

Spotless or Spoiled: Evaluating the Effectiveness of Common Household Cleaning Agents for Bacterial and Fungal Reduction on Apples

Cheng Kathleen, Devji Riz, Sartorelli Marilia, Shen Tyson

Abstract

This study examines the bactericidal efficacy of common household cleaning agents—water, lemon juice, vinegar, and baking soda solution—on reducing bacterial loads on apples. Our hypothesis posited that acidic solutions (lemon juice and vinegar) would disrupt bacterial cell membranes, while baking soda would enhance bacterial removal through its abrasive properties. Apples were swabbed and streaked onto agar plates before and after treatment, with each treatment group including three replicates and a control (unwashed) to establish baseline bacterial presence. Surprisingly, our results revealed that apples with no washing (pre-treatment) harbored the lowest bacterial counts, challenging conventional assumptions about cleaning practices. After treatment, the acidic solutions (vinegar and lemon juice) showed some reduction in bacterial colonies, but all treatments ultimately resulted in higher bacterial counts compared to the untreated apples. For fungal contamination, the opposite trend was observed: vinegar, water, and baking soda solutions resulted in a decrease in fungal CFUs, while lemon juice increased fungal growth. Statistical analysis using p-values of 0.63 and 0.24 indicated no significant differences in bacterial or fungal CFUs between before and after treatments. These findings suggest that common cleaning agents may not be as effective as expected in reducing microbial contamination on apples. Further investigation is needed to explore the mechanisms underlying these results and to refine cleaning practices for produce.

Introduction

The safety of fresh produce has long been a subject of public concern, particularly given the increasing consumption of raw fruits and vegetables, which exposes consumers to potential microbial contamination (Balali, 2020). Apples, one of the most widely consumed fruits globally, are no exception. They are often handled, stored, and transported under conditions that may promote the growth and spread of harmful bacteria, such as *Escherichia coli* and *Salmonella*, both of which have been linked to foodborne illnesses (Janisiewicz, 1999). While some bacterial contamination on apples can be mitigated by thorough washing, the effectiveness of commonly employed cleaning agents—ranging from simple water to more specialized solutions such as vinegar, lemon juice, and baking soda—has not been exhaustively investigated.

Previous research has demonstrated that certain cleaning agents, particularly acidic solutions like vinegar and lemon juice, can significantly reduce bacterial contamination on produce (Kilonzo-Nthenge, 2006). The antimicrobial properties of these agents are attributed to their ability to lower the pH of the environment, disrupting bacterial cell membranes and inhibiting essential cellular functions. For example, vinegar has been shown to reduce bacterial loads on a variety of fruits and vegetables by creating an acidic environment that inhibits microbial growth (Sengun, 2019). Similarly, lemon juice, with its high citric acid content, is thought to exert bactericidal effects, potentially offering similar benefits for apples (Tomotake, 2006). Baking soda, known for its mild abrasiveness and alkaline nature, has also been suggested to remove surface dirt and reduce bacterial contamination on produce through a neutralizing effect (Corn, 2023). However, while previous studies have investigated the efficacy of these agents in isolation, their comparative effectiveness—especially for everyday household use on apples—remains underexplored.

This study aims to address this gap by evaluating the effectiveness of water, vinegar, lemon juice, and baking soda solution in reducing bacterial contamination on apples. Our hypothesis is that if apples are soaked in solutions of vinegar (20%), lemon juice (20%), or baking soda, then fewer bacteria will grow when cultured on agar compared to apples washed with water alone. We predict that acidic solutions (vinegar and lemon juice) will be more effective than water due to their ability to disrupt bacterial cell membranes, while baking soda will show moderate reductions in bacterial count through its abrasive and neutralizing properties. Additionally, we predict that untreated apples will exhibit the highest bacterial load, supporting the idea that washing with water is more effective than no treatment at all. This investigation will provide important insights into the practical effectiveness of these common household cleaning agents, with implications for consumer practices and food safety recommendations.

