OPTIMAL CARBON SOURCES FOR MAXIMIZING CO2 PRODUCTION IN YEAST FERMENTATION

Kate N. Lee - West Lafayette Junior High School, West Lafayette, IN – Grade 8

ABSTRACT

1. Introduction:

Yeast serves as a microscopic biological engine that converts carbohydrates into energy through fermentation. This process is a cornerstone of sustainable biofuel production, offering a renewable alternative to fossil fuels.

2. Problem Statement:

This study investigates how the structural complexity of carbohydrates, monosaccharides, disaccharides, and polysaccharides, affects the rate and efficiency of yeast metabolism and CO2 production.

3. Procedures:

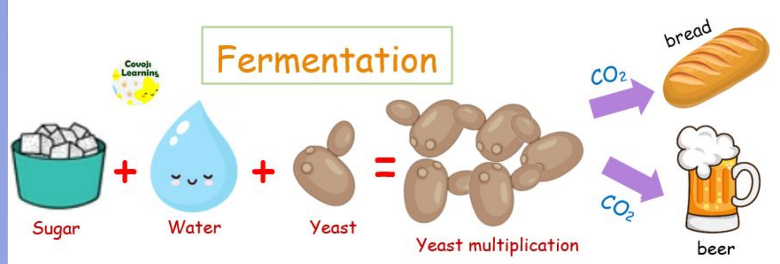
Using a syringe-based system at a constant 35°C, CO_2 output from glucose, sucrose, lactose, and starch over ten minutes was measured. An additional group of starch treated with α-amylase was tested to observe the impact of breaking down complex molecular chains.

4. Results:

Glucose (monosaccharide) exhibited the highest efficiency, exceeding the 10 mL syringe capacity within 8 minutes. Sucrose (disaccharide) followed with a steady rate, while starch alone showed negligible reaction. However, starch treated with α-amylase significantly increased gas production. Despite its disaccharide structure, lactose produced almost no CO_2 due to its specific molecular linkage.

5. Conclusions:

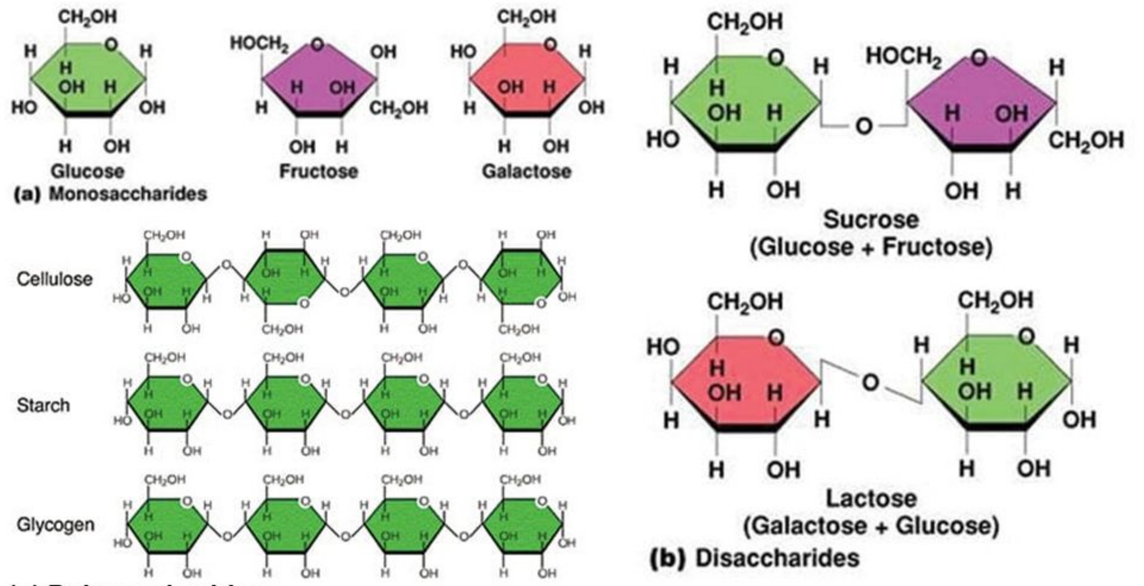
Yeast produces gas faster with simple sugars because their basic structure is easier to process for energy. Complex carbohydrates must be broken down by enzymes into smaller pieces before fermentation can happen. These findings help us choose the best raw materials to make future biofuel production more efficient.



