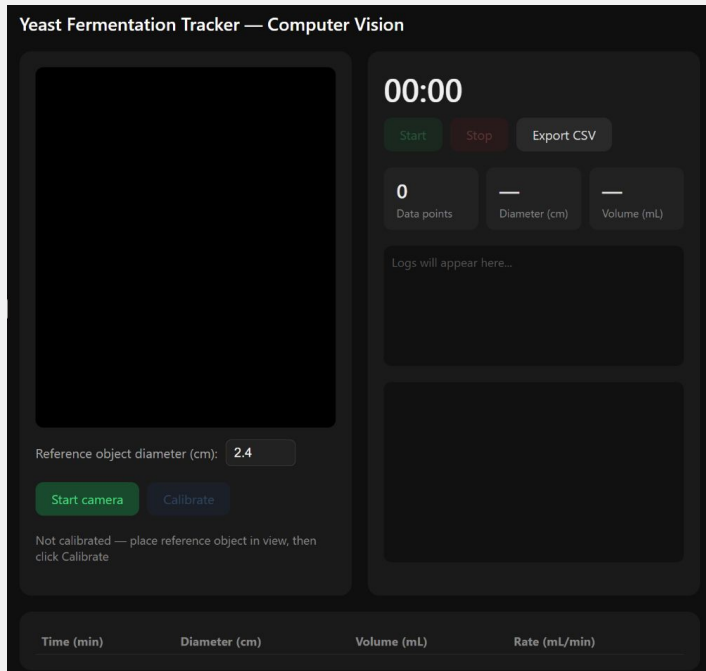


Automated Analysis of Yeast Fermentation Efficiency Across Carbohydrate Structures



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Project ID : MCRO 808

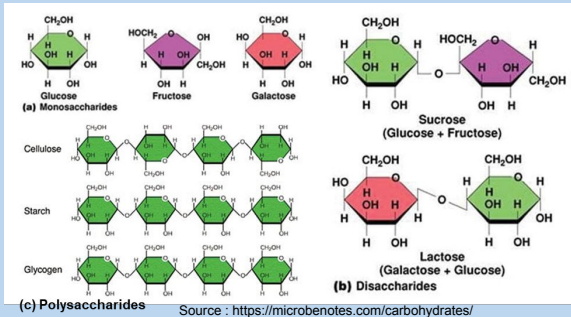
The codes were all written by Kate Lee, the CSV data is claimed by Kate Lee. All "experiments" were done at home.

Introduction : Overview

Introduction

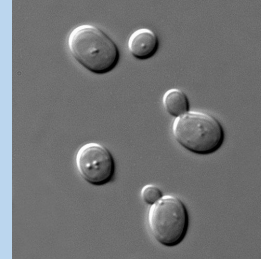
Yeast fermentation provides a sustainable alternative to fossil fuels. Since ethanol and CO₂ are produced in a 1:1 ratio, measuring CO₂ identifies the optimal “bio-fuel” source to maximize renewable energy efficiency.

This investigates how carbohydrate complexity affects yeast metabolism. This led to a unique research question: How does different carbohydrates affect the rate and efficiency of yeast metabolism?



Source : <https://microbenotes.com/carbohydrates/>

Yeast (*Saccharomyces cerevisiae*)



Source : <https://en.wikipedia.org/wiki/Yeast>

- In tentative reaction conditions, yeast reacts with sugar to produce CO₂
- Wanted to explore more about the biological mechanisms behind this common yet extraordinary life process

Motivation



- Observing bread dough double in size inspires to be viewed as microscopic ‘bio-factory’.
- Project aimed to explore biological mechanisms behind extraordinary CO₂ production.