Methods

A pre-post study was conducted to determine bacteria and fungi content in 12 apples before and after each treatment through a 9 day incubation at 37 °C and colony counting.

Twelve organic apples were randomly divided into 4 groups of 3 apples each, and each group was assigned to one of the four treatments: distilled water, vinegar 20% solution, lemon juice 20% solution and baking soda solution. The water treatment consisted of 1500 mL of distilled water. The vinegar treatment was a solution of 300 mL vinegar and 1431 mL distilled water. And a solution of 266 mL lemon juice and 1234 mL distilled water was made for the lemon juice treatment. For the baking soda treatment, 25 g were measured using weight by difference and mixed with 1500 mL of distilled water.

First each one of the three apples in a group was swabbed below the equator and streaked in one of the three corresponding “before” treatment’s agar plate using a cotton swab dipped in distilled water and instructed by a grid underneath it. A similar pattern to the continuous streak method was used, except the agar plate was streaked only 5 times up and down in a symmetrical shape. During this process, an alcohol flame was set near the agar plate to promote sterile conditions.

The apples were left to sit in the solution right after swabbing for 15 min each in separate containers. Right after being removed from the solution, the apples were swabbed below the equator with a cotton swab dipped in distilled water and streaked on the corresponding individual “after” agar plates according to their treatment and following the same pattern described above. The agar plates were incubated at 37 °C for 9 days and bacterial and fungal CFU was counted throughout this period using a light microscope with a 70x magnification.



Figure 1: To the left, apples submerged in 20% vinegar solution and to the right, apples submerged in 20% lemon juice solution. Beakers were sterilized before use and aluminum foil was used to maintain a sterile environment.

Results

The mean number of colony-forming units (CFU) before and after treatment was taken and recorded over time (Figure 4 - Appendix). For example, to find the CFU count 9 days after treatment of water, the mean of CFU for apples “Water 1f”, “Water 2f” and “Water 3f” was taken. Referring to Figure 5 in the Appendix, the mean of 71, 7, and 295 was taken to plot 124.3 in Figure 4A. Both the number of bacterial and fungal CFUs were recorded to generate Figure 4. Bacterial count appeared to increase after immersion in water, vinegar, and baking soda solutions (Figure 4A, B, C). However, a trend of reduction of bacterial colonies after the treatment of lemon juice solution can be seen (Figure 4D). A reverse of this trend can be seen in fungal CFU. Immersion in lemon juice solution increased the levels of fungi after 9 days (Figure 4H). However, fungal CFU decreased in water, vinegar, and baking soda solution apples (Figure 4E, F, G). To further visualize this relationship, the percent change of bacterial and fungal CFU between treatments and control plates was graphed (Figure 2A, B). Where a positive percent change indicates greater colony counts in the treatment plates.

Qualitatively, it is important to note plates with condensation (Figure 3). For example “Baking Soda 3b” is covered in water droplets making colony counting more difficult. However, using a light microscope, proper adjustments were made to focus through this water layer and effectively count colonies. Although Figure 2 shows trends and seemingly distinctive results, calculated p-values of 0.63 and 0.24 report high variance. Thus further analysis is needed before a conclusion is reached.

