Yeast and Respiration Rates: To What Extent Does Saccharomyces Cerevisiae, Baker's Yeast, CO2 Production Levels (ppm) Vary with the Length of Different Sugars?

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ABSTRACT

Saccharomyces cerevisiae, or baker's yeast, is commonly used for baking alongside sucrose. It is understood that yeast's reaction with sugar leads to a high emission of carbon dioxide, ultimately increasing the height of baked goods. However, the carbon dioxide production levels at different chains of sugars, including sucrose, glucose, and starch, or monosaccharides, disaccharides, and polysaccharides, is not well-known. Water was tested as a control group. The paper hypothesizes that as length of the sugar polymer chain increases, the production of carbon dioxide of *Saccharomyces cerevisiae*, or baker's yeast, increases. While the results showed a linear trend similar to the hypothesis, the production levels for the starch experimental group were lower than any other experimental group. This paper concludes that there is no statistical difference between the lengths of the sugar chain and the carbon dioxide production rate can be rejected.

Introduction

Yeasts are eukaryotic and unicellular microorganisms that are members of the fungus kingdom. *Saccharomyces cerevisiae* is a common form used for baking, brewing and more. As fungi, they are classified as ascomycetes, or spore shooters. Because they cannot carryout out photosynthesis, they must use a carbon source [3].

Baker's yeast, *Saccharomyces cerevisiae*, rapidly converts sugars to ethanol and carbon dioxide at both anaerobic and aerobic conditions via cellular respiration where glucose is converted into ATP and carbon dioxide. The production of carbon dioxide by yeast is what causes bread to rise. However, there is a possibility of glucose repression of respiration as seen in *S. cerevisiae* and related species that diverged. Glucose repression of respiration was seen as an evolutionary step to increase ethanol production and to inhibit any growth of microbes [2]. This raises the question of whether the trends of yeast respiration are truly predictable.

Previous studies have shown that sucrose as a source of carbon and energy in yeast is controlled by SUC genes, which confer the ability to produce invertase, or the sucrose-degrading enzyme. SNF1 is the locus essential for sucrose utilization and mutations at the locus were found to be pleiotropic and prevented sucrose consumption in some strains, which also affected monomers. All carbon utilization systems are affected by glucose repression. Previous findings have found that the SNF1 locus is involved in "regulation of gene expression by glucose repression" [1].

Moreover, this experimentation can be applied to fungi in a unicellular life stage in the natural world, analyzing how this might affect carbon dioxide levels in the atmosphere.

H_a: As length of the sugar polymer chain increases, the production of carbon dioxide of *Saccharomyces cerevisiae*, or baker's yeast, increases.

H_0: As length of the sugar polymer chain increases, there is no effect on the production of carbon dioxide of *Saccharomyces cerevisiae*, or baker's yeast.

