How do donut dough expansion rates differ due to the temperature, type of leavening agents, or the quantity of leavening agents?

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Abstract

Making dough requires leavening, which consists of a process of fermentation. Prior to the proofing process is the initial preparation of the dough. The gliadin and glutenin– spherical and elongated components of the gluten protein that help make the dough elastic– have to first be developed through continuous kneading of the mixture. This procedure retains the carbon dioxide gasses during the proofing process. [4] To form the inhibitory tissues, yeast, water, and donut mix must be synthesized to start the interaction between the gluten proteins. As the glutenin is stretched, it allows for the gliadin spheres to disperse, creating a cohesive mixture that allows for the trapping of carbon dioxide gasses. This leads up to the fermentation process, in which it calls for a multistep conversion of molecules with gluten-yeast enzymes to expand the gliadin and glutenin structures. The maltase enzymes of the yeast first convert maltose (a sugar found in starch) into simple sugars. These simple sugars then become suitable for the reaction with the zymase, where it converts the simple sugars into the familiar products of alcohol and carbon dioxide. [5] The carbon dioxide particles then push the periphery of the dough, making it expand.

Introduction

When baking donuts, there are numerous chemical processes that happen when making a final product. One of these infamous processes is the Maillard reaction that occurs when frying donuts. However this reaction is universal as it's applied to many recipes for cooking and baking. But a reaction that specializes in donut chemistry is the process of fermentation, with the utilization of yeast. Donut dough can be made through synthesizing key ingredients like gluten, water, and yeast. In a typical process specified by the carrier company Multifoods, it takes an industrial donut batch approximately 30 minutes to double its size in a 72 degree Fahrenheit environment. [9] Through this experiment, variables including the temperature of the environment, the type of leavening agent, and the quantity of the leavening agent were changed to see if it impacts the rate of dough leavening. Currently in today's standards, there are known facts about these variables, but exploration will also be conducted to explain the changes of these components.

The first variable that will be tested is temperature. Generally, when increasing the temperature of an environment, it will increase the kinetic energy of different molecules. This will allow them to go beyond the activation threshold and allow for more collisions. [6] In this case, the carbon dioxide molecules will have increased kinetic energy and will collide with the glucose molecules more frequently, allowing for more visible expansion in the dough's volume. Thus, it is to be expected that there is proportionality between the reaction rates and change in temperature.

The second variable that will be tested is leavening agents which each have slightly different functionalities although all being used for the same purposes. Baking soda (also known as sodium bicarbonate) is used when all other ingredients are acidic, allowing for the maximum release of carbon dioxide. In contrast, baking powder is used when all other reactants involved already contain some type of base in addition to the baking soda. A special property of this reagent is that depending on the type of baking soda, it will initiate a single or double-acting sequence. Single-acting will cause an immediate release of carbon dioxide gasses when added into the mixture, while a double-acting sequence requires baking for more carbon dioxide to be released. The baking soda that will be used in the experiment (by Argo) is labeled as “double acting”. [7] This experiment will only measure the proofing process, meaning that only the first stage of release will occur. Yeast is different from the other two leavening agents, as it involves a fermentation reaction between its molecules and the glucose. It is expected that each of these leavening agents will have different reaction rates.

The last variable that is going to be tested is the change in quantity. This is similar to the idea of temperature change where it is expected to change the reaction rate. An increase of the leavening reagent, yeast, increases the rate of the fermentation process as there is more maltase present to convert the glucose structures into sugars. Thus, this should be another scenario where the variable, quantity of yeast, is proportional to the change in rising rates. Moreover, this experiment is going to test whether it is a first or second order reaction, observing if reaction rate is actually dependent on quantity. If it is a zero order reaction, the dough's rising rates are independent from yeast quantity.

With these three variables in mind, I hypothesized that if we change variables that affect the composition of the dough (type of leavening agent and amount of leavening agent) or the environment (temperature change), the dough's rising times (time for volume change) will be altered. Three experiments with these three variables will be conducted to see whether changing the composition or the environment influences the proofing time of the dough.

Methodology

The work consisted of three experiments: Testing the influence of the environment (ENVIRONMENT TEST), influence of the leavening reagent (AGENT TEST), and the influence of the amount of leavening agent utilized (QUANTITY TEST) in which they use similar apparatuses and procedures.

The experimental conditions and supplies are described below
ENVIRONMENT TEST: 67 oz California Raised Donut Mix (Multifoods), 31 oz water, 1.25 oz Saf-instant yeast, 9 Pyrex Cups, Mixer (Hobart), Refrigerator (True Manufacturing), Proofer (Cozoc), IOS device (utilized as a stopwatch), Taylor Stainless Steel Digital Kitchen Scale, alternate flat surface (smaller than the circle area of the Pyrex cup), 2 Taylor Refrigerator/Freezer Thermometers
AGENT TEST: 67 oz California Raised Donut Mix (Multifoods), 31 oz water, 9 Pyrex Cups, 0.42 oz Saf-instant yeast, 0.42 oz Argo Baking Powder, 0.42 oz First Street Pure Baking Soda, Proofer (Cozoc), IOS Device (utilized as a stopwatch), Taylor Stainless Steel Digital Kitchen scale, alternate flat surface (smaller than the circle area of the Pyrex cup)
QUANTITY TEST: 67 oz California Raised Donut Mix (Multifoods), 9 Pyrex Cups, 31 oz water, 1.48 oz Saf-instant yeast, Proofer (Cozoc), IOS Device (utilized as a stopwatch), Taylor Stainless Steel Digital Kitchen scale, alternate flat surface (smaller than the circle area of a pyrex cup)

A step-by-step protocol is provided below, which was followed for this study.