INTRODUCTION

Sugar —Fermentation Process / by yeast→ **Ethanol** (CO_2) + **Carbon dioxide** (C_2H_5OH)

- Everybody is using fossil fuels almost every single day. This is leading to the lack of Fossil Fuels. It is widely known that fossil fuels will run out one day. Then, the best way to make the impact smaller is to find an alternative. After some research, there were a bunch of documents which stated that fermentation is a sustainable alternative to fossil fuels. Since ethanol and CO_2 are produced in a 1:1 ratio, measuring CO_2 identifies the optimal 'bio-fuel' source to maximize renewable energy efficiency.



- The research investigates how carbohydrate complexity (monosaccharides, disaccharides, and polysaccharides) affects yeast metabolism. This led to a unique research question: How do different carbohydrates affect the rate and efficiency of yeast metabolism?

HYPOTHESIS

While temperature acts as the primary switch to activate the yeast, the molecular structure of the carbon source determines its performance. If the **molecular complexity** of a carbon source increases, then the **rate of CO2 production** will decrease because complex carbohydrates require additional time to be broken down (hydrolyzed) before fermentation can occur.

RESEARCH OBJECTIVES

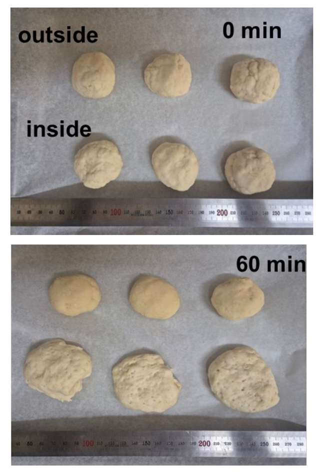
1. **Investigate temperature effects** on yeast activity using bread dough and balloon expansion to find optimal conditions.
2. **Quantitatively evaluate** how carbohydrate complexity impacts fermentation efficiency thru precise measurement.
3. **Analyze role of enzymatic hydrolysis** in starch fermentation to provide insights for biofuel production.

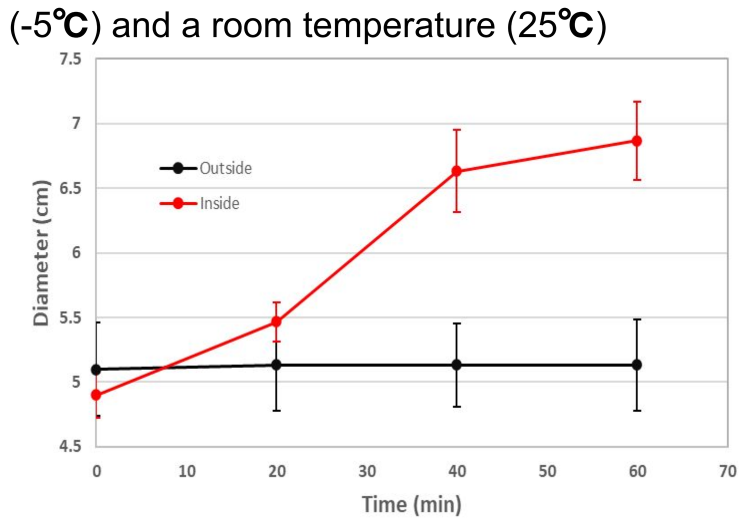
PROPOSED DESIGN

SEE HOW TEMPERATURE CHANGES HOW MUCH BREAD DOUGH RISES → QUANTIFY THAT YEAST PRODUCES HIGHER VOLUME OF GAS AS INCUBATION TEMPERATURE INCREASES TO OPTIMAL RANGE → EVALUATE IMPACT OF MOLECULAR STRUCTURES ON FERMENTATION EFFICIENCY OF YEAST.

