Investigating Osmosis: Effect of Salt Concentration on Osmosis in Cucumber Cells

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ABSTRACT

The phenomenon of osmosis causing water to travel across selectively permeable barriers in order to balance solute concentrations across barriers is an important feature in biological environments (Lodish, Berk, & Zipursky, 2000). The objective of the lab was to determine how different molar concentrations of salt solutions containing cucumber slices will affect the amount of osmosis occurring between cucumber cells and their surrounding environment. We hypothesized that if there is a higher concentration of salt solution inside the cell, then the mass of the cucumber will decrease because the salt concentration in the surrounding environment is greater than the salt concentration within the cell, causing water to flow out of the cell via osmosis. The experiment was conducted by placing slices of cucumber in water in 0.0M, 0.25M, 0.50M, 0.75M, and 1.0M salt concentrations and calculating the percent change in mass for use in statistical analysis. One-way ANOVA was performed and yielded a statistically significant p-value less than 0.0001, which allowed us to reject the null hypothesis. This indicates that as salt concentration increases, the mass of the cucumbers decreases as a result.

INTRODUCTION

Osmosis, a phenomenon that commonly occurs in biological systems, is the spontaneous net movement of molecules through a selectively permeable membrane within a solvent in a direction that equalizes the solute concentrations on the two sides of the membrane (Lodish, Berk, & Zipursky, 2000). It is a key process in the movement of molecules across a biological membrane as it enables the movement of small, non-polar, and hydrophobic molecules to move across the cell while being impermeable to large and polar molecules, which has important implications in several major processes in living organisms such as the maintenance of turgor pressure in plants

(Lodish, Berk, & Zipursky, 2000). This phenomenon can be observed by placing cells into hypertonic, hypotonic, and isotonic solutions and observing which cells shrink, swell, or remain the same size. A hypertonic solution is defined as a solution where the solute concentration is greater than the cell's solute concentration (*Tonicity*, 2020). Similarly, a hypotonic solution would have a lesser solute concentration relative to the cell's concentration, and an isotonic solution would have an equal solute concentration between the solution and the cell, resulting in no net movement of molecules between the membrane (*Tonicity*, 2020). The shrinking or swelling of the cell indicates the direction to which water is moving relative to the cell to equalize the solute concentrations between the cell and the solution.

Unlike animal cells which are only surrounded by a plasma membrane, plant cells are surrounded by a rigid cell wall in addition to their plasma membrane which limits the amount of osmotic influx of water into the cell to prevent it from lysing (Houston et. al, 2016). The osmotic influx of water into the plant cell depending on the solution concentration has special consequences in the maintenance of cellular turgidity that supports the plant and helps to keep it upright (Houston et. al, 2016). In order to better understand the processes that underlie osmosis between plant cells and their environment, we will be determining the effect of osmosis on cucumber cells. This will be accomplished by determining the effect of 0.25M, 0.50M, 0.75M, and 1.0M salt solute concentrations on the percent change of cucumber mass. We hypothesized that if the concentration of salt in the water is increased, then the mass of cucumber will decrease, indicating that osmosis is occurring in a direction to equalize solute concentrations between the solution and the cucumber cells. Through this experiment, we will be able to get an increased understanding of the osmotic processes that underlie the maintenance of turgor pressure in plants, which has crucial implications for plant growth and transpiration.

METHODS

5 cups of salt solutions were pre-mixed (0 M, 0.25 M, 0.50 M, 0.75 M, 1.0 M). To prepare the 0.25M salt solution, we added 1.46 grams of table salt to 100 mL of water. This process was repeated with 2.92 grams of table salt to make the 0.50M sucrose solution, a second time by adding 4.38 grams of table salt to make 0.75M salt solution, and a third time by adding 5.84 grams of table salt to make the 1.0M salt solution. 100 mL tap water was designated the 0M salt solution. The pre-mixing process was repeated two more times so we had a total of fifteen solutions with three replicates per treatment (see Figure 1).

We cut one cucumber into fifteen equal parts. Each slice was trimmed until each had the same approximate surface area and volume in grams then blotted dry with a paper towel. We then weighed each slice and recorded the initial mass in the data table as well as any additional qualitative observations. Cucumber slices were placed into each of the cups and the slices were left in the cups for 24 hours. After 24 hours, we removed them from the cups and rolled each slice on a paper towel in order to ensure excess moisture was removed from the surface of the cucumber. Each cucumber slice was weighed and the mass was recorded in the “Final Mass” column of the data table (see Appendix: Data Table 1) along with any additional qualitative observations or changes that had been observed.

