An Investigation into the Effect of Different Beverages on Eggshell Structure

What is the Effect of Beverage Exposure (Cola, Energy Drink, Milk, Water, and Orange Juice) Over a 4-Week Period, Measured Through Visual Changes, Mass Loss, and Surface Degradation, on Eggshells as a Model for Tooth Enamel?

Extended Essay Subject: Biology

Word Count: 3995

Table of Contents

1. Introduction 4
1.1 Research Question 4
1.2 Context 4
1.3 Background Information 4
1.3.1 Effect of pH on Dental Health 5
1.3.2 Effect of Sugar on Dental Health 5
1.3.3 Tooth Enamel 6
1.3.4 Water's pH and Its Effects 7
1.3.5 Cola's pH, Sugar Level and Its Effects 7
1.3.6 Energy Drink's pH, Sugar Level and Its Effects 7
1.3.7 Orange Juice's pH, Sugar Level and Its Effects 8
1.3.8 Milk's pH, Sugar Level and Its Effects 8
1.3.9 Relationship Between Tooth Enamel and Eggshell 9
1.4 Aim of Study 9
1.5 Hypothesis 10
1.5.1 Null Hypothesis 10
1.5.2 Alternative Hypothesis 10
2. Methodologies 10
2.1 Variables 10
2.1.1 Independent Variable 10
2.1.2 Dependent Variable 11
2.1.3 Controlled Variables 11
2.2 Materials 12
2.3 Method Development 14
2.3.1 Selection of Beverages Used in The Experiment 14
2.3.2 The Reason for Using eggshells in The Experiment 14
2.3.3 The Reason for Choosing 4 Weeks as The Duration of The Experiment 15
2.4 Experiment Steps 15
2.4.1 Preparation 15
2.4.2 Preliminary Measurements 16
2.4.3 Exposure Procedure 16
2.4.4 Observation & Data Collection 16
2.4.5 Final Measurements and Evaluation 17
2.4.6 Conclusion and Interpretation 17
2.5 Evaluation of Ethical Issues and Risks 17
3. Data Collection and Processing 18
3.1 Qualitative Data 18
3.1.1 Photographs of The Eggshells Soaked in Beverages 18

3.1.2 Observations of The Eggshells Soaked in Beverages.....19
3.2 Quantitative Data.....22
3.2.1 Weekly Variation of The Mass of Eggshells 22
3.3 Organizing and Summarizing Data 25
3.3.1 Mean Mass of Eggshells Soaked in Different Beverages 26
3.3.2 Standard Deviation of The Mass of Eggshells Soaked in Different Beverages 27
3.4 Data Visualization 28
3.4.1 Line Graph 28
3.4.2 Bar Graph 28
3.5 Statistical Analysis 29
3.5.1 T-Test 29
4. Discussion 29
5. Evaluations 31
5.1 Strengths 31
5.2 Limitations 32
6. Conclusion.....32
7. Bibliographies.....33

1. INTRODUCTION:

1.1 Research Question:

What is the Effect of Beverage Exposure (Cola, Energy Drink, Milk, Water, and Orange Juice) Over a 4-Week Period, Measured Through Visual Changes, Mass Loss, and Surface Degradation, on Eggshells as a Model for Tooth Enamel?

1.2 Context:

The best way to protect oral health is to protect dental health. However, the foods and drinks that are frequently consumed in daily life affect our dental health. Among the main characteristics of foods and beverages that directly affect our dental health are the acid and sugar ratios of foods and beverages. There is a direct relationship between the sugar and acid content of the food consumed and our dental health.

1.3 Background Information:

According to the World Health Organization (WHO) Global Oral Health Status Report 2022, approximately 3.5 billion people worldwide are affected by oral diseases. [1] One of the leading causes of oral diseases is foods high in sugar. High-sugar and acidic foods and beverages are common and affordable, which is why people often consume them in their daily life.