1. Cups were labeled in accordance to their corresponding treatment and/or subject number (examples: W1 -> Warm Environment, Cup #1; Y3 -> Yeast Treatment, Cup #3; 0.14 -> Cup with 0.14oz yeast). The ENVIRONMENT TEST uses **W**arm, **N**ormal, and **C**old for its treatments having 3 subjects per environment. The AGENT TEST uses **Y**east, **B**aking **S**oda, **B**aking **P**owder for its treatments, having 3 subjects per type of leavening agent. The QUANTITY TEST uses 5 groups labeled in form of “#V”: 0.03V, 0.10V, 0.14V, 0.18V, and 0.28V where each group had one cup. If it was the ENVIRONMENT TEST, thermometers would be placed in their respective environments in the pre-experimental procedure. See figure 1.

A B C

Figure 1: Dough samples in Experiment A (3 in 3 sets) that received each treatment. The warm treatment (A) was labeled W1 (W as in warm), W2, and W3 respectively. The normal treatment (B) was labeled N1 (N as in normal), N2, and N3 respectively. The warm treatment (C) was labeled C1 (C as in cold), C2, and C3 respectively.

2. A scale was then used to measure out quantities relating to the amount of treatments groups the experiment had. The ENVIRONMENT TEST utilized a 72 oz batch, the AGENT TEST utilized a 24 oz batch (repeated 3 times), and the QUANTITY TEST utilized a 12 oz batch (repeated 5 times). To retain consistent dough composition, all tests used 7 min, 5 min, 3 min mixing times respectively, according to dough size.
3. Proofing machine was turned on to allow for dough to be set into a warm environment.
4. The ingredients were incorporated into the mixer (pouring in the yeast last to delay any room temperature proofing moments.
5. The dough was then swiftly put into their cups corresponding to their specified treatments and subject number on their label. To prohibit air-space in the cups, the dough was fluidly pressed down around the circumference of the cup. A flat object is then used to level off the dough at the top of the cup to allow for more accurate measurements.
6. Once all cups were in their environments, the stopwatch was started.
7. Cup volume was collected between intervals of time. The ENVIRONMENT TEST is an exception in which it had different intervals for its treatments due to anticipation that one treatment will take longer than the other (measured in 2 minute, 5 minute, and 30 minute intervals). Otherwise, every treatment in these sets of experiments utilized 2 minute collection intervals. The data was collected for 40 minutes in — minute intervals, with the

rule that if a dough's volume stagnated and it didn't increase by <0.1 for 5 consecutive intervals, the data collection would be terminated. Temperature was also collected through thermometers to collect data about the environment.

After the procedure, tables on excel were recorded with data for each experiment, as shown in Table 1.

Warm Condition			
Time (min)	Sample 1 (fl oz)	Sample 2 (fl oz)	Sample 3 (fl oz)

Table 1: Table of room-temperature samples from Experiment A data

Results/Analysis
ENVIRONMENT TEST:
As expected, the dough in the higher temperature environments tended to rise at a faster rate (Figure 2, 3, 4). Each experiment started with approximately 8 oz of dough, where the time it took for the dough to double can be accounted for. For the dough to double, It took approximately 32 minutes in the warm environment, 50 minutes for the room temperature environment, and 330 minutes for the cold environment. This is mainly under the influence of reaction rates which affects the rate of fermentation between the glucose molecules and the enzymes of the yeast. This will result in more frequent collisions with the gluten structures since carbon dioxide would become more concentrated residing inside the dough. Not only the concentrated space, but the collisions in general can be expedited through higher temperatures resulting also in more frequent collisions.

Warm treatment:

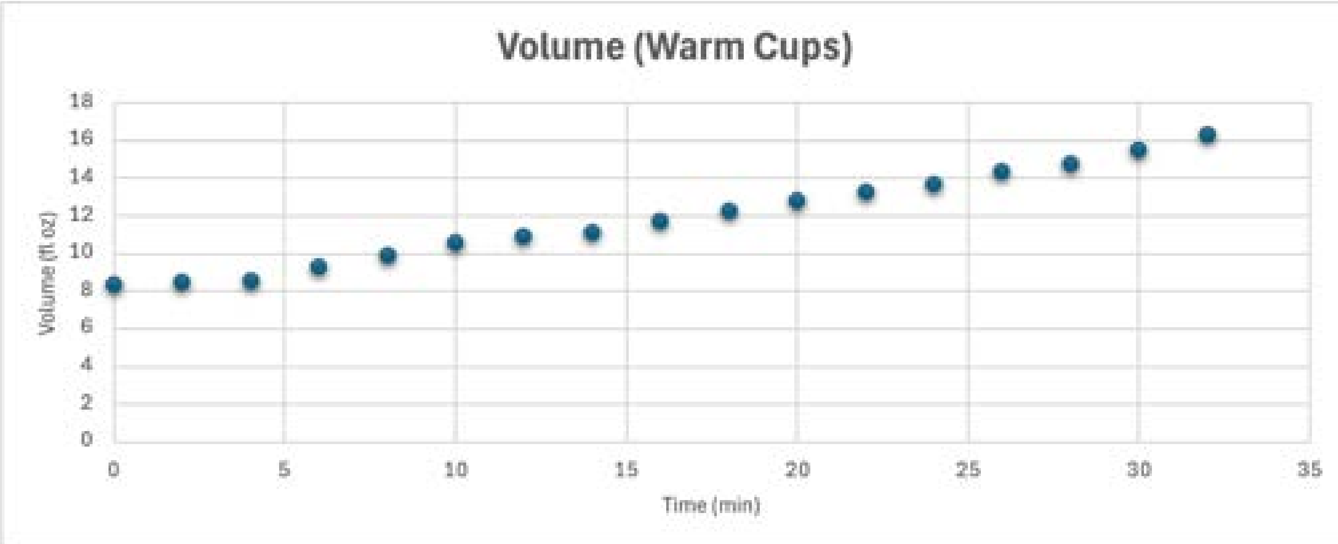

Figure 2: Scatterplot displaying volume in relation to time for dough in the warm environment. Time interval between the points is 2 minutes. The linear relation has an average slope of 0.249 fl oz/min.