Materials and Methods

Photograph of Lab Setup

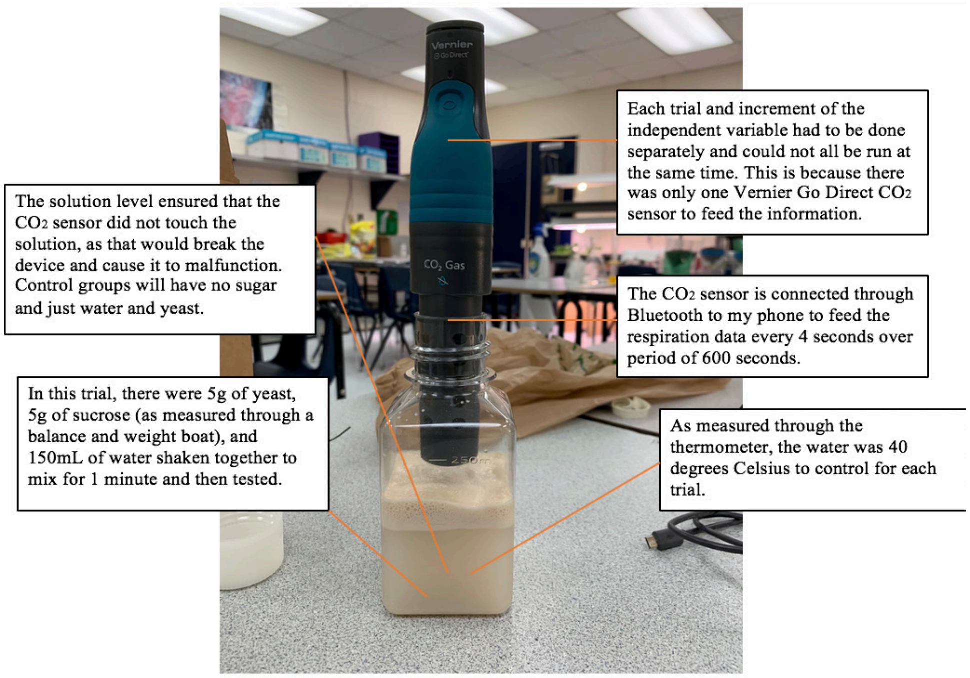

Figure 1. Lab setup

One 250mL Nalgene bottle, one 250mL beaker, and one 100mL graduated cylinder were rinsed and dried in preparation for the lab procedure. Distilled water was applied to rinse graduated cylinders, any remains within the bottle, and the stirring rod. To connect the Vernier, Go Direct CO_2 Bluetooth Sensor, the device was turned on via the power button and matched through Bluetooth to the computer and phone to feed data every 8 seconds. To control these settings, the Bluetooth device was adjusted on the computer to feed data every 8 seconds for 600 seconds as opposed to every 2 seconds for 600 seconds.

Using a balance that estimated to the nearest hundredth of a gram, 5.00 grams of the sugar and 5.00 grams of the yeast were measured out in weight boats. With a graduated cylinder, 150mL were measured out and placed into a 250mL beaker by reading the meniscus of the cylinder. The graduated cylinder was then dried out for later measurements. A hot plate was plugged and set to level 6 as the room temperature water was already nearly 30°C and only needed minimally heating to reach 40°C for the trial. After the water, sugar, and yeast were measured out and ready, they were poured into the Go Direct sensor's 250mL bottle within 20 seconds. Then, a timer was set to a minute and the solution was stirred during that period of time. When the solution was efficiently stirred together, the Vernier Go Direct CO_2 Bluetooth Sensor was placed into the solution's bottle and the "Collect" button was pressed on the computer and cell phone, giving the data as needed.

Once 600 seconds were over, the bottle was rinsed, the sensor was wiped down with paper towel and the given steps were repeated for all other trials for repetition and accuracy. For the trial with just water, the above steps still occurred, but without measuring out 5.00 grams of a given sugar.

Results

Table 1: Carbon Dioxide Production Levels of Sugars (ppm) Over the Course of 600 Seconds (±0.01s)

