Determining the effect of microwave radiation on *Saccharomyces cerevisiae*

Joelle Fernandes

ABSTRACT

Microwaves are part of the electromagnetic spectrum and have frequencies ranging from 300MHz to 300GHz (Zhi et al. 1). They are widely used in households, industrial fields, and for broadcasting. However, with its popularization, attention has shifted to the negative effects it may have on living organisms, as microwave radiation can heat bodily tissue the same way it heats food according to the U.S. Food and Drug Administration (16). In order to determine whether microwave radiation has a harmful effect on living organisms or not, *Saccharomyces cerevisiae*, commonly known as baker's yeast, was microwaved for varying amounts of time and was proofed using warm water and sugar. The volume was recorded after allowing the yeast to proof for 10 minutes. It was found that microwave radiation had a significantly negative effect on the growth of *S. cerevisiae* ($P < 0.001$, $R^2 = 0.867$). A one-way ANOVA test was performed to analyze variation and the difference was found to be statistically significant ($F(6, 14) = 317.5$, $P < 0.0001$) and thus microwave radiation did have an effect on mean proofed volume. Post-hoc comparisons using Tukey's multiple comparisons test indicated that the mean volume for the control group ($M = 25.47$, $SD = 2.21$) significantly differed from all other microwave treatments.

INTRODUCTION

Microwave ovens emit waves that are part of the electromagnetic spectrum with frequencies ranging from 300MHz to 300GHz (Zhi et al. 1). Ever since its invention after World War II, consumer interest has rapidly grown, and it has become a staple in most homes in North America. It is incredibly convenient, allowing individuals to cook and thaw foods in the span of minutes by passing electromagnetic waves through molecules, exciting them and causing them to move rapidly and heat up (Zhi et al. 1). This has led to increased progress in the production of interconnected devices that emit microwave radiation, such as cell phones, tablets, and baby monitors. Microwave ovens do differ from other devices that produce microwaves in rates of energy consumption, as they heat with 1000 watts of radiation, whereas cellphones, which also

emit microwaves (refer to Fig. 1), use less than 1 watt (Davis et al. 4). It was previously thought that microwave fields are incapable of inducing negative bioeffects, but in recent years, concerns have been rising of other possible hazards (Banik et al. 155).