Source :

<http://www.kvalifood.com/page/bread-baking-technique-6-the-rise-of-the-bread-or-fermentation-as-it-is-known/uid/1c8a0b3e-4f7c-11e6-8687-8e3194b43af8>

Introduction: Hypothesis and Objective

Hypothesis

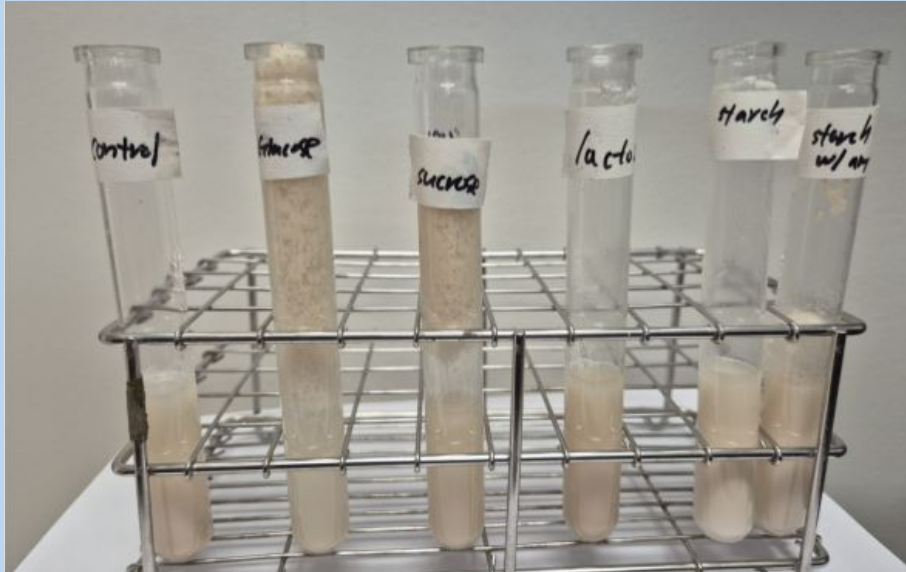
If the molecular complexity of a carbohydrate source decreases, then the CO₂ production rate of the yeast will increase because simpler sugars can be metabolized more quickly without extensive hydrolysis. Additionally, an automated Computer Vision algorithm will provide higher precision than manual measurement by eliminating human error.

Objective

- Analyze yeast activity via bread and balloon expansion, using **OpenCV**, python library to automate measurements and minimize human error.
- Evaluate fermentation efficiency across carbohydrates using syringes, enhanced by **NumPy/Matplotlib** for high-fidelity data analysis.
- Study enzymatic hydrolysis in starches for biofuel insights, using **automated CSV exporting** to model efficient renewable energy processes.

Experimentation: Goals and Proposed Design

Goals



Step 1 : See how temperature changes how much bread dough rises
Step 2 : Demonstrate and quantify that yeast produces a higher volume of gas as the incubation temperature increases toward its optimal range.
Step 3 : Quantitatively evaluate the impact of carbohydrate molecular structures on the fermentation efficiency of yeast.

Proposed Design

STEP 1. THE BREAD DOUGH TEST



STEP 2. EFFECT OF TEMPERATURE ON YEAST GROWTH



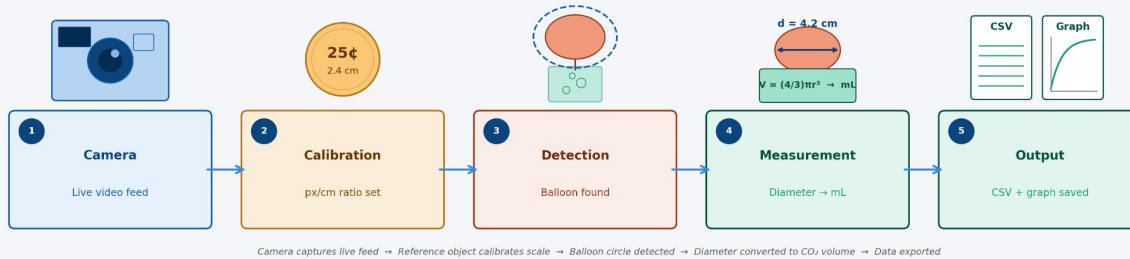
STEP 3. IMPACT OF CARBON SOURCES

Algorithm: Goals and Proposed Design

Goals / Key Information

Algorithm of Computer Vision

Automated balloon measurement pipeline



1. Automate balloon diameter measurement using a camera
2. Eliminate human measurement error from manual ruler readings
3. Continuously track CO₂ volume over time without manual intervention