Quantitative Raw Data-Table 1

Time (s)	Carbon Dioxide Respiration Rate of Yeast (ppm)															
	Sucrose-Trial 1	Sucrose-Trial 2	Sucrose-Trial 3	Sucrose-Trial 4	Glucose-Trial 1	Glucose-Trial 2	Glucose-Trial 3	Glucose-Trial 4	Water-Trial 1	Water-Trial 2	Water-Trial 3	Water-Trial 4	Starch-Trial 1	Starch-Trial 2	Starch-Trial 3	Starch-Trial 4
0	7393.50	1472.00	1360.67	1632.67	585.33	3124.00	1838.00	3290.33	914.33	890.33	693.33	727.33	1504.33	1524.00	1838.67	1368.67
8	8064.00	8050.00	2881.67	2007.67	2002.67	3335.33	2669.67	7143.00	1646.00	1041.33	890.33	924.67	3274.33	2307.00	2263.00	5742.67
16	8650.00	10872.00	3496.67	2395.67	2544.33	3401.00	3171.67	8571.00	2041.33	1140.00	985.33	975.33	3998.33	2736.00	2473.67	7508.67
24	9094.67	12747.67	3825.00	2750.33	2751.00	3508.67	3538.67	9574.67	2416.00	1264.33	1009.33	1013.33	4245.33	2957.00	2514.00	8387.67
32	9789.00	14024.00	3898.33	3119.00	2809.33	3629.00	3722.00	10540.67	2719.67	1318.00	1059.00	1079.67	4312.00	2999.33	2581.67	8579.33
40	10022.00	14954.33	4304.67	3523.33	2921.33	3755.33	3803.33	11342.00	2898.67	1389.33	1125.67	1152.33	4416.33	3074.00	2660.33	9112.67
48	10229.00	15801.33	4413.33	4105.00	3036.67	3883.00	3928.00	12124.33	2993.00	1461.33	1196.00	1223.00	4539.33	3167.33	2738.33	9182.00
56	10581.67	16655.67	4540.33	4687.33	3182.33	3997.67	4078.33	12528.00	3126.00	1535.00	1265.00	1294.00	4663.00	3258.33	2819.33	9296.67
64	10891.00	16832.00	5114.00	5293.67	3795.33	4102.67	4217.33	12852.67	3273.67	1610.00	1333.33	1366.00	4776.67	3352.33	2902.67	9423.33
72	11109.00	17138.00	5613.67	5910.33	4084.33	4208.33	4375.67	14407.33	3418.67	1681.67	1401.00	1437.67	4879.00	3441.33	2480.00	9540.00
80	11338.67	17526.67	5735.67	6499.67	4321.33	4302.33	4534.67	14624.33	3554.33	1747.00	1466.00	1506.00	4969.67	3524.33	2637.33	9655.00
88	11579.33	17924.33	6037.67	6924.67	4638.00	4377.67	4690.33	14964.33	3674.00	1812.33	1522.67	1567.33	5060.33	3595.33	2921.33	9752.33
96	11818.33	18318.67	6703.67	7502.33	4720.33	4459.00	4846.33	15388.33	3780.67	1873.33	1575.67	1623.33	5151.33	3668.33	2945.33	9851.33
104	12051.00	18745.33	6829.67	7828.67	5401.00	4536.67	4996.67	15865.00	3870.67	1928.00	1629.67	1683.00	5239.00	3735.67	3019.33	9950.67
112	12295.00	19169.67	7014.00	8338.33	5919.33	4609.00	5179.67	16355.33	3955.00	1981.00	1680.00	1739.33	5324.33	3807.33	3111.00	10044.67
120	12543.33	19569.33	7288.33	8775.67	6423.67	4681.67	5363.00	16834.67	4020.33	2039.67	1726.33	1792.67	5398.33	3872.00	3207.00	10168.33
128	12781.67	19955.33	7596.33	9060.00	6763.00	4750.00	5548.00	17356.67	4090.00	2106.00	1773.00	1845.00	5466.00	3934.00	3308.33	10286.33
136	13138.00	20460.33	7935.33	9272.00	6907.67	4821.00	5735.67	17865.00	4146.33	2169.00	1818.33	1894.33	5534.33	3989.33	3407.33	10393.33
144	13613.00	20973.67	8323.00	9555.00	7415.67	4899.00	5926.67	18368.33	4199.33	2225.67	1862.00	1936.00	5589.33	4040.33	3501.33	10494.67
152	14085.67	21449.67	9362.00	9882.33	7968.33	5000.00	6122.00	18870.00	4250.00	2283.67	1903.00	1984.00	5650.33	4090.67	3588.33	10585.67
160	14547.33	21915.33	9864.33	10324.00	8166.33	5162.00	6300.33	19356.67	4295.67	2343.00	1946.67	2045.00	5712.33	4141.00	3681.00	10680.67
168	14990.67	22354.00	10080.33	10821.67	9149.00	5356.00	6506.00	19820.67	4336.00	2397.00	1988.00	2111.33	5773.33	4192.33	3763.00	10777.33
176	15380.00	22766.00	10456.00	11325.00	9630.33	5567.00	6718.67	20390.67	4373.33	2456.67	2039.33	2182.00	5830.00	4237.33	3847.67	10857.67
184	15825.00	23145.67	10879.33	11837.00	9758.33	5759.67	6930.00	21011.33	4408.00	2519.00	2092.00	2269.33	5889.33	4278.00	3929.00	10935.67
192	16271.33	23500.00	11354.00	12288.00	9996.67	5990.00	7142.33	21600.00	4440.00	2575.67	2145.00	2668.00	5950.00	4327.33	4009.67	11032.00
200	16706.67	23863.67	11817.33	12785.33	10382.33	6228.33	7368.00	22177.33	4469.67	2636.67	2205.00	3235.67	6010.00	4373.00	4092.00	11118.33

Table 2. Raw data of carbon dioxide production over 600 seconds for all trials.
Qualitative Raw Data-Table 2