Water is one of the most consumed beverages in the world. Water does not contain sugar or any substance that will adversely affect dental health. Therefore, it is recommended to be consumed frequently by dentists. However, after water, soft drinks such as cola, animal and plant-based milks, energy drinks and fruit juices such as orange juice are the most consumed beverages.[2] The main reason these beverages are frequently consumed by adolescents is that they are very

[1] "Oral Health." *World Health Organization*, World Health Organization, www.who.int/news-room/fact-sheets/detail/oral-health. Accessed 13 Mar. 2025.

[2] by Nawon, Posted, and Nawon. "Top 10 Most Consumed Beverages in the World." *Nawon Food and Beverage*, 4 July 2024, nawon.com.vn/top-10-worlds-most-consumed-beverage/?srsltid=AfmBOopFaPQinqafg2Z8hAkRF6bMA9pRfJHCDVLVlbg2hIRmPTr5NXfP.

easy to access. They are generally available in every supermarket and their prices are very affordable.

1.3.1 Effect of pH on Dental Health:

pH allows us to understand whether a substance is acidic or basic.[3] Since the acidity of the beverage consumed directly affects oral health, it is very important to look at the pH ratio of the beverages consumed to protect oral health. pH between 0 and 7 indicates that the substance is acidic. 0 pH indicates the most acidic. 7 pH is neutral. Substances between 7 and 14 pH are considered basic. 14 pH is the most basic. The natural pH of the mouth is close to neutral (7 pH). [4] However, the decrease in pH affects dental health as it will cause acidity. When foods and drinks with a pH below 5.5 are consumed, dangers such as tooth enamel erosion and tooth decay occur.

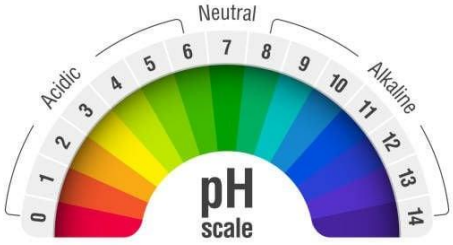


Figure 1: pH scale [5]

1.3.2 Effect of Sugar on Dental Health:

Another substance that affects dental health is sugar. Sugars in foods and drinks that are frequently used in daily life cause tooth decay. Bacteria in plague use sugar as an energy source

[3] Moore, Dr. Durning. "How Bottled Water Ph Impacts Dental Health." *Smile Moore Dental*, 7 Jan. 2025, www.drdurningmoore.com/understanding-the-ph-of-bottled-water-and-its-impact-on-oral-health/#:~:text=The%20natural%20pH%20of%20your,consuming%20acidic%20foods%20or%20drinks.

[4] "Action on Sugar." *Sugars and Tooth Decay - Action on Sugar*, www.actiononsugar.org/sugar-and-health/sugars-and-tooth-decay/#:~:text=When%20sugar%20is%20consumed%20it,to%20be%20removed%20%5B2%5D. Accessed 13 Mar. 2025.

[5] "Havuzların PH Değeri Kaç Olmalıdır?" *Havuzcu Market*, www.havuzcumarket.com/blog/icerik/havuzlarin-ph-degeri-kac-olmalidir. Accessed 13 Mar. 2025.

and release acid as a waste product. Over time, this acid dissolves tooth enamel and causes cavities.[4] The Scientific Advisory Committee on Nutrition (SACN) in the United Kingdom conducted a study in 2014 and found that sugar consumed damages tooth enamel and causes tooth decay.[6] In addition, it was also found that the rate of tooth decay decreased with a decrease in sugar. Dentists recommend that free sugar consumption should be less than 5% of energy intake to maintain dental health.[4]

1.3.3 Tooth Enamel:

The relationship between the acid and sugar content of the food and beverages consumed and dental health is that the acid and sugar in the food and beverages consumed directly affect the dental enamel. Dental enamel is the outermost layer of the tooth that protects the tooth from decay and damage. [7] Tooth enamel protects against tooth decay, tooth erosion and abrasion. The tooth enamel is made up of calcium and phosphorus. The minerals, which make up 95% of the enamel, bind together to form ultra-strong crystallites (small crystals).[7] The rest of the enamel is made up of water and protein. The sugars and acids in the beverages consumed cause the enamel to erode and when the enamel is eroded, the teeth become more prone to staining and the risk of decay increases.