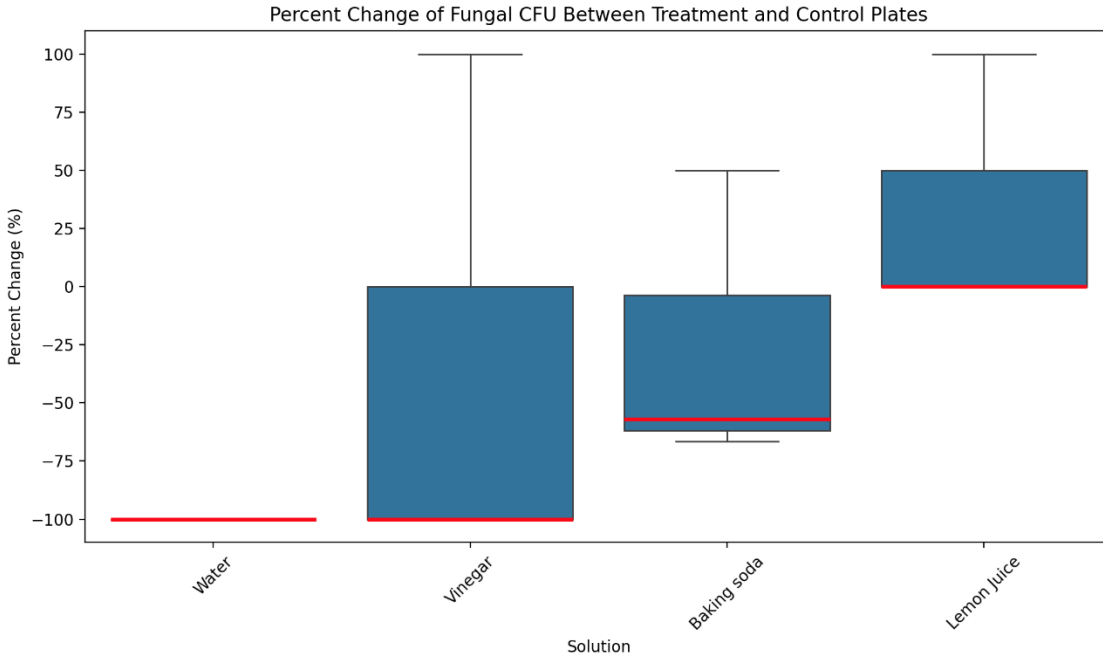


Figure 2A: Percent change of fungal colony count between the treatment and control plates after 9 days of incubation. Whiskers represent upper and lower limits, and the red line represents the median of each replicate.

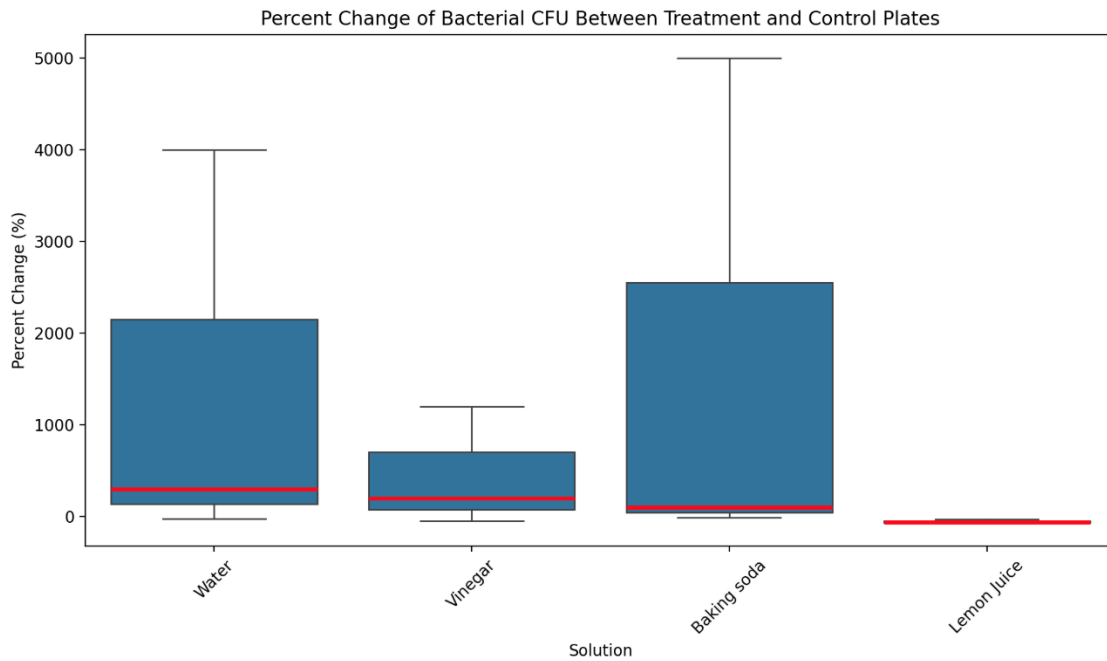


Figure 2B: Percent change of bacterial colony count between the treatment and control plates after 9 days of incubation. Whiskers represent upper and lower limits, and the red line represents the median of each replicate.