Normal Treatment:

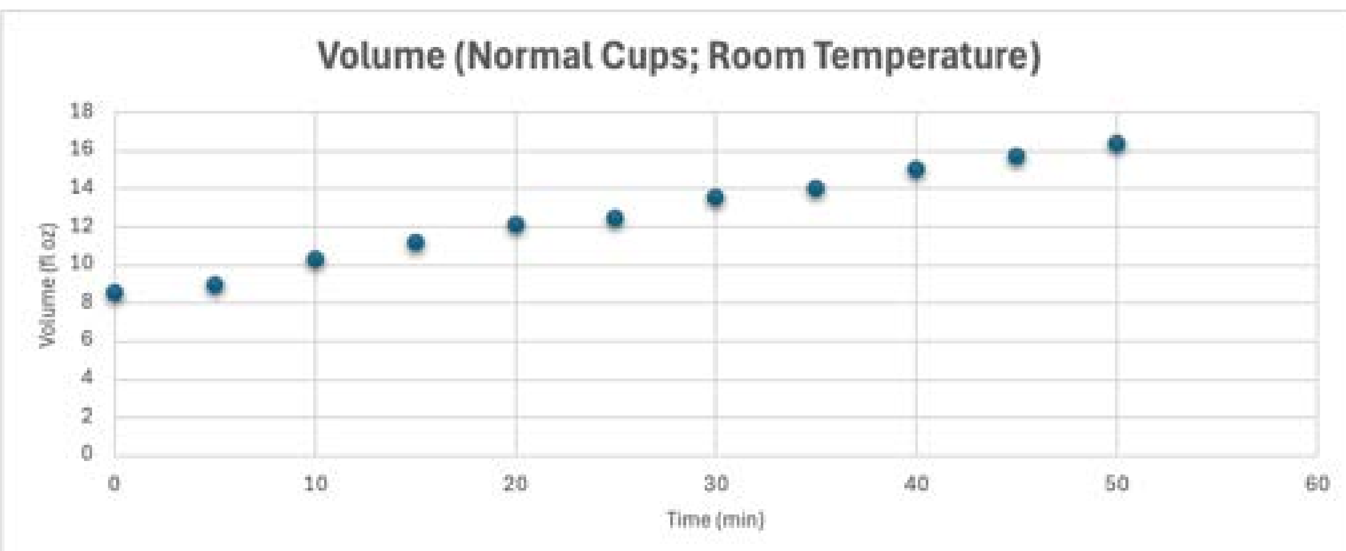

Figure 3: Scatterplot displaying volume in relation to time for dough in the normal environment, at room temperature. Time interval between the points is 5 minutes. The linear relation has an average slope of 0.156 fl oz/min.

Cold Treatment:

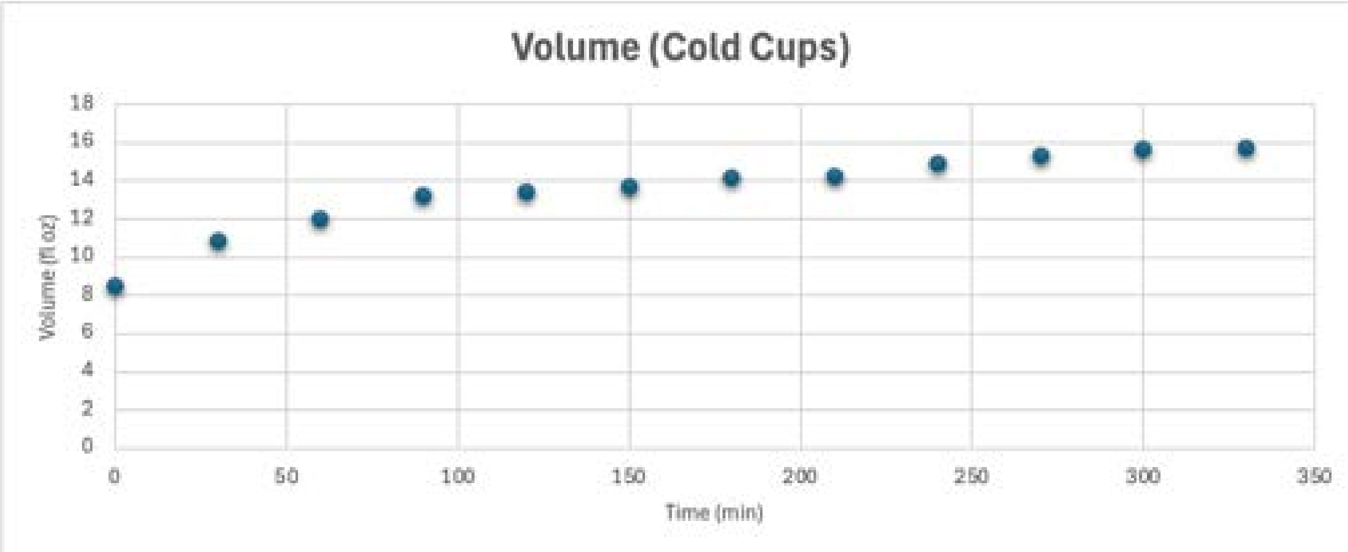

Figure 4: Scatterplot displaying volume in relation to time for dough in the cold environment. Time interval between the points is 30 minutes. The linear relation has an average slope of 0.02 fl oz/min.