RESULT 1 - THE BREAD DOUGH TEST

Design: The growth of dough diameter was compared between a cold outside environment (-5℃) and a room temperature (25℃)





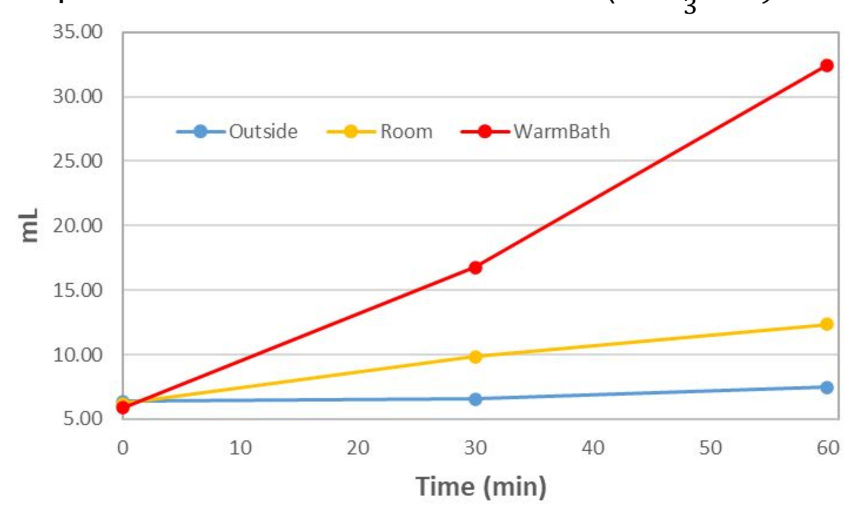
Method:

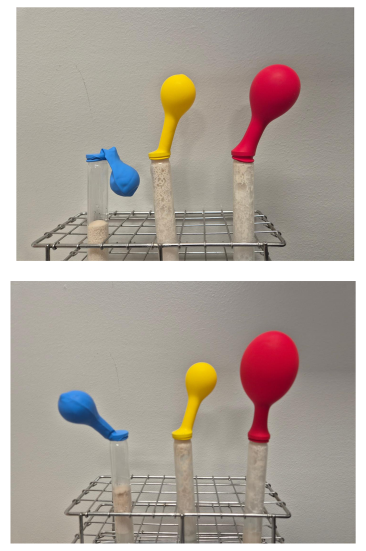
1. Dough preparation: Mix 1.5 cups of flour, 1.5 teaspoons of yeast, 1 tablespoon of sugar, and 1/2 cup of warm water. Knead the dough and divide it into three identical balls.
2. Cold and room temperature: Place one ball in outside (-5℃) and other in a room (25℃).
3. Observation: Measure diameter of each dough ball every 20 minutes for one hour. This process was repeated three times (triplicate) to ensure reliability and accuracy of data.

- **Outside (-5℃):** The dough showed negligible growth, as the freezing temperature inhibited the metabolic activity of the yeast
- **Inside (25℃):** The dough showed a steady and significant increase in diameter, indicating that the warmth successfully activated the yeast to produce CO2 gas.

PART 2 - EFFECT OF TEMPERATURE ON YEAST GROWTH

Design: Attach balloons to tube containing yeast and glucose at different temperatures. To quantify the results, treat the balloons as spheres and calculate their volume ($v = \frac{4}{3}\pi r^3$).





Method:

1. Preparation: 10 mL of water is dispensed into three separate 20 mL test tubes. To each tube, 1 g of sucrose and 0.5 g of yeast are added simultaneously to ensure identical starting conditions.
2. Place a balloon over the top of each tube.
3. Put one tube in outside (0℃), room (21℃), and warm water bath (35℃).
4. Data Calculation: The diameter of each balloon was measured, and the volume was determined using the formula.

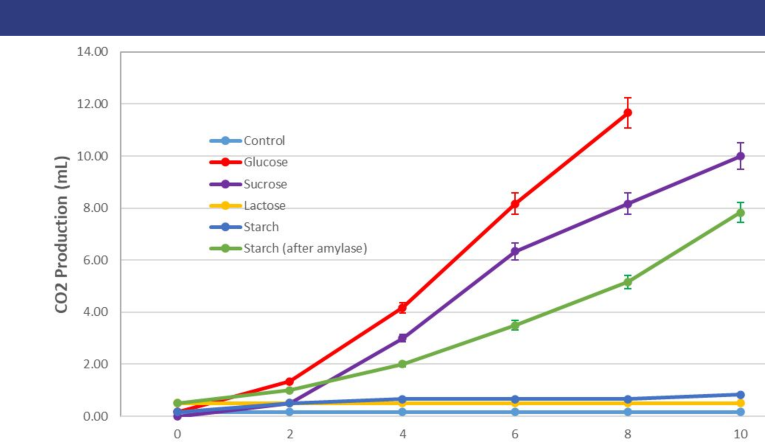
- **Temperature effect:** A clear trend was observed where higher temperatures resulted in greater balloon inflation, confirming that heat accelerates yeast fermentation.
- **Observation:** While the balloons did inflate, they did not grow drastically expected over time. This limited expansion suggests that the gas pressure of yeast was not strong enough to fully stretch the thick rubber of balloons.