208	17112.33	24229.00	12260.33	13271.33	10852.67	6479.67	7595.33	22672.67	4492.33	2703.00	2280.33	3786.67	6075.33	4419.33	4166.00	11211.00
216	17518.67	24583.67	12726.00	13762.67	11353.00	6728.00	7829.67	23191.67	4510.00	2785.33	2386.33	4362.00	6139.33	4464.67	4241.67	11302.33
224	17901.67	24926.33	13189.33	14235.33	11871.67	6981.67	8079.67	23725.67	4528.67	2902.33	2915.67	4929.67	6200.33	4504.00	4315.00	11399.00
232	18261.33	25257.00	13658.67	14709.67	12406.00	7244.00	8354.33	24220.00	4542.00	3537.67	3285.67	5613.33	6269.33	4545.33	4392.33	11492.33
240	18619.33	25559.33	14119.33	15171.33	12947.33	7524.00	8631.00	24711.67	4555.33	3919.33	3715.67	6213.00	6333.67	4591.33	4468.00	11588.00
248	18955.33	25855.00	14559.33	15633.00	13452.33	7826.00	8904.33	25202.00	4560.00	4370.67	4121.67	6870.00	6406.33	4635.67	4549.33	11671.67
256	19272.33	26170.33	15000.67	16086.00	13929.00	8159.00	9168.00	25673.00	4569.33	4851.00	4483.67	7483.33	6475.33	4677.67	4623.67	11776.00
264	19593.00	26476.67	15419.67	16543.00	14446.67	8532.33	9460.67	26128.00	4579.33	5464.67	4844.67	7843.00	6549.67	4722.33	4695.67	11872.33
272	19861.33	26764.00	15843.00	16987.00	14954.00	8903.33	9755.00	26582.00	4589.00	6166.33	4951.33	8314.00	6624.67	4764.67	4772.00	11963.00
280	20214.67	27040.67	16263.67	17418.00	15445.00	9228.00	10066.00	27001.67	4597.00	6926.33	5081.33	8923.67	6660.00	4800.00	4851.00	12035.33
288	20616.67	27308.67	16682.33	17791.67	15942.67	9599.67	10476.67	27405.33	4608.00	7662.00	5280.33	9081.33	6735.00	4841.33	4932.33	12114.00
296	20905.00	27570.67	17110.33	18213.67	16428.67	9971.67	10882.67	27792.00	4618.00	8398.67	5521.00	9334.00	6812.33	4881.67	5025.00	12192.33
304	21269.00	27807.00	17471.33	18623.00	16814.33	10440.67	11296.67	28135.00	4628.33	9127.00	5770.00	9651.33	6885.33	4917.67	5128.67	12273.67
312	21654.00	28050.67	17888.33	19024.33	17264.00	10907.33	11701.33	28516.67	4639.00	9703.67	6023.00	10003.00	6955.00	4960.33	5232.67	12361.33
320	22018.00	28304.00	18295.33	19418.67	17708.33	11377.67	12124.00	28896.00	4645.00	10139.67	6272.00	10478.00	7031.67	5002.00	5341.00	12441.67
328	22283.33	28526.33	18696.33	19789.67	18150.00	11837.67	12542.67	29245.33	4660.67	11070.33	6506.33	10955.00	7108.33	5052.33	5453.33	12517.00
336	22629.00	28761.67	19095.33	20213.00	18591.67	12298.33	12967.00	29582.00	4687.33	11247.67	6735.67	11376.00	7183.00	5106.33	5562.00	12591.00
344	22976.33	28987.00	19487.67	20714.33	19006.33	12744.00	13368.67	29921.00	4723.00	11592.67	6944.33	11830.67	7240.00	5154.00	5672.00	12661.00
352	23317.00	29212.67	19861.67	21179.33	19372.00	13190.33	13810.67	30388.33	4765.00	12038.33	7134.00	12269.67	7310.00	5209.67	5778.67	12744.67
360	23662.67	29441.00	20328.33	21653.00	19777.00	13631.33	14285.67	30908.33	4810.00	12524.00	7317.00	12679.00	7383.33	5262.00	5877.00	12815.00
368	23916.00	29651.00	20809.00	22115.67	20223.33	14057.33	14759.67	31410.00	4857.33	13024.00	7487.67	13075.67	7449.00	5310.33	5974.00	12874.67
376	24237.00	29853.00	21285.67	22557.00	20744.67	14427.00	15232.00	31934.67	4907.00	13539.00	7624.67	13450.33	7522.67	5356.67	6077.00	12935.33
384	24530.33	30027.67	21725.00	22961.67	21270.00	14834.67	15693.00	32452.33	4962.67	14040.67	7776.33	13808.00	7592.00	5409.33	6180.00	13002.00
392	24847.33	30351.00	22164.00	23372.00	21776.00	15232.00	16145.33	32920.00	5021.33	14530.67	7920.33	14145.33	7660.33	5469.00	6281.00	13059.67
400	25148.67	30673.67	22575.00	23788.00	22254.33	15628.67	16599.33	33319.67	5093.00	14993.00	8064.67	14468.00	7722.00	5523.33	6389.33	13121.00