When the slopes (relations between time and volume) were further analyzed, the relations of the slope values through each experiment were expected: 0.02(C) < 0.156 (N) < 0.249 (W). Refer to Table 2 and Figure 5. The slope increased as the environment had a higher temperature. This supported the hypothesis that higher temperatures contribute to faster rising times for dough. A rough secondary equation could be constructed by comparing the temperature and slopes through another data set where for every unit increase of temperature, the rising rate of the dough increases by 0.0033 fl oz/min. Although consisting of only three points for the data set, it can still help explain the strong positive correlation between temperature and rising rates.

Condition	Average Rate of Rising (fl oz/min)	Standard Deviation (fl oz/min)
Cool	0.022	0.023
Room-temperature	0.156	0.067
Warm	0.249	0.114

Table 2: Table showing the average rising rates of the dough and the standard deviation between all collected intervals for all environments.

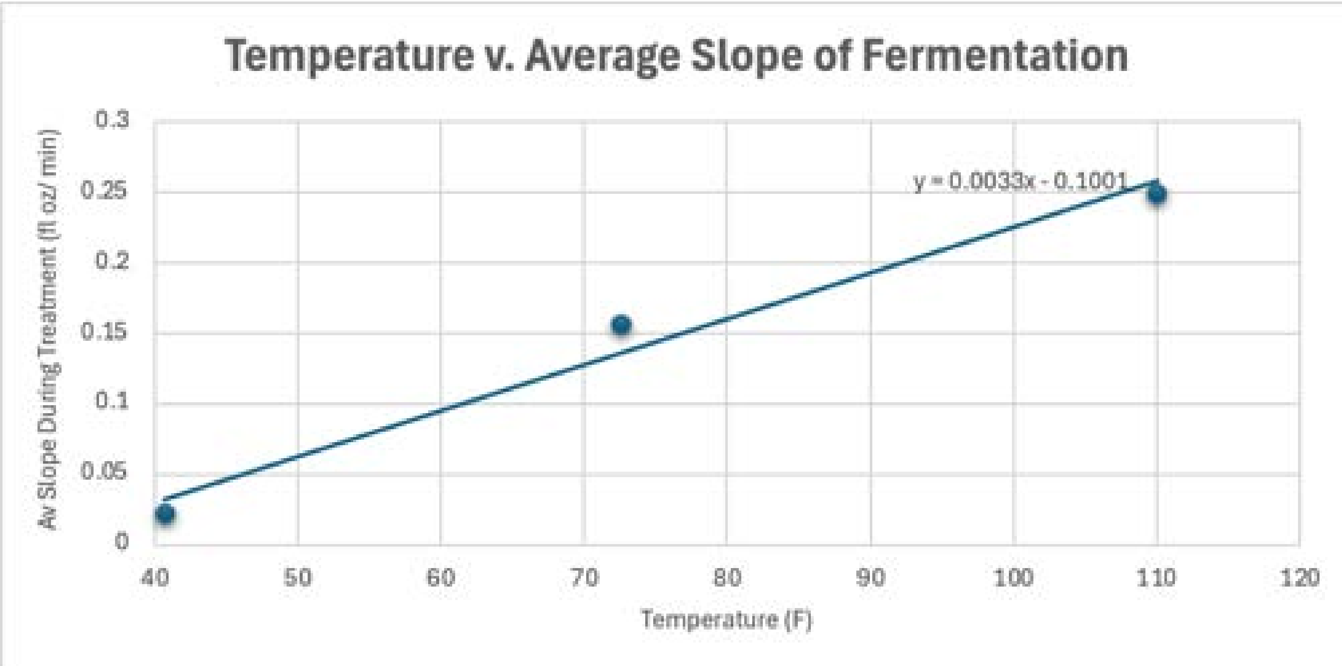

Figure 5: Scatterplot displaying a positive linear correlation between temperature and average slope of rising rates for dough in different treatments.

Experiment B:
This experiment demonstrates that yeast is the best leavening agent for the donuts tested (Figure 6, 7). The rising rate for yeast is greater than the baking soda and the baking powder (0.321<0.0908<0.0479), where it continues a linear growth path while the others tend to deviate towards logarithmic growth. This is an apparent pattern for the less effective treatments, like the dough that utilized the room temperature or cool environments in Experiment A. Additionally, the reason why baking soda or baking powder was not as effective is that the donut mix was not for the use of baking soda or baking powder. Multifoods stated within its instructions to use yeast. The main reason is due to the fact that traditional donut mix is only weakly acidic in terms of pH. The pH balance of a donut after ambient cooling is 5.51. [8] Without being critically basic or acidic, which baking soda or baking powder require, they are not very strong leavening agents. Because yeast is a biological reagent and doesn't require a certain pH to react well, yeast is the best alternative for making donuts. This could indicate that the yeast enzymes have denatured through the leavening process leading to slower reaction rates decreasing the slope in the depicted graph.

