Biology 342 101

The Effect of Food Availability on the Cellular Respiration of Yeast

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Abstract

In this experiment, I observed which conditions were optimal for cellular respiration of yeast *(Saccharomyces cerevisiae)*. Because CO_2 is released during respiration of yeast, this provides a way of measuring how much cellular respiration has taken place (Rymer, 2019). As CO_2 is produced, the gas can be trapped and measured. I manipulated the amount of food (in this case, the amount of sucrose) to see how this affected the rate of cellular respiration by yeast. I measured the volume of CO_2 collected at 4 different treatment levels: 0g of sucrose (control), 5 g of sucrose, 15 g of sucrose, and 30 g of sucrose. Since yeast must get their food from their surrounding environment in order to grow and reproduce, I hypothesized that if we use 15 g of sucrose, then this treatment level with the yeast will produce the most CO_2 and will therefore have the fastest rate of cellular respiration (mL CO_2/minute). If we were to add 0 g of sucrose or 30 g of sucrose (i.e. too little or too much sucrose), then these environments will show to be the least optimal conditions for yeast activity and produce the least CO_2 with the slowest rate of cellular respiration (mL CO_2/minute). After completing the data collection phase of my experiment, the cellular respirations rates were calculated for each treatment. A one-way ANOVA test was used to evaluate the statistical difference between these results. It was found that the results were statistically significant with a reported p-value of 1.0629e-65 which is less than the threshold of 0.05 ($p < 0.05$). Therefore, there was sufficient evidence to reject the null hypothesis and we can conclude that of the three treatment levels, adding 5 g of sucrose (treatment group B) was the most optimal conditions for cellular respiration of yeast. For future studies, we can evaluate the effects of manipulating other environmental factors on the growth of yeast, such as temperature, pH levels, and type of sugar (i.e. glucose, fructose, galactose).

Introduction

Yeast has played an important role in the production of food and beverages for centuries. They are responsible for the rising of bread dough and the fermentation of wines, whiskey, brandy, and beer. Yeast also plays an initial role in the production of vinegar (Pepin, 2018). When yeast is used in dough, it undergoes a chemical reaction that releases CO_2, which creates pockets of gas that allow the dough to rise before being baked. This process is known as leavening. Leavening can be achieved with other leavening agents such as eggs, cream of tartar, and baking soda and vinegar. During the case of leavening with yeast, the CO_2 gas is being released as the yeast reacts with oxygen and sucrose, breaking it down to release carbon dioxide which gets trapped within the batter. This is what creates the pockets of gas that allow doughs and batters to rise.

Yeast are small, single-celled microorganisms that are a member of the fungus family. Fungi differ from other plants in that they have no chlorophyll. Therefore, yeast must get their food from their surrounding environment to grow and reproduce (Rymer, 2019). Yeast require carbohydrates, such as sugar and starch, to perform cellular respiration. In aerobic environments, they turn this food into energy and release carbon dioxide gas and water as a result (Arroyo-Lopez et al., 2009). In the case of sucrose, the cellular respiration reaction (under aerobic conditions) is:

$$C_{12}H_{22}O_{11(aq)} + 12O_2 \xrightarrow{\textit{Yeast Enzymes}} 11H_2O + 12CO_{2(g)}$$

In the case of sucrose, the fermentation reaction (under anaerobic conditions) is:

$$C_{12}H_{22}O_{11(aq)} + H_2O \xrightarrow{\textit{Yeast Enzymes}} 4C_2H_5OH_{(aq)} + 4CO_{2(g)}$$

Yeast are unlikely to ferment unless under special anaerobic conditions. In the aerobic respiration reaction, we see that in the presence of sucrose and oxygen, the yeast enzymes undergo a set of metabolic reactions that converts this chemical energy into energy and then release water and CO_2 as products. Conversely in anaerobic conditions, we observe fermentation occur in yeast. In the fermentation reaction, we see that in the presence of sucrose and water, the yeast enzymes undergo a set of metabolic reactions that converts this chemical energy into alcohol and CO_2 as products. In any case, it is the production of CO_2 that is the basis of my experiment as I will be manipulating the amount of food available to the yeast in my different treatment levels, and this will result in different productions of CO_2 by yeast.