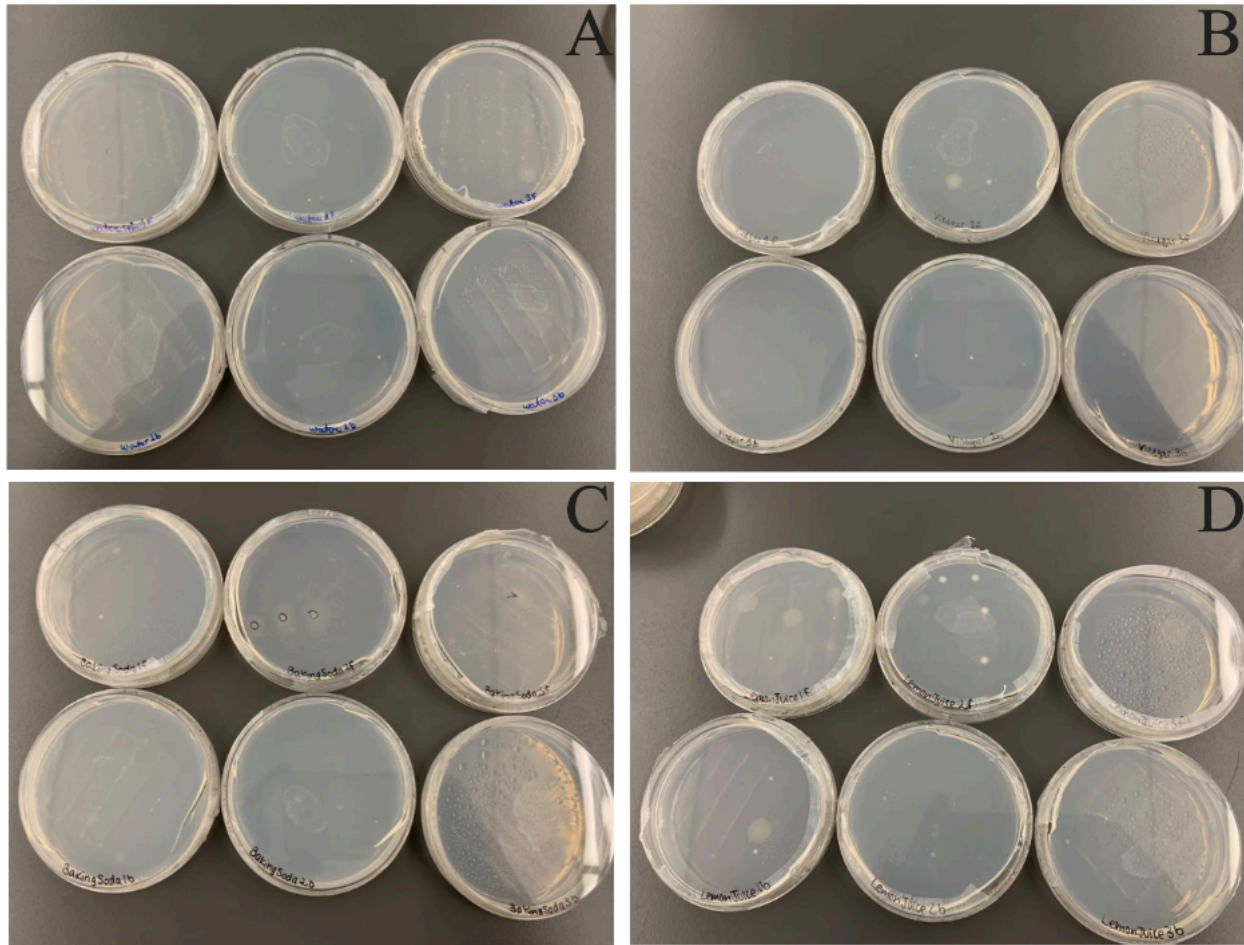


Figure 3: Agar plates 8 days after treatment with solutions. Groups of plates are broken into sections of water (A), vinegar (B), baking soda (C), and lemon juice (D). For each section, the top 3 plates were taken from apples after immersion in solution, while the bottom three were taken before treatment.