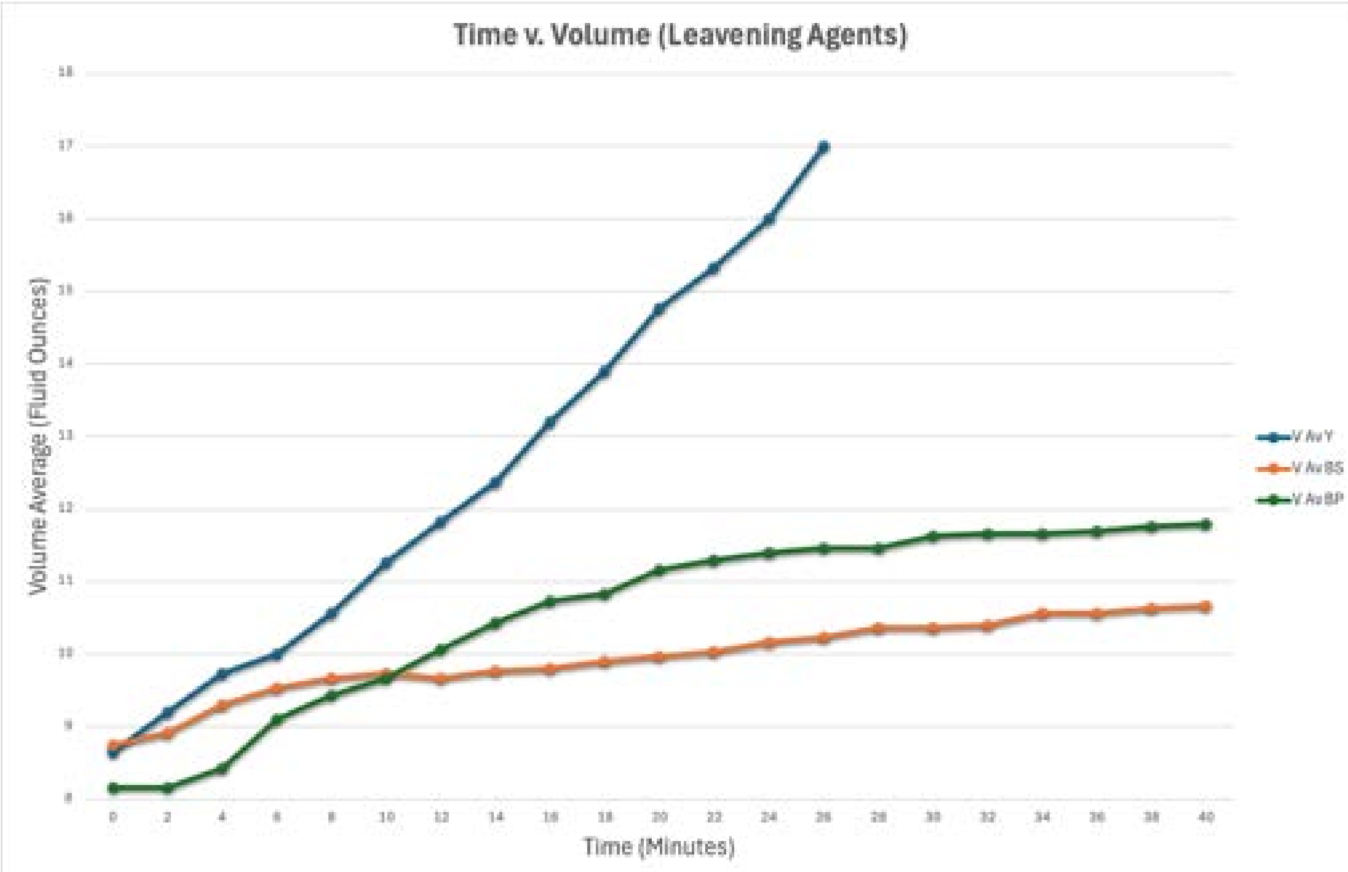

Figure 6: Line graph displaying volume in relation to time for three treatments (Yeast, Baking Soda, and Baking Powder). "V Av Y" represents the average volume of the dough under the treatment of yeast. "V Av BS" represents the average volume of the dough under the treatment of baking soda. "V Av BP" represents the average volume of the dough under the treatment of baking powder.