408	25441.00	30974.67	22978.00	24201.33	22749.00	16019.67	17025.67	33762.33	5167.00	15428.33	8210.00	14779.67	7787.33	5582.67	6494.00	13174.00
416	25736.67	31300.33	23406.00	24580.00	23231.33	16404.00	17442.67	34222.67	5275.33	15845.00	8350.00	15068.00	7846.00	5646.33	6601.67	13232.33
424	26016.67	31567.00	23810.33	24946.67	23702.00	16780.33	17858.33	34657.33	5404.67	16241.67	8480.00	15350.33	7907.33	5710.00	6733.00	13293.67
432	26282.33	31833.67	24201.33	25311.00	24150.33	17135.67	18264.00	35063.33	5546.33	16571.00	8615.33	15588.67	7972.00	5772.00	6881.67	13345.67
440	26553.67	31695.67	24576.00	25681.67	24600.33	17483.67	18610.33	35497.00	5692.00	16926.67	8736.67	15839.67	8024.33	5835.33	7034.00	13389.00
448	26798.00	31298.67	24929.00	26022.00	24977.33	17847.00	18984.00	35910.00	5846.00	17279.67	8857.00	16072.00	8091.33	5899.33	7189.33	13437.67
456	27049.67	31180.00	25282.00	26354.67	25382.33	18179.33	19395.67	36287.67	5997.67	17609.33	8967.67	16290.67	8158.67	5959.00	7357.67	13489.67
464	27269.33	31278.67	25636.00	26679.67	25778.67	18510.00	19817.33	36736.33	6140.67	17915.67	9086.00	16515.00	8220.33	6025.00	7515.67	13535.00
472	27530.00	31536.67	25971.00	27004.00	26182.67	18795.67	20333.33	37110.67	6278.33	18209.33	9179.67	16752.33	8288.67	6085.00	7693.67	13586.33
480	27764.33	31828.33	26301.67	27274.67	26558.67	19124.00	20912.67	37520.33	6414.67	18496.67	9287.00	16956.33	8342.33	6155.00	7857.67	13633.00
488	27991.33	31866.00	26637.00	27542.33	26926.33	19452.67	21447.33	37887.00	6546.33	18767.67	9394.67	17154.00	8403.33	6229.00	8024.67	13685.00
496	28245.33	31744.33	26931.33	27805.00	27274.67	19765.00	21965.00	38201.33	6663.33	19025.00	9501.33	17346.33	8459.67	6303.33	8181.00	13734.00
504	28490.33	31822.33	27192.67	28080.33	27646.33	20098.67	22491.67	38535.33	6773.67	19268.33	9602.00	17546.33	8513.67	6383.00	8350.00	13775.67
512	28708.00	32045.67	27495.33	28341.33	28000.67	20536.67	22961.00	38915.00	6888.00	19513.00	9704.67	17719.00	8571.33	6478.00	8513.00	13826.33
520	28932.33	32392.67	27805.67	28603.67	28316.67	20953.67	23429.00	39281.00	7008.67	19737.33	9807.33	17890.00	8614.00	6580.00	8676.00	13862.00
528	29168.67	32757.00	28110.00	28854.33	28639.67	21352.33	23887.00	39593.33	7140.67	19935.67	9895.67	18032.00	8680.00	6680.33	8837.67	13904.00
536	29400.33	32967.00	28399.33	29077.67	28960.33	21737.00	24253.00	39942.33	7285.33	20206.33	9983.67	18191.00	8769.67	6798.67	8993.00	13945.00
544	29609.00	33145.67	28677.33	29298.33	29283.33	22120.33	24677.00	40245.33	7451.33	20477.67	10105.67	18352.33	8891.00	6934.00	9151.00	13986.33
552	29804.33	33261.67	28948.00	29510.33	29540.67	22440.67	25089.00	40553.00	7623.33	20736.33	10224.00	18507.00	9053.33	7077.33	9302.67	14029.33
560	30004.33	33405.00	29221.00	29753.33	29792.00	21922.67	25463.67	40868.67	7790.33	20991.00	10341.00	18647.33	9251.00	7237.00	9448.00	14076.67
568	30279.67	33652.33	29500.00	29993.00	28958.00	21891.00	25826.67	41168.00	7951.00	21233.33	10436.33	18803.33	9472.33	7407.67	9609.67	14120.67
576	30575.67	33861.67	29741.67	30319.67	28734.67	22010.33	26226.33	41458.33	8120.00	21468.00	10560.33	18935.00	9715.00	7598.00	9766.33	14155.00
584	30888.67	34126.67	29981.67	30649.67	28688.67	22238.67	26621.00	41730.67	8280.67	21709.33	10668.67	19066.00	9972.00	7795.67	9919.67	14198.00
592	31191.33	34417.67	30332.00	30984.00	28860.67	22580.33	27010.67	41983.67	8422.00	21922.33	10773.33	19194.67	10310.00	7991.33	10103.00	14238.00
600	31507.67	34750.67	30635.67	31339.33	29160.00	22965.00	27371.00	42319.67	8549.33	22127.67	10883.67	19330.33	10673.33	8195.00	10327.00	14276.67