Discussion

After the 9 days of incubation at 37 °C, differences between before and after treatments were observed in all treatments with a higher number of bacteria colonies present in the after treatment for water, vinegar and baking soda and a lower number of colonies present in the after treatment for lemon juice. The inverted trend was observed for fungal CFU; lemon juice had a higher number of fungal CFU in the after treatment while other treatments had lower values. The calculated p-values for percent change in CFU for bacteria and fungi were respectively 0.63 and 0.24 indicating no significant difference between the before and after treatment CFU.

Although both p-values did not indicate a statistically significant difference between before and after treatments, the lower p-value for the fungal CFU ($p=0.24$) might suggest a potential difference between the groups that warrants further investigation.

It is possible that variations in colony-forming units were influenced by experimental conditions, such as inconsistencies in immersion times or swabbing methods, which could contribute to the observed variance. Additionally, the choice of incubation temperature ($37\text{ }^{\circ}\text{C}$) and the upside down plate position might have disfavored fungal growth, potentially skewing the results (Hocking, 2014). Future studies could benefit from a broader range of incubation temperatures to better simulate environmental conditions and observe the growth dynamics of both bacteria and fungi.

One of the possible reasons for higher than expected numbers of bacteria content in the apples after the water treatment is that the apples were not dried after soaking, leading to presence of water on its surface that might have contained populations of bacteria. A similar experiment accounted for drying with paper towels and observed a diminution in CFU numbers. The same could be a possible explanation for the high CFU numbers after vinegar treatment. (Parnell & Harris, 2003)

The observed increase in fungal CFU after lemon juice treatment is particularly intriguing, as acidic environments are generally expected to suppress microbial growth. This may suggest the presence of fungal species that are acidophilic or otherwise resistant to the pH changes induced by lemon juice. Identifying these species could provide valuable insights into the microbial ecology of treated produce.

Similarly, the increase in bacterial CFU after water, vinegar, and baking soda treatments raises questions about the potential for these solutions to disrupt the surface biofilm, releasing previously adhered bacteria into the solution and subsequently redistributing them across the apple's surface. Investigating the specific mechanisms of bacterial adherence and biofilm disruption could clarify these observations.

Finally, the high variability in CFU counts across treatments highlights the need for larger sample sizes and more replicates to reduce the impact of outliers and improve statistical power. Incorporating complementary methods, such as DNA sequencing, could also offer a more comprehensive understanding of the microbial communities present before and after treatment, providing additional context to the observed changes in CFU.

Conclusion

This study investigated the effectiveness of four household cleaning agents—water, vinegar, lemon juice, and baking soda—in reducing bacterial and fungal contamination on apples. While lemon juice treatment demonstrated a trend toward reducing bacterial colony-forming units (CFU) after treatment, other treatments, including water, vinegar, and baking soda, resulted in increased bacterial CFUs. Conversely, fungal CFUs were reduced following water, vinegar, and baking soda treatments, but increased after lemon juice treatment.

Despite these observed trends, statistical analysis revealed no significant differences in the percent change of CFUs between before and after treatments for either bacteria ($p = 0.63$) or fungi ($p = 0.24$). However, the lower p-value for fungal CFUs may indicate a potential effect that requires further investigation.

The findings of this study suggest that while household cleaning agents may exhibit qualitative differences in their effects on microbial contamination, their quantitative impact is highly variable and not statistically significant under the conditions tested. Further research with larger sample sizes, improved experimental consistency, and complementary analytical techniques is necessary to clarify these trends. Such studies could provide more robust recommendations for consumers aiming to minimize microbial contamination on fresh produce.