The percent change in mass (±%) was calculated from the data to determine how much osmosis occurred in the 24 hour time period for further statistical analysis. These values indicated how much water was lost or gained as a result of osmosis throughout the course of the experiment. A one-way ANOVA test was then conducted to determine if the experiment results were significant. The assumptions of ANOVA were checked with QQ plot and histogram visualization, which confirmed that the assumptions were not violated. As the ANOVA results were statistically significant, a post hoc Tukey test was also carried out.

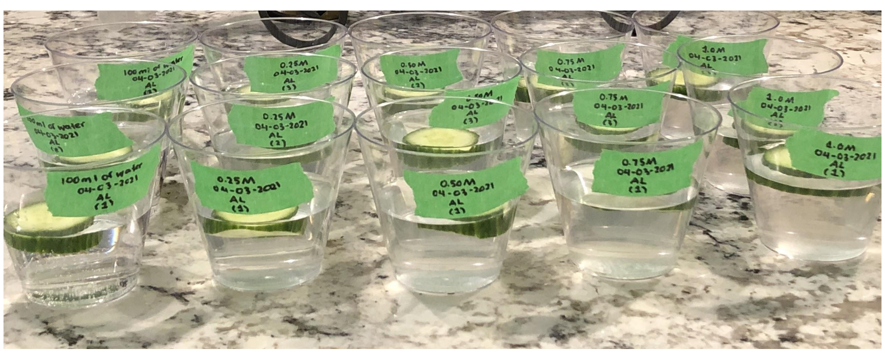

Figure 1: Experimental setup.

RESULTS

Figure 2: Cucumber slices soaked in a 1.0 M salt solution (left) and 0 M salt solution (right) after 24 hours.

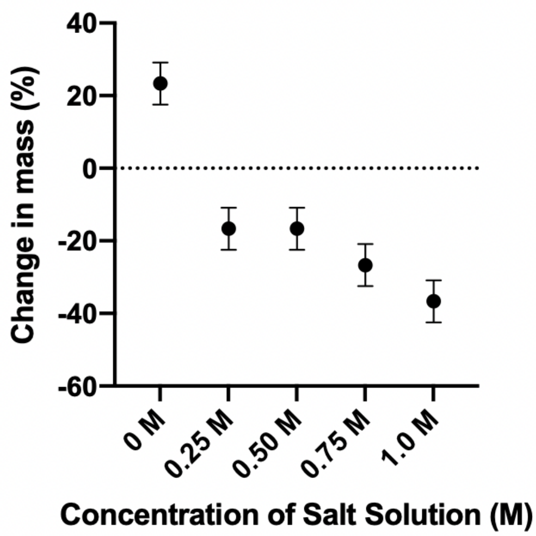

Figure 3: The mean change in cucumber mass decreases with increased salt concentrations. Points indicate the mean change in mass (±%) of cucumber slices in response to salt treatments of 0 M (n=3), 0.25 M (n=3), 0.50 M (n=3), 0.75 M (n=3) and 1.0 M (n=3). Errors bars indicate standard deviation. One-way ANOVA and Tukey statistical analysis on the data was performed. $p < 0.0001$.

Taking the results of the experiment, one-way ANOVA analysis ($\alpha = 0.05$, 95% CI) was performed using Graphpad Prism V.9.0 which showed that the average percent changes in cucumber mass are statistically different ($df_{treatment} = 4$, $df_{residual} = 10$, $F_{4,10} = 43.70$, $p < 0.001$). The mean percent changes in mass for each were found to be: +23.33% (SD = 5.77, 0M), -16.66% (SD = 5.77, 0.25M), -16.66% (SD = 5.77, 0.50M), -26.66% (SD = 5.77, 0.75M), and -36.66% (SD = 5.77, 1.0M). The data was normal and required no transformations, and ANOVA assumptions were not violated. A Tukey Test was also performed in order to determine significance between groups. The test showed that the comparisons between 0M and 0.25M, 0M and 0.50M, 0M and 0.75M, 0M and 1.0M, 0.25M and 1.0M, and 0.50M and 1.0M were significantly different. Standard deviations in the data are indicated by the error bars.

DISCUSSION

The goal of this paper was to determine the effect of different solute concentrations on osmosis in plant cells. With the assumptions that all salt solutions were correctly measured and made and that the cucumber slices were equal in surface area and volume, we found that the calculated percent changes in mass for each salt concentration were found to be non-zero percentages, which indicated that osmosis was occurring between the salt solutions and the cucumber slices. The p-value ($p < 0.0001$) obtained from one-way ANOVA analysis indicated that our results were statistically significant. This allows us to reject the null hypothesis that changing the concentration of salt in a solution will not affect the percent change in the mass of cucumber slices.