Table 3. Observational data from each group, collective of all trials.
Observational Data of Respective Sugars and its Reaction with Yeast and Water

	Sucrose	Glucose	Water	Starch
Observations	During all trials, foaming started very early and quickly. The yeast solution started to with yellowish-white bubbles of high volume. There was a key division between the solution at the bottom and top; the top was more viscous than the bottom. During trial 3, there was a slight error in that the bubbles of the solution started to rise higher than expected, causing me to have to lift the CO_2 sensor a bit and, potentially inhibiting some results.	There was an equal level of foaming at all trials. The solution at the bottom was thinner; however, there were chunks of yeast and sugar that were slowly popping out of the bottom over time. It was less viscous than the sucrose solution. There was a key division between the solution at the bottom and top; the top was more viscous than the bottom.	There was little, if any, reaction. The solution was tainted yellowish-brown as a result of the yeast. During trial 2, there was a chunk of yeast solution that did come to the top of the solution. The yeast, when stirred, didn't dissolve with the water.	It was extremely difficult to mix the starch with the solution in under a minute. The starch tended to clump together, leading to more mixing and also trouble inserting it into the bottle without disrupting the surrounding environment. Visible reaction was minimal. The solution wasn't as viscous as sucrose and was closer to glucose. The solution was tainted a yellowish-brown and was even throughout.

Figure 2. Sucrose trial 3

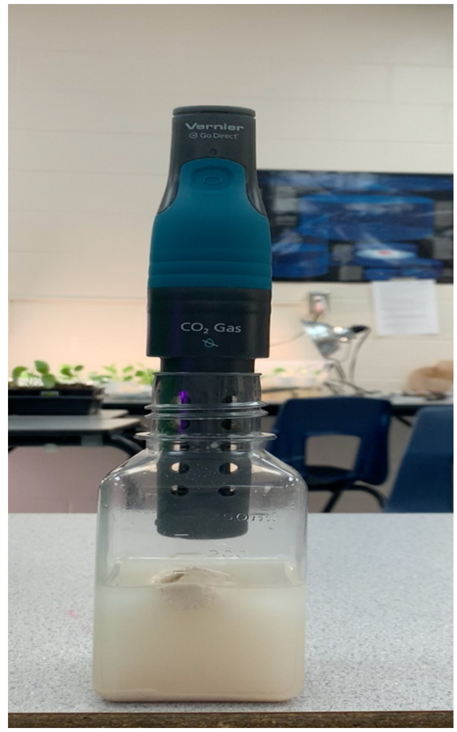

Figure 3. Water trial 1

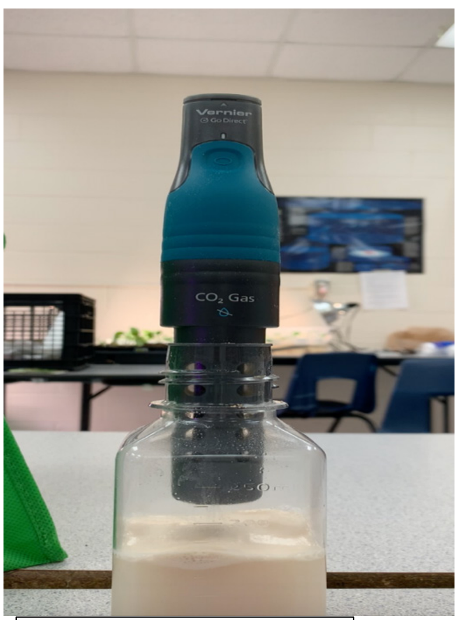

Figure 4. Glucose trial 2.