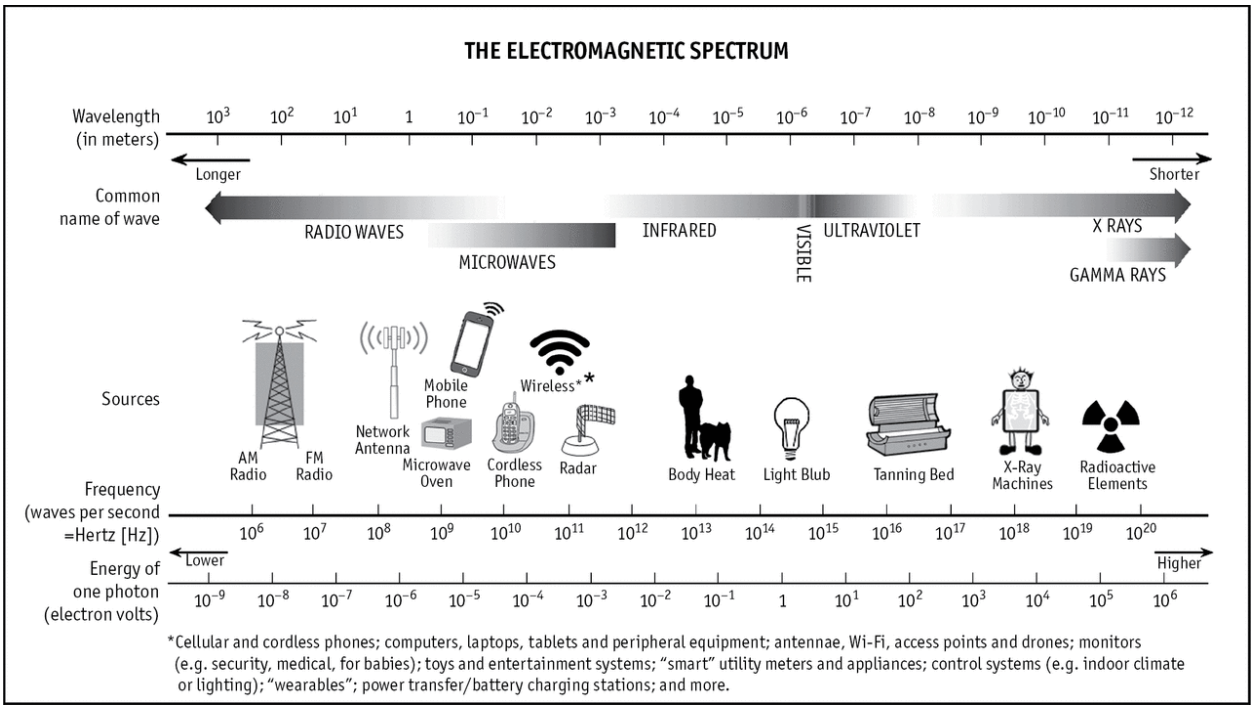

Figure 1. The electromagnetic spectrum from: Devra Davis et al. "Oxford Medicine."

One issue at hand is the fact that several electronic devices emit radiation using an irregular signal, meaning they pulse with rapid changes in electric and magnetic fields (Davis et al. 4). This pulsed nature may be biologically important because it allows opportunities for cell death and carcinogenesis. Additionally, microwaves of different pulse repetition frequencies have the potential to athermally induce biological effects by differentially partitioning ions (Banik et al. 156). Differential ionic partition has the ability to change the rate and direction of biochemical reactions (Banik et al. 156). This raises the question: Do the microwave ovens we own in our homes negatively biologically impact us? In order to answer this question, an experiment was conducted using *Saccharomyces cerevisiae*, commonly known as baker's yeast. The yeast was

microwaved and allowed to proof to determine whether microwave radiation has a harmful effect on living organisms or not. This specific yeast was chosen due to the fact that yeasts are representative of eukaryote fundamental cellular processes (Botstein and Fink 1439). It was hypothesized that if microwave radiation does stunt the growth of *Saccharomyces cerevisiae*, then proofed yeast that has been exposed to microwave radiation will yield a significantly lower volume than proofed yeast that has not been exposed to microwave radiation. This is because live yeasts feeds on sugars during proofing and produce a visible layer of bubbles on the surface due to the release of carbon dioxide, which expands the volume (Bernstein 6). Thus, if the yeast has been killed or damaged due to microwave radiation, it will not feed or produce a foamy layer, resulting in a lower total volume.

METHODS

OVERVIEW

A small portion of yeast was microwaved on a damp paper towel for differing amounts of time (5 seconds, 15 seconds, 20 seconds, 30 seconds, 45 seconds, and 60 seconds). One group was not microwaved to serve as a control group. The yeast was then proofed by being mixed with warm water and sugar in glass measuring cups. The volume was recorded after allowing the yeast to proof for 10 minutes. This indicated which groups of yeast were growing the most and which groups of yeast were damaged by radiation and could not grow. An ANOVA statistical test was performed to determine significance of results. A post-hoc Tukey test was subsequently performed to compare the means of all treatments to the mean of every other treatment.

MATERIALS

A 2450MHz LG brand 0.9 cubic foot microwave was used to microwave a total of 90mL of *Saccharomyces cerevisiae*. Each trial used 5mL of yeast, 30mL of warm water (between 100º and 110ºF) and 2.5mL of white granulated sugar. Yeast was microwaved on a damp paper towel placed on a ceramic dish. In order to properly measure proofed yeast, glass measuring cups were used. All materials used in the experiment were labeled using masking tape and a sharpie.

DESIGN & PROCEDURE

The relationship between yeast and microwave radiation was studied in this experiment. The independent variable in this study was time of exposure, while the dependent variable was volume. First, to serve as a control group, one teaspoon (5mL) of active dry yeast was placed into a narrow glass measuring cup and an eighth of a cup (30mL) of warm (100-110ºF) water and half a teaspoon (2.5mL) of sugar was added. The initial volume was recorded. The mixture was combined by stirring with a spoon and was then allowed to proof for ten minutes. The final volume of yeast was recorded, and total proofed volume was calculated by subtracting the initial volume from the final volume. This was repeated twice for a total of three control trials.

For treatment groups, one teaspoon of active dry yeast was placed on a damp paper towel on a microwave safe dish and was microwaved for five seconds. The microwaved yeast was placed into a narrow glass measuring cup and an eighth of a cup (30mL) of warm (100-110ºF) water and half a teaspoon (2.5mL) of sugar was added. The initial volume was recorded. The mixture was combined by stirring with a spoon and was then allowed to proof for ten minutes. The final volume of yeast was recorded, and total proofed volume was calculated by subtracting the initial

volume from the final volume. This was repeated twice for a total of three trials. The procedure was repeated for microwave times of 10s, 20s, 30s, 45s, and 60s.

