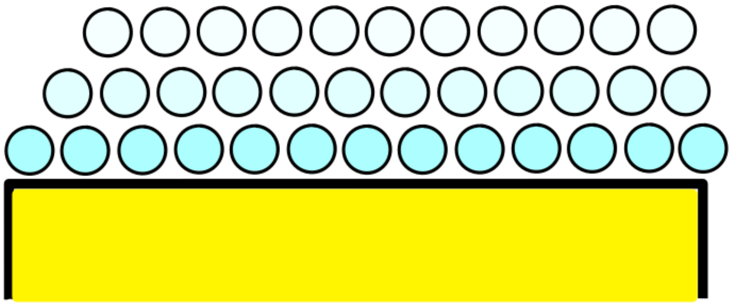

Figure 10. Basic representation of how we hypothesized the salt, sunlight, and water would interact. Water is continuously drawn from the pineapple with more salt added.