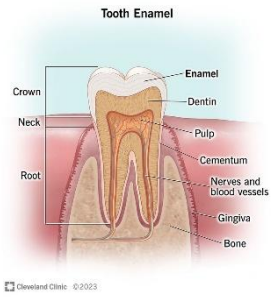


Figure 2: Tooth Enamel [7]

[6] England, Public Health. "SACN Carbohydrates and Health Report." *GOV.UK*, GOV.UK, 17 July 2015, www.gov.uk/government/publications/sacn-carbohydrates-and-health-report.

[7] professional, Cleveland Clinic medical. "Tooth Enamel: What It Is & How to Preserve It." *Cleveland Clinic*, 1 May 2024, my.clevelandclinic.org/health/body/24798-tooth-enamel.

1.3.4 Water's pH and Its Effects:

After consuming acidic foods and drinks, it is recommended to drink water to balance the acidity of the mouth. The pH value of water is between 6.5 and 8.5[8], which helps to balance the acidity of the mouth. Therefore, water is the control group in this experiment.

1.3.5 Cola's pH, Sugar Level and Its Effects:

Acids such as citric acid, phosphoric acid and carbonic acid in acidic drinks cause tooth enamel dissolution and mineral loss.[9] Cola contains phosphoric acid[10], which damages the enamel in the teeth. In addition, other acids and sugars in cola can erode tooth enamel and increase the risk of cavities and other dental problems.[11] Since this experiment investigates the effect of a standard cola on dental health, a non-diet classic cola is used. 12 oz. cola contains 39 grams of sugar.[12] In addition, the cola acidity is 2.52 pH.[13]. This shows that cola is highly acidic.

1.3.6 Energy Drink's pH, Sugar Level and Its Effects:

The acidic taste in energy drinks is given by the citric acid in the energy drink. Therefore, there is a high level of citric acid in energy drinks.[14] Citric acids directly affect the tooth enamel, so frequent consumption of energy drinks leads to erosion of the tooth enamel. In addition, a 100

---

[8] "What to Know about the Ph of Water." *Medical News Today*, MediLexicon International, www.medicalnewstoday.com/articles/327185#:~:text=In%20its%20purest%20form%2C%20water,somewhere%20between%206.5%20and%208.5. Accessed 13 Mar. 2025.

[9] *The Harms of Acidic Beverages on Teeth | Dentevim Dental Clinic*, www.dentevim.com/en/the-harms-of-acidic-beverages-on-teeth. Accessed 13 Mar. 2025.

[10] "What Are the Ingredients of Coca-cola Classic?" *What Are the Ingredients of Coca-Cola Classic?*, www.coca-cola.com/hk/en/about-us/faq/what-are-the-ingredients-of-coca-cola-classic#:~:text=Phosphoric%20Acid%20%E2%80%93%20The%20tartness%20of,the%20use%20of%20phosphoric%20acid. Accessed 13 Mar. 2025.

[11] Forest Lake Family Dental. "Does Coke Ruin Teeth in General?" *Forest Lake Family Dental*, 16 Sept. 2024, www.forestlakefamilydental.com/does-coke-ruin-teeth-in-general/#:~:text=While%20enjoying%20a%20Coke%20now,and%20cause%20other%20dental%20problems.

[12] "How Much Sugar Is in Coca-cola?" *How Much Sugar Is in Coca-Cola?*, www.coca-cola.com/hk/en/about-us/faq/how-much-sugar-is-in-coca-cola. Accessed 13 Mar. 2025.

[13] *Tea Coffee Acids Soft Drinks*, www.beyondsmilesparkridge.com/wp-content/uploads/2019/12/pH-Values-of-beverages-and-drinks.pdf. Accessed 13 Mar. 2025.