For this experiment, I questioned how the amount of sucrose affects the aerobic respiration of yeast. Furthermore, I questioned what would be the optimal amount of sucrose for the production of CO_2 gas, as this would be a good measurement of cellular respiration activity. Since yeast must get their food from their surrounding environment in order to grow and reproduce, I hypothesized that if we use 15 g of sucrose, then this treatment level with the yeast will produce the most CO_2 and will therefore have the fastest rate of cellular respiration (mL CO_2/minute). If we were to add 0 g of sucrose or 30 g of sucrose (i.e. too little or too much sucrose), then these environments will show to be the least optimal conditions for yeast activity and produce the least CO_2 with the slowest rate of cellular respiration (mL CO_2/minute).

In this experiment, the CO_2 gas was trapped by a balloon attached to a water bottle where the yeast experiments took place. The cellular respiration rate of the yeast was calculated by measuring the volume of CO_2 collected by the balloon and dividing it by the amount of time it took for that volume to form, for a rate with units mL CO_2/minute. I manipulated the amount of food (in this case, the amount of sucrose) to see how this affected the rate of cellular respiration by yeast. I measured the volume of CO_2 collected at 4 different treatment levels: 0g of sucrose (control), 5 g of sucrose, 15 g of sucrose, and 30 g of sucrose. I made it so that there were 3

samples at each treatment level, over a total of 3 trials. For each trial, after the first 15 minutes I recorded initial observations, then made additional observations at 10-minute intervals up to 45 minutes. My observations involved measuring and recording the circumference of the balloon, and a description of the cellular respiration activity by yeast.

Methods and Materials

1. **Preparation of samples at each of the four treatments, over a total of three trials**
   First, I labelled 12 empty plastic water bottles A through D with a marker and masking tape, ensuring I had 3 bottles for each treatment level. I then boiled water in a kettle and had a separate bowl filled with water and ice. I took a thermometer and an empty bowl, and I filled this bowl with a mixture of boiled water, ice water, and tap water until the temperature of the water in the bowl reached 40 degrees C. This is to ensure consistency in water temperature across all bottles for each trial. Using a funnel, I added 80 mL of my 40 degree C water to each of the 12 bottles and to each bottle, I dissolved the following amounts of table sugar (sucrose) in each:

   Bottles A- 0 g (water only; this was my control)
   Bottles B- 1 (5 g) teaspoon sugar
   Bottles C- 1 tablespoon (15 g) sugar
   Bottles D- 2 tablespoons (30 g) sugar

   Using a spoon, I proceeded to add 1 teaspoon (5 g) of rapid-rise, active dry yeast to each bottle and stirred. I then placed a balloon of standard 7.8 cm size on the opening of each bottle, and sealed it securely in place with some masking tape. As soon as all the bottles were sealed with a balloon, I began my stopwatch to record my observations up to 45 minutes. Periodically, I stirred the contents of each bottle by spinning the it slowly with my hand. I left the bottles to rest, and after the first 15 minutes I recorded my initial observations. I then made additional observations at 10-minute intervals up to 45 minutes. My observations involved measuring and recording the circumference of the balloon and describing the yeast activity. To measure the circumference of the balloon, I wrapped a string around the balloon at its widest point, then measured the length of the string using a ruler. I could then use the circumference the determine the radius of each balloon, which would be used in my volume calculations. I then disposed and emptied the contents of the 4 water bottles and repeated all steps of the experiment an additional 2 times. This made it so that there were 3 samples at each treatment level, over a total of 3 trials.

2. **Collection of Data**

   The volume of the balloon was recorded by using the formula for the volume of a sphere:

$$V = \frac{4}{3}\pi r^3$$

I used the measured circumference of the balloon to determine the radius of the balloon by rearranging the formula for the circumference of a circle (*circumference = 2πr).* I could then use the radius to calculate the volume of the balloon. In hindsight, CO_2 would also collect in the bottle and any overflow would rise up and fill the balloon. This is why I also measured the foam level height in the bottle and assumed the bottle shape to be a perfect cylinder to calculate the volume of CO_2 in the bottle. The volume of the bottle was recorded by using the formula for the volume of a cylinder:

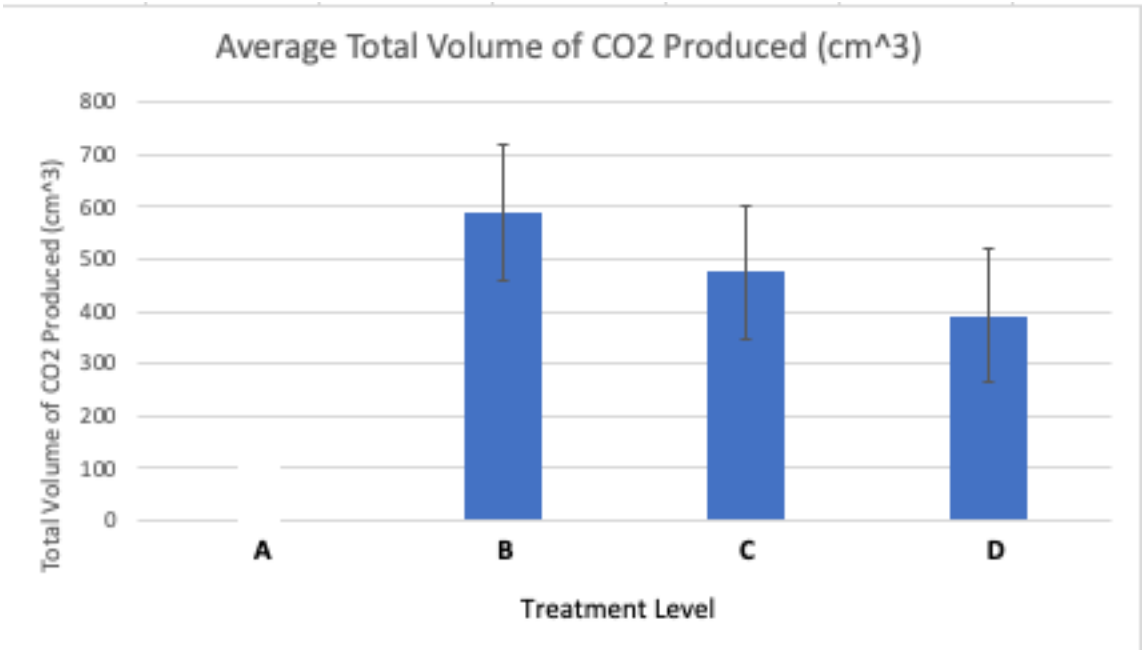
$$V = \pi r^2 h$$

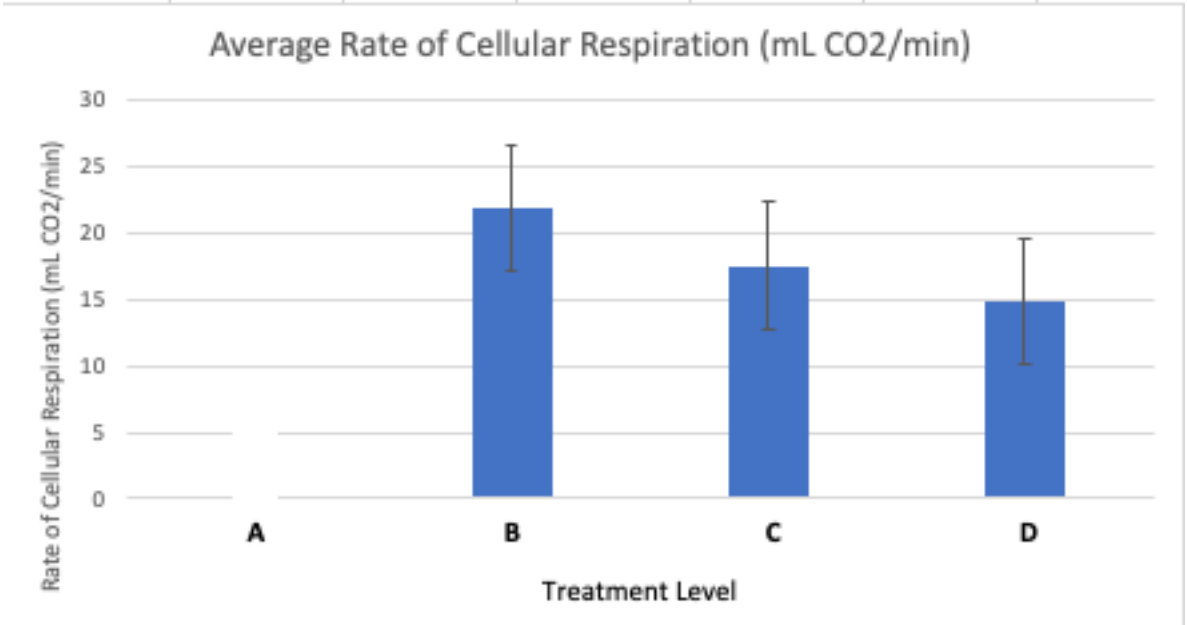
The total volume of CO_2 was calculated by adding the volume of a sphere and cylinder together for each bottle. From there, the rate of cellular respiration was calculated by dividing the total volume (balloon + bottle) by the amount of time of my trial (45 minutes) for a rate with units: mL CO_2/minute. I then tabulated all of the total volumes of CO_2 produced by each bottle at each treatment level over a total of 3 trials, and did the same with all of the rates of cellular respiration in a separate table. I was then left with two tables of data on which I would perform my data analyses on.