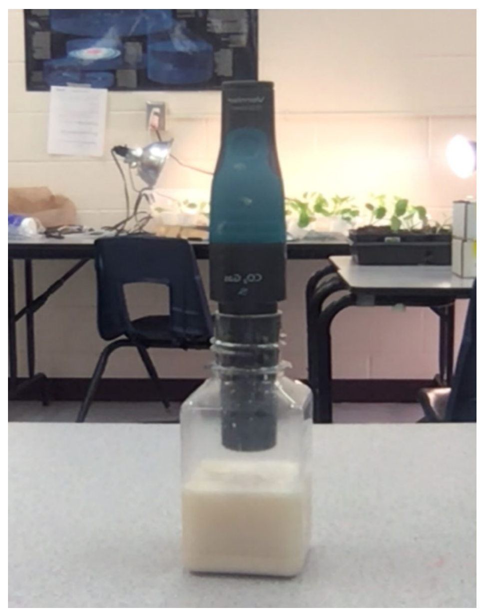

Figure 5. Starch trial 4

Table 4. Condensed data per trial, average of carbon dioxide production for each trail.

Table 4. Condensed data per trial, average of carbon dioxide production for each trail.

Average Carbon Dioxide Production per each Trial and Sugar Type (ppm)				
	Sugar Type			
	Sucrose	**Glucose**	**Water**	**Starch**
Trial 1	20491.4	16294.1	4983.11	6835.11
Trial 2	25819.5	11626.0	9780.60	5007.39
Trial 3	16972.9	12846.6	5531.93	5510.27
Trial 4	17788.0	27034.3	9449.33	11772.0

Table 5. Distribution's spread and mean.

Mean and Standard Error/Deviation per Group of Sugar's Reaction with Yeast (ppm)				
	Sucrose	**Glucose**	**Water**	**Starch**
Mean	20268.0	16950.3	7436.23	7281.19
Standard Error	500.246	601.7313	335.127	189.862
Standard Deviation	8722.09	10491.54	5843.14	3310.35
Final Average	12983.9			

Table 6. ANOVA testing and group variability required to conduct the test.

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	528347282.2	3	176115760.7	8.695312154	0.002450455	3.490294819
Within Groups	243049253.6	12	20254104.47			
Total	771396535.8	15				

SS_B = variability between groups
$SS_{W.}$ = variability within groups
df = degrees of freedom

M = number of independent samples
MSB = variance estimate between groups
MSW = variance estimate within groups