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Appendix

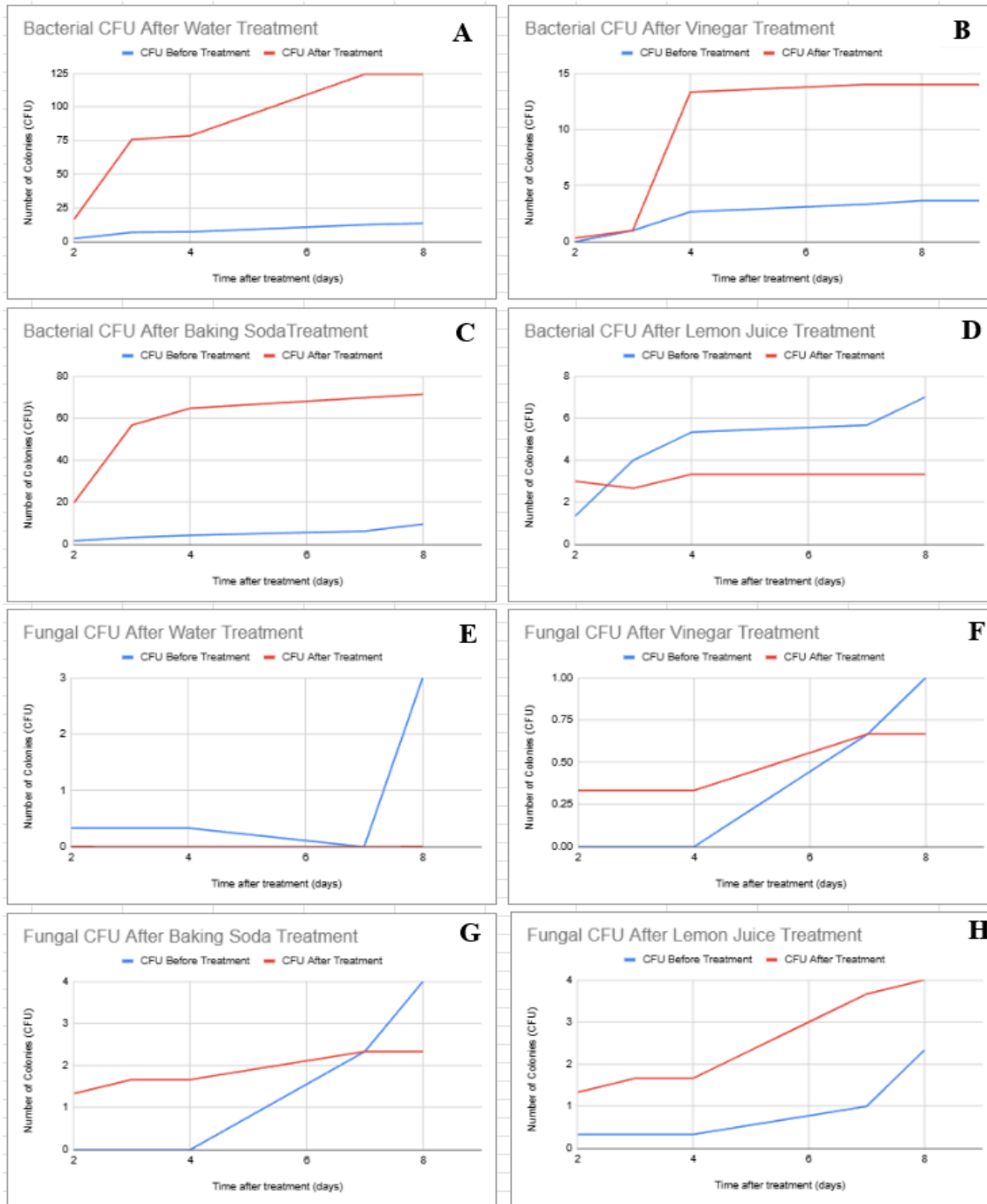


Figure 4: Number of bacterial (A, B, C, D) and fungal (E, F, G, H) CFU found after treatment of solutions. Colonies were recorded before (0d) and 2, 3, 4, 7, 8 and 9 days after solution treatment of water (A, E), vinegar (B, F), baking soda (C, G), and lemon juice (D, H). A one-way ANOVA assessed the percent change in CFU before and after the treatment of various solutions. Bacterial treatments found $p = 0.63$ and fungal treatments found $p = 0.24$.