3. Statistical Analysis

In order to evaluate my results, I performed a one-way ANOVA test on both data tables (total volume CO2 and rates of cellular respiration) which contained data from each treatment group over three trials. A one-way ANOVA test was used because it allows me to test my hypothesis when dealing with the means of more than two groups. In this case, there were four different groups being tested with varying levels of sucrose. A one-way ANOVA is especially useful when only one independent variable is being altered between groups, which in this experiment was the amount of sucrose available for the yeast. This allows one to determine whether there is in fact a statistically significant difference between the different treatment groups by comparing their respective means. The one-way ANOVA generates a p-value which could then be used to reject or fail to reject the null hypothesis. The null hypothesis for this experiment is that there is no significant difference between the four test groups, meaning that despite altering the amount of sucrose available for the yeast between groups, there would be no significant difference in their rates of cellular respiration. If my results were determined to be statistically significant by the one-way ANOVA, then I would then proceed to perform a corresponding post hoc Tukey's Test to assess the statistical significance of the differences in means of each treatment group. In any case, all statistical tests would be performed on Microsoft Excel.

Results


Average Total Volume of CO2 Produced (cm^3)
Total Volume of CO2 Produced (cm^3)
800
700
600
500
400
300
200
100
0
A
B
C
D
Treatment Level


Average Rate of Cellular Respiration (mL CO2/min)
Rate of Cellular Respiration (mL CO2/min)
30
25
20
15
10
5
0
A
B
C
D
Treatment Level

Discussion

As yeast is a fungus, and needs a constant supply of energy for its growth, the sugar used in this experiment supplies this energy. In anaerobic conditions, yeast use oxygen to release energy from sugar during cellular respiration. Therefore, the more sugar available for the yeast, the more activity it will perform and the faster its growth will be. As mentioned previously, yeast can still perform metabolic processes even in the absence of oxygen (anaerobic conditions). If there is a lack of oxygen, the yeast can still release energy from sugar, but in this process known as fermentation, the by-products are alcohol and carbon dioxide.

Conclusion

In conclusion, after running a one-way ANOVA test on the experimental results, I determined that the differences in the means of my four treatment groups were in fact statistically significant. Therefore, I can conclude that the amount of sucrose available for yeast is an important factor in optimizing the conditions for cellular respiration by yeast. Furthermore, I can conclude that because treatment level A produced the greatest total volumes of CO_2 and fastest rates of cellular respiration, this indicated that for 5 g of Active Dry Yeast, 5 g of sucrose is the optimal amount of sucrose required for effective cellular respiration by yeast.

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Appendix

One-way ANOVA test on the total volumes of CO2 produced by each treatment group

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	36	0	0	0
Column 2	36	21194.0989	588.724969	11648.9442
Column 3	36	17116.4564	475.457121	8789.74708
Column 4	36	14106.0015	391.833375	5615.26278

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7063009.14	3	2354336.38	361.45552	1.0629E-65	2.66925636
Within Groups	911888.392	140	6513.48852			
Total	7974897.54	143				

One-way ANOVA test on the rates of cellular respiration observed by each treatment group

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	36	0	0	0
Column 2	36	789.309784	21.9252718	52.016324
Column 3	36	631.436957	17.5399155	26.3287511
Column 4	36	533.055355	14.8070932	28.8131078

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	9764.85888	3	3254.95296	121.500864	8.6384E-39	2.66925636
Within Groups	3750.5364	140	26.7895457			
Total	13515.3953	143				

Literature Cited

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