[14] "The Role of Citric Acid in the Soft Drink and Energy Beverage Industry." *Total Ingredientes*, Total Ingredientes, 17 Feb. 2025, www.totalingredientes.com.br/en/post/the-role-of-citric-acid-in-the-soft-drink-and-energy-beverage-industry.

ml energy drink contains 11 grams of sugar [15] and has a pH value of 3. 37[13] The sugar and acid ratio of the energy drink causes the energy drink to damage the tooth enamel.

1.3.7 Orange Juice's pH, Sugar Level and Its Effects:

Orange juice contains citric acid, just like the energy drink. Citric acid is naturally found in citrus fruits such as oranges, lemons, tangerines and grapefruits[16] and erodes tooth enamel. Moreover, orange juice is another beverage that is high in acid and sugar and is frequently consumed in daily life. 100 ml of orange juice contains an average of 8.81 grams of sugar.[17] The pH of orange juice is 3.9.[18]

1.3.8 Milk's pH, Sugar Level and Its Effects:

Phosphorus is an important substance for the development of teeth. Foods and drinks containing phosphorus should be consumed to protect dental health and strengthen dental enamel. Cow milk is among the substances with high phosphorus content. 100 ml of milk contains 99 milligrams of phosphorus.[19] This makes milk a drink that protects and strengthens the dental enamel. In addition, the sugar content of 100 ml of cow's milk is 5.32 grams.[20] Moreover, the pH of milk is between 6.7 and 6.9, which is a value close to neutral pH.[21]

---

[15] : "Product Q&A." *Red Bull Gives You Wings - RedBull.Com*, www.redbull.com/gb-en/energydrink/what-are-the-nutrition-facts-of-red-bull-energy-drink. Accessed 13 Mar. 2025.

[16] "Citric Acid in Juices." *ICIQ*, 11 Dec. 2024, iciq.org/outreach/schools-and-high-schools/from-the-laboratory-to-the-classroom/citric-acid-in-juices/.

[17] "Freshly Squeezed Orange Juice." *Calories in 100 Ml of Freshly Squeezed Orange Juice and Nutrition Facts*, www.fatsecret.com/calories-nutrition/generic/orange-juice-freshly-squeezed?portionid=1136675&portionamount=100.000. Accessed 13 Mar. 2025.

[18] Abdela, Woubit, et al. "Effects of Orange Juice Ph on Survival, Urease Activity and DNA Profiles of Yersinia Enterocolitica and Yersinia Pseudotuberculosis Stored at 4 Degree C." *Journal of Food Safety*, U.S. National Library of Medicine, Nov. 2011, pmc.ncbi.nlm.nih.gov/articles/PMC3212038/#:~:text=Undiluted%20orange%20juice%20(UD)%20%3D,and%20NaOH%20neutralized%3D%20pH%207.0.

[19] "Milk." *THE NUTRITIONAL COMPOSITION OF DAIRY PRODUCTS*, 22 Apr. 2021, milk.co.uk/nutritional-composition-of-dairy/milk/.

[20] "Milk." *Calories in 100 Ml of Milk and Nutrition Facts*, www.fatsecret.co.in/calories-nutrition/generic/milk?portionid=1136438&portionamount=100.000. Accessed 13 Mar. 2025.

[21] "Ph Determination of Milk and Milk Products: A Smartphone-Based Method Using a Chemically Bound Ph Indicator." *pH of Milk and Milk Products,* www.sigmaaldrich.com/US/en/technical-documents/protocol/analytical-chemistry/photometry-and-reflectometry/ph-of-milk-and-milk-products?msockid=1d441febf6296a2d04a90a92f7ec6b51. Accessed 13 Mar. 2025.