The results of our experiment demonstrate that the percent change in mass of the cucumber slices decreases as the salt concentration of the solution increased as seen in Figure 3, indicating that an inverse relationship exists between the percent change in mass of the cucumber and the concentration of the salt solution. This supports our hypothesis that if the concentration of the salt solution increases, then the change in mass of the cucumber slices decreases. When cucumber slices were soaked in a 0M salt solution, there was a positive increase in percent change of mass, indicating that the cucumber swelled as a result of the influx of water into the cucumber cells. This implies that the 0M salt solution is hypotonic with respect to the cucumber cells as water from the solution moves into the cells to decrease the solute concentration inside the cell to equalize the two sides, causing the plant cells to swell and become turgid. However, in the 0.25M, 0.50M, 0.75M, and 1.0M salt solutions, the percent changes of mass were negative which indicates that the cucumber shrunk due to osmosis driving water out of the cell in order to balance the solute concentrations between the cucumber cells and their external environment. Likewise, this implies that these salt concentrations are all hypertonic with respect to the cucumber cell as water moves out of the cell in an attempt to decrease the solution concentration. These results align with previous studies which show that water tends to move towards the direction that equalizes the solute concentrations on the two sides of the semi-permeable membrane in the process of osmosis (Lodish, Berk, & Zipursky, 2000; Minkov, 2013). Through these observations, we are also able to infer that an isotonic point exists between 0M and 0.25M at around 0.15M. Here, the salt solution concentration is isotonic to the cucumber cells, so there is no net movement of water and thus no change in the size of the cells.

One experimental error that could have potentially impacted the results of the experiment was the use of imprecise equipment. Trials were completed with kitchen scales that reported to the nearest gram such that the amount of salt added to each replicant varied slightly, which may have caused the level of osmosis to vary during the 24 hour period. In order to make sure the masses of cucumber and salt are consistent with one another, a kitchen scale with higher precision would be more ideal as it would allow for more exact measurements. Furthermore, experimental errors could have also been reduced through modifications to the procedure. In the procedure, the cucumber had a slightly irregular shape which was then cut into circular slices with the skin on. The shape of this cucumber may have caused variability within the results as some cucumber slices may have been larger in diameter and therefore would've had more flesh and less skin. Furthermore, since the diameter of each section of cucumber may have been different, there would've been variability within the surface area to volume ratio. If the surface area of the cucumber is larger, then there is a larger surface area in contact with the water which allows for more water to rush in or out of the cells which can affect the rate of osmosis (Sinibaldi, 2014). In future experiments, each cucumber should be molded into a cube shape such that the surface area to volume ratio of each cucumber is the same and equally permeable.

CONCLUSION

In conclusion, we reject the null hypothesis that changing the concentration of salt in a solution will not affect the percent change in the mass of cucumber slices. ($df_{treatment} = 4$, $df_{residual} = 10$, $F_{4,10} = 43.70$, $p < 0.001$). As the concentration of the salt solution increases, the change in mass of the cucumber slice decreases. The cucumber slice gained mass and swelled where mass change is positive, but lost mass and shrunk where mass change is negative. These findings provide further insight into the effect of osmosis in the maintenance of turgidity in plant cells, which can have important implications in understanding key processes such as transpiration and growth in plants.

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APPENDIX

Data table 1 - The concentrations of salt solution and the mass of cucumber slice

Concentration of Salt Solution (M)	Initial Mass (grams)	Final Mass (grams)		
0 (Water)	10	12	13	12
0.25	10	9	8	8
0.50	10	8	8	9
0.75	10	7	7	8
1.0	10	6	6	7

<u>Sample calculation for percentage change in mass for each slice of cucumber:</u>

(Final mass-initial mass)/initial mass*100 = ±% Percentage change in mass

<u>Sample calculation for amount of salt needed to create the salt solutions of different molarities:</u>

Molecular weight of NaCl (table salt): 58.44 g/mol

100 mL * (10^-3 L/ mL) * (1.0 mol/L) = 0.1 mol

(58.44g/mol) * 0.1 mol = 5.84 grams

To make a 1.0 M NaCl solution, you need to dissolve 5.84 grams of table salt in 100 mL of water.

Data table 2 - Observations of cucumber placed in solutions of varying salt concentrations (Qualitative data and scientific statements)

	Day 1 (Before submerged in salt solution)	Day 2 (After submerged in salt solution for 24 hours)
Water	Flat cylinder shape, firm, smooth skin, light green in color, dark green outer peel	Very firm, smooth skin, same flat cylinder shape, same color
0.25 M Salt Solution		Less firm, outer edge

		slightly shrivelled, smooth skin, same shape as before, darker green in color
0.50 M Salt Solution		Slightly soft and squishy, smooth skin, shrivelled corners, darker green in color, center is slightly transparent
0.75 M Salt Solution		Soft and squishy, smooth skin, shrivelled, dark green in color, center is slightly transparent
1.0 M Salt Solution		Very soft and squishy, smooth skin, shrivelled, darker green color, center is slightly transparent