Data were entered into the computer program Prism and a one-way ANOVA test was performed to evaluate the hypotheses by testing if mean volumes between proofed yeast differed. Data were also entered into R Studio to perform a correlation test and determine Pearson's correlation coefficient. Post-hoc analysis was performed (Tukey's multiple comparisons test) to determine where the significant differences existed by comparing the means from each group.

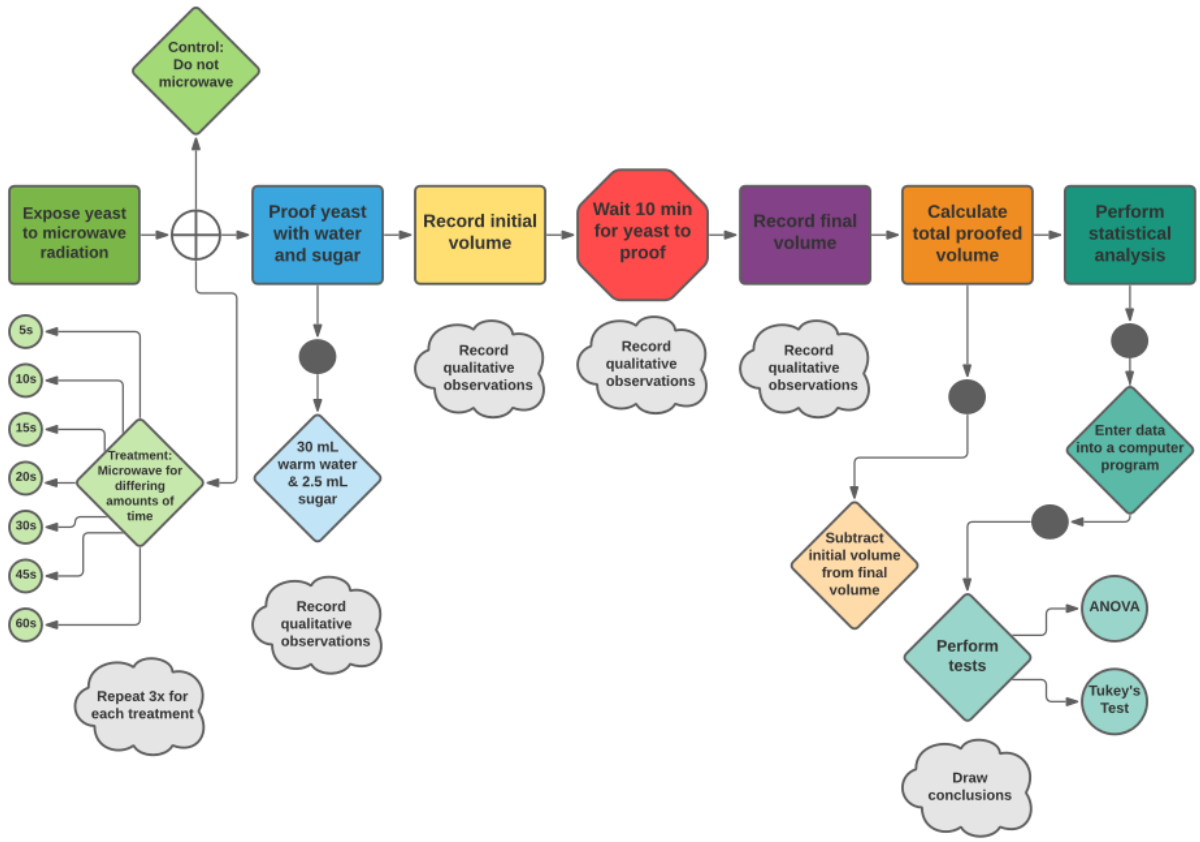

Figure 2. Methodology flowchart indicating each step of the experiment.

RESULTS

Twenty-one trials were performed. A one-way ANOVA was conducted to evaluate the effect of microwave radiation on proofed volume of *Saccharomyces cerevisiae*. The ANOVA test yielded significant variation among conditions ($F(6, 14) = 317.5$, $p = <0.0001$). A post-hoc Tukey test showed that the control group (M = 25.47, SD = 2.21) differed significantly from the 5s treatment (M = 18.83, SD = 0.38), 10s treatment (M = 18.23, SD = 0.35), 20s treatment (M = 10.43, SD = 0.44), 30s treatment (M = 2.70, SD = 0.82), 45s treatment (M = 0.83, SD = 0.49), and 60s treatment (M = 0, SD = 0). The 5s treatment group differed significantly from all treatments except for the 10s treatment. The 30s treatment was not significantly different from the 45s and 60s treatments. Results of the Pearson correlation were determined using R Studio, and indicated that there was a strongly negative relationship between time exposed and volume of yeast ($r(19) = -0.9311$, $R^2 = 0.867$, $P = 9.152 \times 10^{-10}$). Figure 4 shows how the volume of proofed yeast decreased as time microwaved increased.