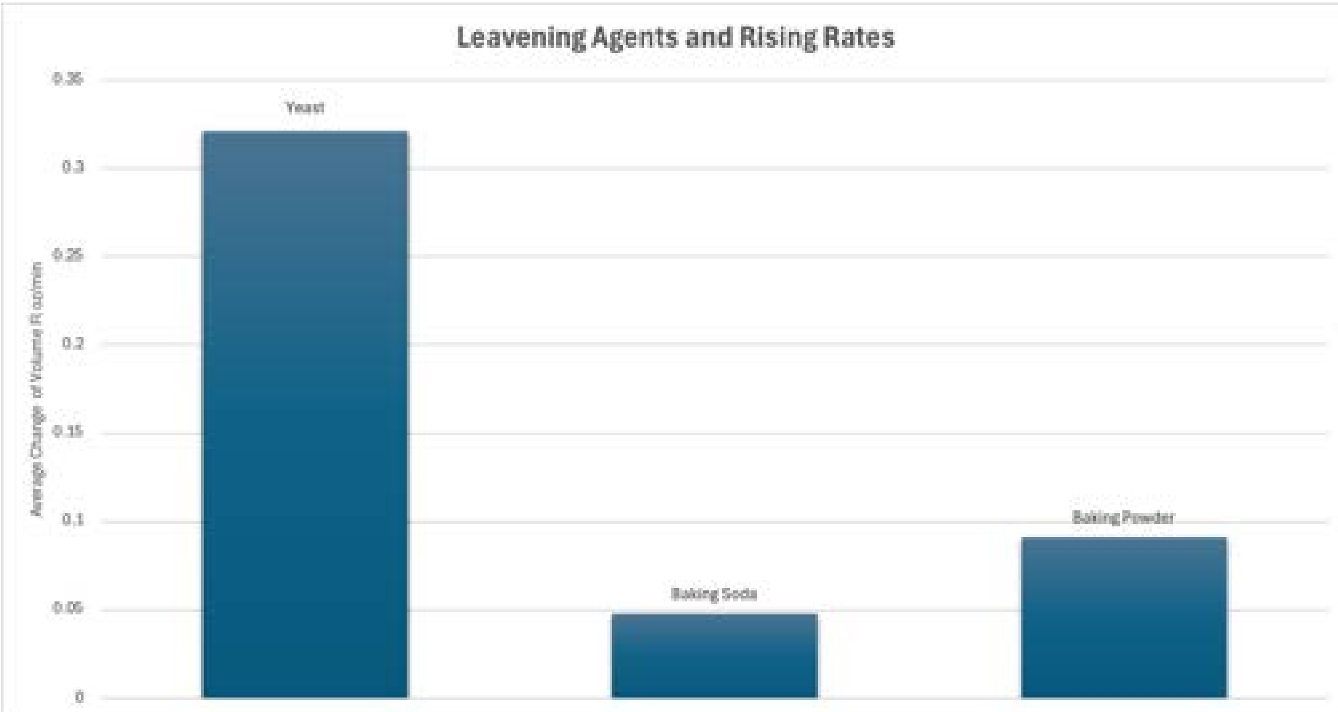

Figure 7: Bar graph depicting average rising rates of 0.321, 0.0479, and 0.0908 for Yeast, Baking Soda, and Baking Powder respectively.

Experiment C:
The results of the experiment demonstrated that rising time tended to be the greatest at the median quantity of yeast in the experiment (Figure 8, 9). Although it may be expected that the rising time is greatest where the quantity of the leavening agent is also the greatest, that is far from true, as no growth was observed with the dough that received the high quantity yeast treatment (0.28 oz). The main cause of this flattened curve is most likely due to the denaturation of enzymes from high kinetic energy reacting through the mixture. This kinetic energy is linked from the high temperatures in the proofer as well as the overpopulation of enzymes releasing too much energy. When explaining the order of the reaction, it is considered to be a second order reaction as the quantity and rate relations follow a parabolic path.

As for the treatments that received little to no yeast treatment, there are simply less collisions and interactions between the yeast enzymes and the glucose structures leading to slower reaction rates.

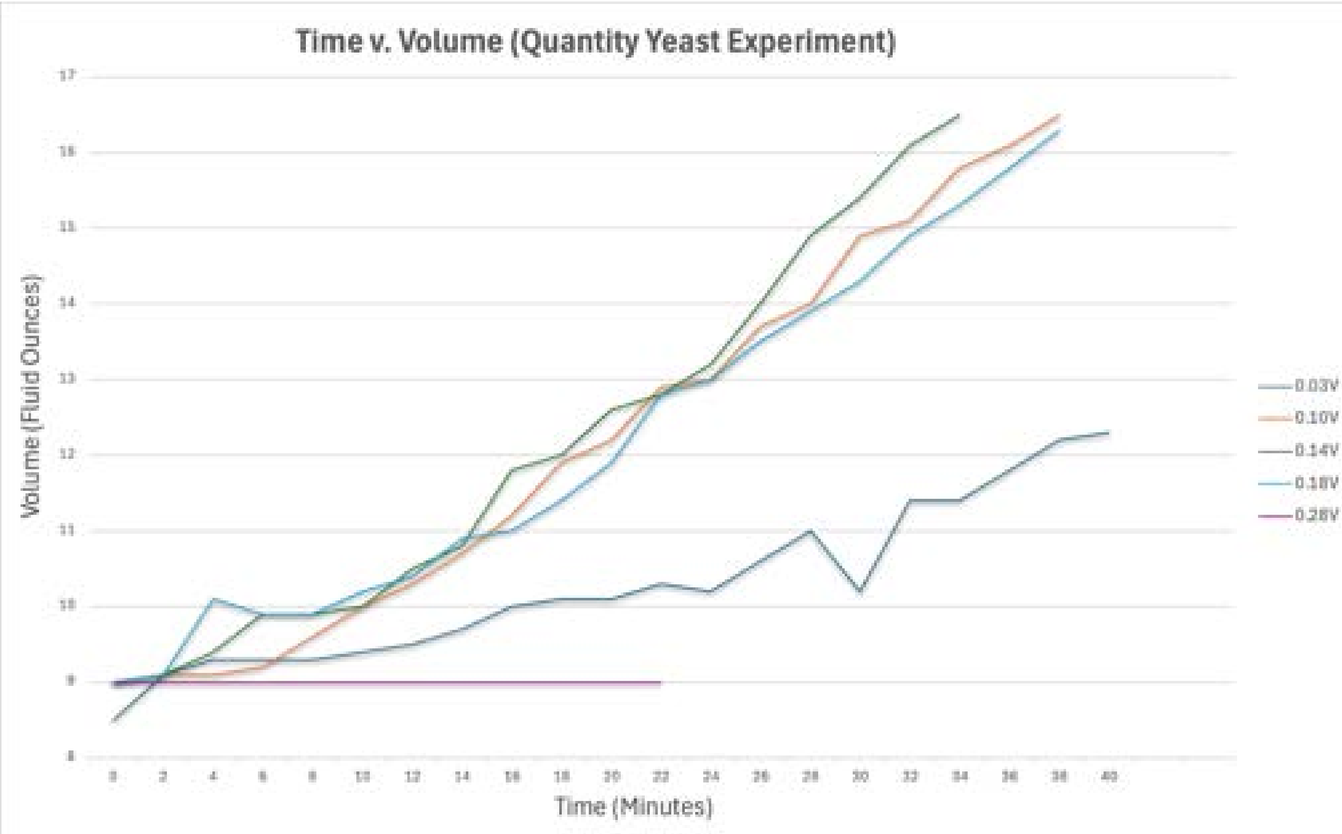

Figure 8: Line graph depicting volume change over time for treatments of different yeast quantities. The purple line correlates to yeast quantities that weighed 0.28oz that was added into the mixture, the light blue line correlates to yeast quantities that weighed 0.18oz that was added into the mixture, the green line correlates to yeast quantities that weighed 0.14oz that was added into the mixture, the yellow line correlates to yeast quantities that weighed 0.10oz that was added into the mixture, and the dark blue line correlates to the yeast quantities that weighed 0.03oz that was added into the mixture.