1. **OpenCV** detects and measures the balloon using the camera.
2. **NumPy** processes the pixel data.
3. **Math** calculates CO₂ volume from diameter.
4. **Matplotlib** generates the graphs.
5. **CSV** saves the data.
6. **OS** finds your Desktop automatically.

Algorithm : Broken Down

**CAMERA CAPTURES
LIVE VIDEO FEED**

**REFERENCE OBJECT
DETECTED**

**DIAMETER IS CONVERTED
TO CO₂ VOLUME**

**DATA LOGGED
AUTOMATICALLY 30 SEC**

**RESULTS EXPORTED AS
CSV , PLOTTED INTO
GRAPHS**

Experimentation: Step 1

Comparison of Bread Dough Expansion at Different Temperatures

Goal : See how temperature changes how much bread dough rises.

Design : Growth of dough diameter compared between cold outside environment(5C) and room temperature (25C).

Procedures

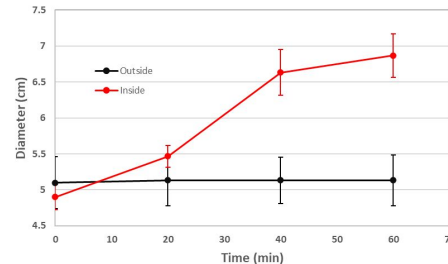
- Dough preparation**: Mix 1.5 cups of flour, 1.5 teaspoons of yeast, 1 tablespoon of sugar, and 1/2 cup of warm water. Knead the dough and divide it into three identical balls.
- Cold and room temperature**: Place one ball in outside (-5C) and the other in a room (25C).
- Observation**: Measure the diameter of each dough ball every 20 minutes for one hour. This process was repeated three times (triplicate) to ensure the reliability and accuracy of the data. This experiment was conducted 10 times.

RESULTS : PART 1

Comparison of bread dough expansion at different temperatures



RESULTS : PART 2



Outside (-5°C): Dough showed negligible growth, as freezing temperature inhibited metabolic activity of the yeast.

Inside (25°C): The dough showed steady and significant increase in diameter, indicating that warmth successfully activated yeast to produce CO₂ gas.

Experimentation: Step 2

Quantitative Measurement of CO₂ Production Using Balloon Volume at Different Temperatures

Goal : Demonstrate and quantify that yeast produces a higher volume of gas as the incubation temperature increases towards its optimal range.

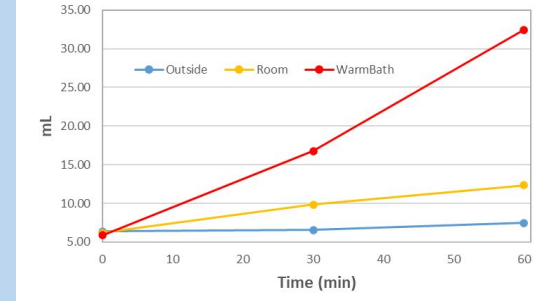
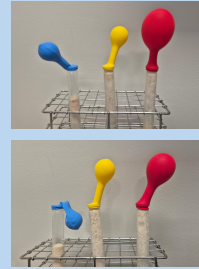
Design

Attach balloons to tube containing yeast and glucose at different temperatures. To quantify the results, treat the balloons as spheres and calculate the volume.

Procedures

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

Results



Temperature effect: A clear trend was observed where higher temperatures resulted in greater balloon inflation, confirming that heat accelerates yeast fermentation.