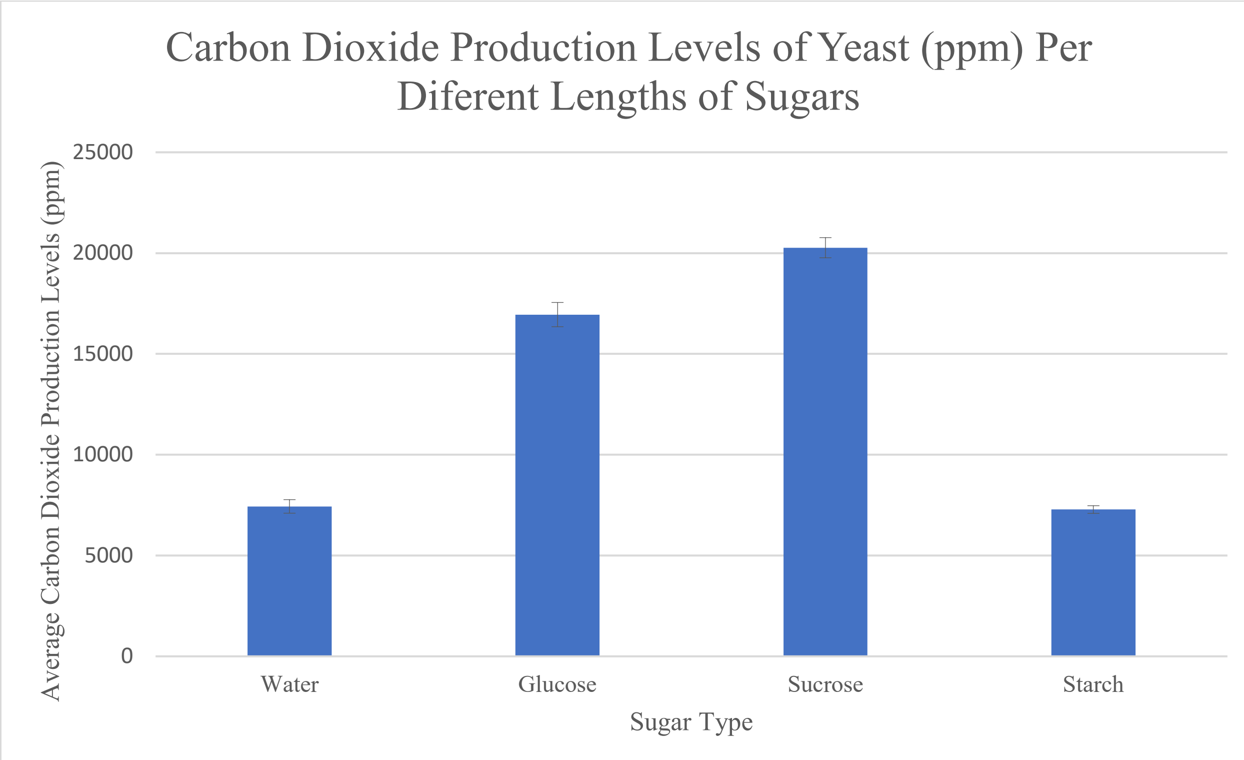

Figure 6: Graph of carbon dioxide respiration of yeast in different lengths of sugars.

Discussion

As per the research question, the collected data show that the null hypothesis of there is no statistical difference between the lengths of the sugar chain and the carbon dioxide production rate can be rejected. This is because the probability or p-value is 0.002450455, which is far less than the significance value of 0.05. There is a 0.0245% probability that the true means of all the groups are equal.

Although we can reject the null hypothesis, it does not mean that the alternative hypothesis is confirmed. This can be analyzed through a simple look at the bar graphs that shows the sample mean and standard error of the distribution. If the alternative hypothesis was true, the production would increase from water to starch and show a more linear trend. However, it only increased from water to sucrose and the starch data showed a downward trend from the given data, perhaps due to its solubility with water. Therefore, there is not enough evidence to support a correlation between the length of a saccharide and its carbon dioxide production levels.

In the real world, sucrose is common sugar, and therefore, most often used for purposes like baking or brewing. Perhaps it is also used in the real world because in comparison to other accessibly saccharide, sucrose has the highest carbon dioxide production levels and, therefore, would lead to the highest rise in bread or other baking elements. Since the yeast was not mutated, there were no problems in being able to identify high carbon dioxide production levels for the sucrose trials. This controls for the potential outliers that previous studies had predicted [1].

Overall, the methodology of the experiment went well. Using the carbon dioxide sensor was a good option to being able to control for any human error and because the data was very accessible, either through my phone or computer. The levels of the sugar, water, and yeast were very well controlled for, as they never reached the carbon dioxide sensor, but the carbon dioxide production was still picked up. Although it was hard to control for room temperatures as these trials were done at different times and often on different days, this error was eliminated through heating the water to a set number and controlling this temperature within the trial's bottle.

As seen in the raw data, there were a few outlier trials for the starch. The starch values fluctuated greatly due to the fact that it was hard to mix the solution since starch is very thick and resistant to water. The variance in the ANOVA testing is quite large, but the end production levels of carbon dioxide stayed the same, which served as a control for this large value.

A limitation of the ANOVA test is that it assumes that the data is normally distributed even though there are a few digressions that may not be accounted for in the statistical data. Therefore, the data must be transformed as needed. Another limitation of this test is that assumes that each group has the same or very similar standard deviations, which it does not. Instead, it varies by several thousand within each group. Moreover, the ANOVA test doesn't tell us how the data differ from the null hypothesis, just that it does. The f-statistic given only tells us if we can reject the null hypothesis, but not to which extent each group differs from the initial assumption.

References

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