Figure 3. Sample control group which has not been exposed to microwave radiation and has been allowed to proof for 10 minutes. The foamy layer at the top indicates proofed volume.

SAMPLE CALCULATION

$$Final\ Volume\ Recorded = 58.1mL$$
$$Initial\ Volume\ Recorded = 30.0mL$$
$$Total\ Proofed\ Volume = Final\ Volume - Initial\ Volume$$
$$Total\ Proofed\ Volume = 58.1 - 30.0 = 28.1mL$$

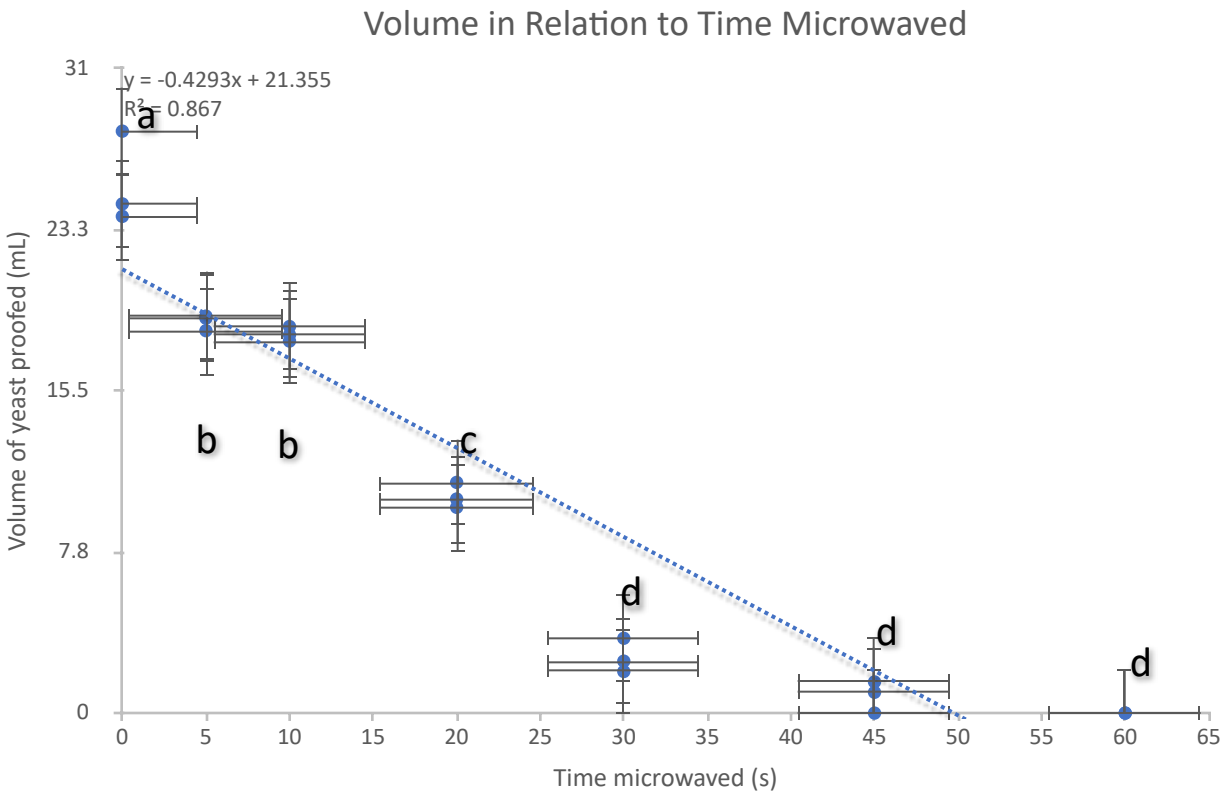

Figure 4. Calculated volumes of proofed yeast was significantly negatively related to the amount of time exposed to microwave radiation ($P < 0.001$, $R^2 = 0.867$). Points represent the volume of proofed yeast in millilitres for each given time among 21 independent trials. Vertical and horizontal bars represent 95% confidence intervals. Statistically significant differences were found between group means as determined by one-way ANOVA ($F(6, 14) = 317.5$, $P < 0.0001$). Groups which cannot be significantly distinguished share the same lowercase letter as determined by Tukey's multiple comparisons test. Data were collected in Surrey, B.C. in November 2020.