Observation: While balloons did inflate, they did not grow as drastically as expected over time. This limited expansion suggests that "pushing power" (gas pressure) of yeast was not strong enough to fully stretch thick rubber of balloons.

Accuracy: Although this experiment visually confirms that warmth activates yeast, using balloons is not the most accurate way to measure exact gas volume.

Experimentation: Step 3

Evaluation of Impact of Molecular Structures on Fermentation Efficiency of Yeast.

Goal : The objective of this research is to quantitatively evaluate the impact of carbohydrate molecular structures on the fermentation efficiency of yeast (*Saccharomyces cerevisiae*).

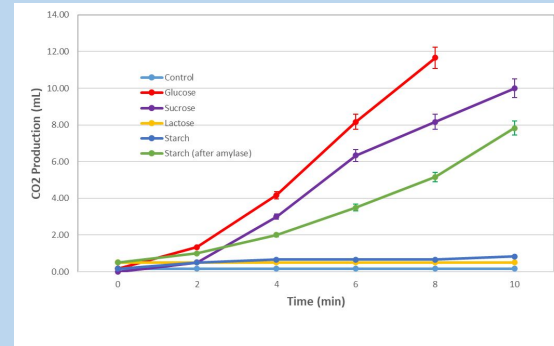
Design

High-Precision Syringe Displacement: (35C): Tracks exact CO₂ volume, eliminating balloon elasticity issues to enable high-fidelity kinetic modeling

Procedures

- Solution preparation:** 10 mL of warm water is dispensed into 20 mL test tubes, and 1 g of each carbon source is dissolved. For the "Starch + amylase" group, 100 mg of amylase is incubated for 5 minutes to ensure hydrolysis before adding yeast.
- Fermentation:** 0.5 g of yeast is added to each tube simultaneously. The tubes are immediately sealed with airtight caps and connected to 10 mL syringes.
- Data Logging & Analysis:** Recorded CO₂ displacement every 2 minutes. Raw data was processed using NumPy and Matplotlib to generate high-fidelity fermentation curves and calculate precise metabolic rates.

Results



- Glucose (Fastest):** Highest efficiency (1.7±0.1 mL/min); exceeded 10 mL capacity within 8 minutes.
- Sucrose:** Second most efficient fuel with a steady fermentation rate.
- Enzyme Effect:** Starch treated with α -amylase showed significantly increased gas production.
- Lactose:** Negligible reaction due to its specific molecular linkage.

Advancements(after Regionals)

```
optimal.py x
10 REFERENCE_CM = 2.4 # diameter of your reference object in cm (e.g. a quarter)
11 CAPTURE_INTERVAL = 30 # seconds between auto-captures
12 OUTPUT_CSV = "fermentation_data.csv"
13 #
14
15 pixels_per_cm = None
16 data_log = [] # list of (elapsed_min, diameter_cm, volume_mL)
17
18 def volume_from_diameter(d_cm):
19     r = d_cm / 2
20     return (4/3) * math.pi * r**3 * 1000 # cm^3 -> mL (approx)
21
22 def find_circles(frame):
23     """Detect circular objects in frame, return list of (x, y, r) in pixels."""
24     gray = cv2.cvtColor(frame, cv2.COLOR_BGR2GRAY)
25     blurred = cv2.GaussianBlur(gray, (11, 11), 0)
26     circles = cv2.HoughCircles(
27         blurred, cv2.HOUGH_GRADIENT, dp=1.2,
28         minDist=50, param1=100, param2=30,
```