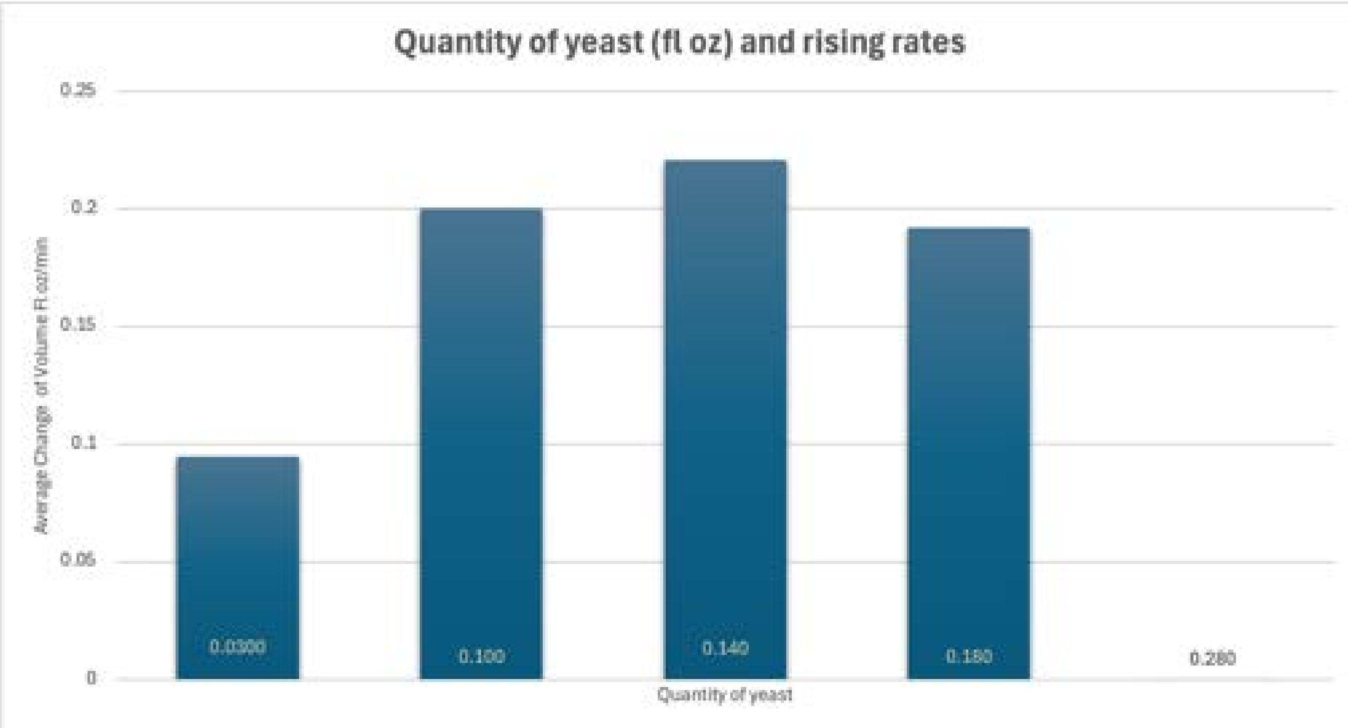

Figure 9: Bar graph depicting average rising rates of 0.0950, 0.200, 0.221, 0.192, and 0 for mixtures that had 0.03, 0.10, 0.140, 0.180, and 0.280 fl oz quantities of yeast respectively.

Experiences during the experiment process and error analysis

Before conducting the experiment, the apparatus had to be originally constructed to fit a mixture of our donut's everyday composition. In other words, having the suitable amounts of yeast, donut mix, and water that we would expect in a donut on an everyday basis.

There are some notes that can be made when conducting each part of the experiment. In experiment B, notes can be taken regarding the different types of leavening agents. With yeast, the dough tended to be less tacky and not stick as much to the mixer after the mixing process. However, with the other leavening agents (with baking soda/baking powder), it was the opposite in which the dough was more attached to the surface of the mixer (Figure 10, 11).

Figure 10: Dough mixed with yeast; not sticking to the sides of the container

Figure 11: Dough mixed with baking soda; sticking to the sides of the container

Planning this experiment involved constructing many workarounds which despite such efforts, still led to unavoidable errors. This is apparent by looking at the standard deviations of each data set leading to a loss of precision, as well as sudden declines in the observable data (in which dough volume should always stay the same/increase with respect to time when receiving treatment, unless acted upon by an external force which would thus deflate the dough decreasing dough volume). To start off, standard deviation can be caused by the difficulty of observing the dough measurements on the Pyrex Cups (Figure 12, 13). Using a flat object to smoothen the dough before adding the cups into the proofer was a way to ensure evenness on the dough's surface. However, as time progressed, the dough tended to formulate a higher peak toward the center of the glass, which made measurements more difficult to read.

Figure 12: Depiction of the dough before it underwent the proofing treatment.

Figure 13: Depiction of dough after it underwent the warm proofing treatment

The proofing leads to unevenness in dough volume which can cause illusory readings. This is the primary cause of why some readings may appear high or lower than they actually are.

Another issue was that the dough had air bubbles, which can make readings appear to have a greater volume than it actually is. This demonstrates that there are inconsistencies with the mixture as air bubbles lack concentration of the dough.