PART 3 - IMPACT OF CARBON SOURCES ON YEAST FERMENTATION

Design: Using 10 mL syringes at a constant 35C, measure the CO2 production from carbohydrates with different structural complexities.

Method:

1. Yeast: Active dry yeast (0.5 g per tube).
2. Carbon sources (1 g per tube):
   - Monosaccharide: glucose
   - Disaccharides: sucrose, lactose
   - Polysaccharide: corn starch
3. Enzyme: commercial α-amylase (digestive enzyme).
4. Laboratory Equipment: 10 mL syringes, 20 mL test tubes with airtight rubber stoppers, a water bath, and a digital scale



Carbon Source	Control	Glucose	Sucrose	Lactose	Starch	Starch with amylase
Production rate (mL/min)	0.0±0.0	1.7±0.1	1.3±0.1	0.0±0.0	0.0±0.0	0.7±0.2

- **Glucose (Fastest)**: highest rate of CO2 production (1.7±0.1 mL/min) among all groups. Due to its exceptionally fast fermentation, the gas volume exceeded the 10 mL measurement capacity of the syringe within 8 minutes
- **Sucrose**: Second most efficient fuel; slower but more consistent progression than glucose.
- **Starch & Amylase**: While untreated starch showed no reaction, the starch treated with α-amylase showed a significant increase in gas production. This indicates that yeast cannot directly ferment complex starches without prior enzymatic breakdown.
- **Lactose:** Produced negligible CO2, proving yeast cannot metabolize this specific disaccharide.

DISCUSSION

- The results support the hypothesis that as carbohydrate molecular complexity increases, the rate of yeast fermentation decreases.
- Glucose, a monosaccharide, was immediately available for yeast metabolism and produced the highest rate of CO_2.
- Sucrose, a disaccharide, required additional processing before fermentation and therefore produced CO_2 more slowly than glucose.
- Untreated starch showed almost no CO_2 production, indicating that yeast cannot directly utilize complex polysaccharides. However, when starch was pre-treated with α-amylase, CO_2 production increased significantly, demonstrating that breaking starch into smaller sugars enables fermentation.
- Lactose produced little to no CO_2 despite being a disaccharide, showing that yeast cannot utilize lactose as a carbon source under these conditions.

ERROR ANALYSIS

- **Temperature control**: Lack of precise home temperature regulation may have caused minor variations in yeast metabolic rates.
- **Reaction start time**: Rates were calculated exclusively from the 2-8 minutes linear region to offset initial sealing delays.
- **Enzyme efficiency**: Unconfirmed hydrolysis completion during the 5-minute incubation may have influenced starch fermentation data.

APPLICATIONS

Optimizing bio-ethanol production

- Bio-ethanol is widely produced from corn starch, but yeast cannot directly ferment starch without breaking it into smaller sugars. This study shows that enzymatic pre-treatment is essential for improving fermentation efficiency.
- By reducing carbohydrate size, yeast can produce CO_2 (and ethanol) more rapidly, helping to maximize bio-ethanol yield and support sustainable energy production.

Advancements in food science and fermentation technology

- In food fermentation, yeast performance also depends on the type of carbohydrate available. These results show that providing yeast with easily fermentable sugars or enabling starch breakdown can improve fermentation speed and consistency.
- This principle can be applied to baking and brewing to better control rising time, texture, and product quality.

CONCLUSION

- Yeast fermentation efficiency decreases as carbohydrate molecular complexity increases.
- Simple sugars were fermented rapidly, while complex carbohydrates required size reduction before fermentation could occur.
- CO_2 production served as a reliable indicator of fermentation efficiency.
- Controlling carbohydrate structure can improve fermentation processes in bio-ethanol production and food fermentation.

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