Python

```
index.html styles.css scripts + HTML RUN
1 <!DOCTYPE html>
2 <html lang="en">
3 <head>
4 <meta charset="UTF-8">
5 <meta name="viewport" content="width=device-width, initial-scale=1.0">
6 <title>West Fermentation Tracker</title>
7 <style>
8 * { box-sizing: border-box; margin: 0; padding: 0; }
9 body { font-family: system-ui, sans-serif; background: #f0f0f0; padding: 1rem; }
10 h1 { font-size: 1.5em; font-weight: 500; margin-bottom: 1rem; color: #fff; }
11 @grid { display: grid; grid-template-columns: 1fr 1fr; gap: 1rem; }
12 @media (max-width: 700px) { @grid { grid-template-columns: 1fr; } }
13 <div class="card" style="background: #1a1a1a; border-radius: 12px; padding: 1rem; }
14 <div style="width: 100%; border-radius: 8px; background: #000; }
15 <div style="display: flex; }
16 <div style="display: grid; grid-template-columns: repeat(3, 1fr); gap: 8px; margin-bottom: 1rem; }
17 <div style="background: #222; border-radius: 8px; padding: 0.5rem 0.8rem; }
18 <div style="font-size: 20px; font-weight: 500; }
19 <div style="font-size: 11px; color: #888; margin-top: 2px; }
20 <div style="display: flex; gap: 8px; flex-wrap: wrap; margin-bottom: 1rem; }
21 <div style="padding: 8px 16px; font-size: 11px; border-radius: 8px; border: none; cursor: pointer; font-family: inherit; }
22 <div style="background: #1a1a1a; color: #4ade00; }
23 <div style="background: #1a1a1a; color: #871717; }
24 <div style="background: #1a1a1a; color: #004ade; }
25 <div style="background: #2a2a2a; color: #000; }
26 <div style="border: 1px solid #000; border-collapse: collapse; font-size: 12px; }
27 <div style="font-size: 12px; padding: 5px 6px; color: #888; border-bottom: 0.5px solid #333; }
28 <div style="padding: 4px 8px; border-bottom: 0.5px solid #222; color: #ddd; }
29 <div style="background: #111; border-radius: 8px; padding: 0.5rem; margin-bottom: 1rem; }
30 <div style="width: 100%; }
31 <div style="width: 100%; border-collapse: collapse; font-size: 12px; }
32 <div style="text-align: left; padding: 5px 6px; color: #888; border-bottom: 0.5px solid #333; }
33 <div style="padding: 4px 8px; border-bottom: 0.5px solid #222; color: #ddd; }
34 <div style="background: #111; border-radius: 8px; }
35 <div style="display: flex; align-items: center; gap: 8px; margin-bottom: 1rem; font-size: 11px; color: #aaa; }
36 <div style="width: 80px; background: #222; border: 0.5px solid #444; color: #fff; border-radius: 6px; padding: 5px 8px; font-size: 11px; }
37 </style>
```

HTML/Javascript

At LRSEF, I said...

Measuring could have been an error.

- Measuring diameter manually with a ruler isn't always accurate.
- Human eye reading has around 1~2 mm error
- Only a few data points were retrieved from each experiment.
- The center of the sphere might not have been the exact location that I calculated.

Now, in my project...

I minimized the error discrepancies.

- Used OpenCV, library you could use in Python.
- Converts pixels to centimeters (reference object).
- Logs diameter and CO2 volume automatically every 30 seconds to increase convenience.
- Exports everything to CSV file (to Excel)
- Generates graphs automatically(javascript version)
- Continuous data stream

Conclusion & Implications

- **Hypothesis Verified:** The experiment confirmed that molecular complexity inversely affects fermentation rates. Glucose (monosaccharide) showed the highest efficiency, while starch (polysaccharide) required enzymatic hydrolysis to be effectively metabolized.
- **Algorithmic Precision:** The transition to a Computer Vision pipeline successfully eliminated the human measurement error, providing a high-fidelity, continuous data stream for metabolic modeling.
- **Optimal 'Bio-fuel' Source:** By analyzing the 1:1 ratio of ethanol to CO₂, this study identifies that simple sugar structures or enzyme-treated starches are the most efficient sources for maximizing renewable energy production.
- **The 'Biological Engine' Model:** This research proves that both environmental activation (temperature) and fuel quality (carbohydrate structure) must be optimized to achieve peak biological efficiency.

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