The last issue revolves around the uncontrollable properties of yeast activation in dough where there is a continuous rise in the dough’s volume. Before adding the dough into their environments, there was a delay from the point of time the yeast was initially added into the mixture. This is because it took time to measure out ~8 oz of dough into each container. This means that all dough that was getting a treatment had to rise in room temperature air for the first 5-10 minutes which can cause a stagnation of dough volume earlier on than expected. This can make the rising rate of the dough behave logistically earlier than usual, as dough already underwent some of the rising in room temperature before being put into the treatment. This could be the reason why logarithmic growth is visible in some of the treatments for the environment and agent tests.

Another underlying inaccuracy of the experiment is during the environment experiment where cups were being subjected to the cold environment. Before they were added into the environment, there was initially a 5-10 minute gap between when the baking reagent was added into the mixture to when the cups had been placed in their environment. This can cause the reaction rates to still occur faster than displayed, as the temperature of the mixture is still decreasing allowing the maltose conversion rates to adapt to the cold environment. This may be the reason why the graph appears to be growing logarithmically.

Conclusion

It can be concluded that differences in temperature conditions, leavening agents, and their quantity can all influence how long it takes for the dough to rise, therefore proving the hypothesis. When there was an increase of temperature, it was discovered that the rates also rose supporting the initial proportionality hypothesis. At the 42 degree environment, the rate of expansion was 0.02fl oz/min. At the 110 degree environment, the rate of expansion was 0.25fl oz/min. When there was a change in the leavening agents, there also appeared to be a change in the rising rates which further supports the hypothesis of altered reaction rates with a change of variable. For example, when yeast was added, it had a rising rate of 0.321 fl oz/min. But as for baking soda, it had a rising rate of 0.0479 fl oz/min which was significantly lower than yeast. As for the quantity of yeast, it also had an impact of changing rising rates. When there was 0.03 fl oz of yeast, it had a significantly lower rising rate than when there was 0.14 fl oz of yeast. With a synthesis of all this information, it is reasonable to conclude that it is possible to deviate from the original recipe with the change of the variables (temperature, leavening agent, and quantity of yeast).

The hypothesis was that the change of these three variables: temperature, leavening agent, and quantity of yeast, affect rising rates. However, one researcher can come up with another question discussing if they add more water to their mixture that it would have noticeable differences. Another can initiate a discussion of adding copious amounts of salt. Another plausible research question is seeing if adding diet coke into the mixture would have profound results. There is a pattern from all of this, and that is by the fact that there are many different ways to affect the rising rates of dough. The main reason this research was conducted is to improve a donut recipe of a family business for possibly expediting the rising times due to services constantly being in rush-hour. By knowing what temperature, reagent, or quantity that dough should be proofed with, the most efficient delectable treats can be baked for the satisfaction of customers. This research contributes to the field of fermentation science and can help understand the chemical process and influences of proofing at a better level. Such as knowing the most efficient method is of a biological process where enzymes interact to form carbon dioxide. Further research can find out other different ways rising rates can be influenced which can be used to make “the best proofing technique” for all donut stores. Another way this can be expanded upon is improving the experiment construct as some discrepancies were apparent in the data due to the unevenness in the volume of the dough as well as temperature maintenance.

References

1. Lawandi, Janice. “The Science behind Yeast and How It Makes Bread Rise.” *Kitchn*, Apartment Therapy, LLC., 1 May 2019, www.thekitchn.com/the-science-behind-yeast-and-how-it-makes-bread-rise-226483. Accessed 31 July 2024.
2. Creative, Efelle. “Donut-Making Tips: Yeast-Raised Donuts.” *Belshaw*, www.belshaw.com/donut-making-tips-yeast-raised-donuts#:~:text=Proofing%20%2D%2D%20Proof%20box%20should,surface%2C%20the%20donut%20is%20underproofed. Accessed 31 July 2024.
3. Wang, Crystal. “The Science behind the Perfect Dough.” *TutorOcean*, 26 Nov. 2021, corp.tutorocean.com/the-science-behind-the-perfect-dough/. Accessed 31 July 2024.
4. “Attack of the Gluten.” *American Chemical Society*, www.acs.org/education/resources/highschool/chemmatters/past-issues/archive-2011-2012/gluten.html#:~:text=Gluten%20is%20composed%20of%20two,hydrogen%20bonds%20with%20each%20other. Accessed 31 July 2024.
5. Committee, B. C. A. (2015, October 24). *Enzymes*. Pressbooks. https://opentextbc.ca/ingredients/chapter/enzymes/#:~:text=The%20two%20principal%20enzymes%20present,yeast%20activity%20in%20the%20dough.
6. NagwaEd. (n.d.). *The effect of temperature on the rate of yeast fermentation*. Nagwa. https://www.nagwa.com/en/videos/739169868543/
7. “Baking Powder vs. Yeast vs. Baking Soda.” *Bob’s Red Mill*, 2 Feb. 2018, www.bobsredmill.com/blog/healthy-living/baking-powder-vs-yeast-vs-baking-soda/. Accessed 14 Dec. 2024.
8. Channaiah, L. H., Michael, M., Acuff, J., Lopez, K., Vega, D., Milliken, G., Thippareddi, H., & Phebus, R. (2018, December). *Validation of a simulated commercial frying process to control* salmonella *in donuts*. Foodborne pathogens and disease. https://pmc.ncbi.nlm.nih.gov/articles/PMC6306667/#:~:text=The%20donut%20pH%20after%20ambient,and%20temperature%2Dcontrolled%20water%20baths.
9. “Yeast Raised Donut Mixes & Bases.” *BakeMark*, 23 Aug. 2024, bakemark.com/bmk-subcategories/yeast-raised-donut-mixes-bases/.