DISCUSSION

Because the p-value is much less than 0.05, the results are statistically significant at a 95% confidence level, and the null hypothesis can be rejected. That is, the mean volume of proofed yeast is different for yeast that has been exposed to microwave radiation and yeast that has not been exposed to radiation. This is consistent with literature, as Vrhovac et al.'s study found similar results when three *S. cerevisiae* strains exhibited different patterns of growth after 15-, 30-, and 60- minute exposures to a 905 MHz electromagnetic field (131). This can be explained by fermentation.

Proofing is a process in fermentation demonstrated by the equation:

$$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$$

It is used to test the viability of yeast by suspending it with warm water and a source of carbohydrates. Live yeast cells consume the carbohydrates and expel carbon dioxide gas, which is what causes the yeast to expand, increasing its volume. When the yeast cells were exposed to microwave radiation for long periods of time, they yielded lower volumes, meaning they could have been damaged by either thermal or athermal damage. One argument is that the heat produced by the microwave oven killed the yeast via thermal damage. Yeast begins to die off at temperatures of 120ºF and will completely die at 140ºF (Barnes 11). Thus, if the microwave heated the yeast to past this threshold, the yeast would have been killed or severly damaged. This damaged yeast would not have expanded to produce a foamy layer, which could explain why the volume was significantly lower for groups that were exposed to radiation. This could also explain why the 30s, 45s, and 60s treatments did not differ significantly. After 30 seconds, the yeast was likely killed by thermal damage as it passed the threshold of 140ºF, and so all treatments more extreme than 30s would yield the same result, which is what was observed after 45s and 60s.

Another argument is that the yeast cells are damaged athermally. Microwave radiation indirectly damages DNA repair mechanisms (Vrhovac et al. 133), which could ultimately induce DNA damage in *S. cerevisiae*. This is because mutagenic lesions form during exposure to chemicals and radiation, which disrupts mitotic recombination during mitosis (Vrhovac et al. 133). Thus, if DNA repair mechanisms were inhibited due to radiation, growth of *S. cerevisiae* would be stunted, and it would not proof, resulting in a low volume.

One possible source of error that could explain why there was a large amount of variation for the control groups is variation in the temperature of water used. When proofing yeast, it is essential that the water is between 100-110ºF (Bernstein 4). If the water is too hot, it will kill the yeast cells, but anything too cold will not allow for the sugar granules to dissolve, and the yeast will not be warmed to a temperature that is favourable for fermentation. Because a thermometer was not used, the water used in this experiment was not heated precisely to 100ºF, and it cooled as time passed. This means each control group may have used slightly different temperatures of water to proof, and this could have caused variation in the final proofed volume. This is a possible explanation as to why the standard deviation is so high for the control group. Besides a thermometer, to improve this experiment very narrow measuring cups could have been used, such as graduated cylinders, for more accurate volume readings. Moreover, repeating each treatment several more times would have allowed for more confidence in the results.

Future experiments could analyze how *S. cerevisiae* responds to different types of microwave radiation, such as the radiation emitted by cellular devices. Cell phones are used much more often than microwave ovens, and so if they do cause negative bioeffects, they could be detrimental to our health. Future studies should also analyze the role microwave radiation plays in damaging the DNA repair mechanisms of *S. cerevisiae*, in order to better understand the specific effect microwaves have on the DNA of living organisms.

CONCLUSION

Ultimately, *S. cerevisiae* was microwaved for varying amounts of time and was proofed using warm water and sugar in order to determine whether microwave radiation has a harmful effect on living organisms or not. Upon analysis, there were statistically significant differences

between group means as determined by one-way ANOVA ($F(6, 14) = 317.5$, $P < 0.0001$), indicating that microwave radiation does have an effect on mean proofed volume. A post-hoc Tukey Test revealed that the control group significantly differed from all treatment groups ($M = 25.47$, $SD = 2.21$). It is concluded that microwave radiation has a significantly negative effect on the growth of *S. cerevisiae* ($P < 0.001$, $R^2 = 0.867$).

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APPENDIX

Table 1. Recorded volumes of proofed yeast for each amount of time microwaved. Columns indicate the amount of time yeast was exposed to microwave radiation. Data were collected in Surrey, B.C. in November 2020 and a total of 21 trials was run.

Time microwaved (s)	0	5	10	20	30	45	60
Volume (mL)	28.0	18.4	18.6	11.1	2.0	1.5	0.0
	24.5	19.1	17.9	10.3	3.6	0.0	0.0
	23.9	19.0	18.2	9.9	2.5	1.0	0.0

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