BACTERIA												
Day	Water 1b	Water 2b	Water 3b	Vinegar 1b	Vinegar 2b	Vinegar 3b	Baking Soda 1b	Baking Soda 2b	Baking soda 3b	Lemon 1b	Lemon 2b	Lemon 3b
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	3	4	0	1	2	3	1	1	0	3	1
4	6	11	4	0	2	6	3	3	4	0	10	2
7	6	12	4	1	3	6	4	4	5	3	10	3
8	19	13	6	1	3	7	10	4	5	3	10	4
9	20	14	7	1	3	7	12	3	14	4	10	7
Day	Water 1f	Water 2f	Water 3f	Vinegar 1f	Vinegar 2f	Vinegar 3f	Baking Soda 1f	Baking Soda 2f	Baking Soda 3f	Lemon 1f	Lemon 2f	Lemon 3f
2	0	0	0	0	1	0	1	0	0	1	0	0
3	17	0	32	1	2	0	1	36	22	0	7	2
4	35	4	189	1	39	0	2	142	26	0	5	3
7	40	4	192	2	40	0	3	161	30	1	6	3
8	71	7	295	2	40	0	9	169	31	1	6	3
9	71	7	295	2	40	0	10	169	35	1	6	3
FUNGI												
Day	Water 1b	Water 2b	Water 3b	Vinegar 1b	Vinegar 2b	Vinegar 3b	Baking Soda 1b	Baking Soda 2b	Baking soda 3b	Lemon 1b	Lemon 2b	Lemon 3b
2	0	0	1	0	0	0	0	0	0	1	0	0
3	0	0	1	0	0	0	0	0	0	1	0	0
4	0	0	1	0	0	0	0	0	0	1	0	0
7	0	0	1	0	0	0	0	0	0	1	0	0
8	0	0	1	1	1	0	5	2	0	3	0	0
9	1	7	1	1	1	1	7	2	3	3	4	0
Day	Water 1f	Water 2f	Water 3f	Vinegar 1f	Vinegar 2f	Vinegar 3f	Baking Soda 1f	Baking Soda 2f	Baking Soda 3f	Lemon 1f	Lemon 2f	Lemon 3f
2	0	0	0	0	0	0	0	3	1	4	0	0
3	0	0	0	0	1	0	0	3	1	4	0	0
4	0	0	0	0	1	0	1	3	1	4	0	1
7	0	0	0	0	1	0	1	3	1	4	0	1
8	0	0	0	0	2	0	3	3	1	6	4	1
9	0	0	0	0	2	0	3	3	1	6	4	2

Figure 5: Record of raw data for CFU count.

Source	DF	Sum of Square	Mean Square	F Statistic	P-value
Groups (between groups)	3	7269414.38	2423138.127	0.6106	0.6268
Error (within groups)	8	31747667.43	3968458.428		
Total	11	39017081.81	3547007.437		

Figure 6: One-way ANOVA for percent change of bacterial CFU after 9 days of various treatments (Water, Vinegar, Baking Soda, Lemon Juice) (StatsKingdom, 2024).

Source	DF	Sum of Square	Mean Square	F Statistic	P-value
Groups (between groups)	3	26838.1518	8946.0506	1.7152	0.2408
Error (within groups)	8	41727.1354	5215.8919		
Total	11	68565.2871	6233.2079		

Figure 7: One-way ANOVA for percent change of fungal CFU after 9 days of various treatments (Water, Vinegar, Baking Soda, Lemon Juice) (StatsKingdom, 2024).