1.3.9 Relationship Between Tooth Enamel and Eggshell:

Drinks that are widely used in daily life such as cola, orange juice, energy drinks, milk and water directly affect our dental health. While cola, energy drinks and orange juice damage the dental enamel, milk and water protect the dental enamel. Cola, energy drinks and orange juice are highly acidic and sugary drinks. This is why they cause cavities. Milk, on the other hand, is rich in phosphorus, which strengthens the enamel. Since the pH of water is close to the neutral pH of 7, it balances the acidity of the mouth. For ethical reasons, eggshells will be used in this experiment since real teeth cannot be used. Eggshells are very similar in structure to dental enamel. Eggshells are composed of calcium carbonate.[22] This helps to mimic tooth enamel in experiments. Eggshells are also affected by acids and sugars, just like teeth. Thus, based on the appearance and texture changes in eggshells exposed to beverages, it is possible to estimate the texture and appearance changes in the enamel of teeth exposed to beverages. In addition, the difference in the mass of the eggshell exposed to beverages compared to the eggshell before exposure in beverages gives the effect of beverages on the erosion of the tooth enamel.

1.4 Aim of Study:

The aim of this experiment was to investigate the effect of beverages commonly used in daily life (Cola, Energy Drink, Milk, Water, and Orange Juice) on the surface, color and mass of the eggshell. Since the structure and content composition of the eggshell and the structure and composition of dental enamel are similar, the results of the experiment can be used to predict the effect of beverages commonly used in daily life (Cola, Energy Drink, Milk, Water, and Orange Juice) on dental enamel.

---

[22] Johnson, Doug. "What Are the Similarities between Eggshells and Teeth?" *Sciencing*, Sciencing, 30 Aug. 2022, www.sciencing.com/similarities-eggshells-teeth-8427281/.

1.5 Hypothesis:

1.5.1 Null Hypothesis:

H_0: There will be no change in the surface, mass, or color of the eggshells soaked in cola, energy drink, orange juice, milk, and water for 4 weeks.

1.5.2 Alternative Hypothesis:

H_A: Based on the results of a 2014 study, the Scientific Advisory Committee on Nutrition (SACN) in the United Kingdom[6] there will be a change in the surface, mass, or color of the eggshells soaked in cola, energy drink, orange juice, milk, and water for 4 weeks.

2. METHODOLOGIES:

2.1 Variables:

2.1.1 Independent Variable:

Variable Type	**Variable**	**Clarification**	**Setup**
Independent Variable	Different Types of Beverages (Cola, Energy Drink, Milk, Water, Orange Juice)	We soaked eggshells into different beverages for a period of 4 weeks.	We put eggshells of equal mass (5.00 grams) into transparent plastic cups

Table 1: Independent Variables

2.1.2 Dependent Variables: (Continuation of the tables is provided on the next page.)

Variable Type	Variable	Clarification	Setup
Dependent Variable	Alterations in Eggshell Mass (g)	The loss of mass was determined by weighing the eggshell before and after exposure.	Digital balance (Δ= smallest division = ±0.01 g)
Dependent Variable	Alterations in Eggshell Appearance	İdentified through to the consideration of discoloration	Visual analysis (photos)
Dependent Variable	Alterations in Eggshell Surface Integrity	Evaluated by assessing cracks, plasticity, and structural deterioration.	Eggshells soaked in water (Control group)

Table 2: Dependent Variables

2.1.3 Controlled Variables: (Continuation of the tables is provided on the next page.)

Variable Type	Variable	Clarification	Setup
Controlled Variables	Eggshell Type and Size	All eggshells are derived from the same kind of egg and identical in size (5.00 grams) to ensure uniformity.	Standardized eggshells

Controlled Variables	Volume of Beverage	Each eggshell sample is immersed in a constant volume (100 ml) of beverage to ensure uniform exposure.	1000 ml Graduated Cylinder ($\Delta = \frac{\text{smallest division}}{2} = \frac{10\text{ ml}}{2} = \pm 5$ ml)
Controlled Variables	Exposure Time	All eggshell samples remain in the beverages for 4 weeks.	Timer
Controlled Variables	Storage Conditions	All samples are maintained in the same environment with regulated temperature and light exposure.	Same Room
Controlled Variables	Observation Intervals	Observations and measurements are documented at constant time intervals.	Timed observations

Table 3: Controlled Variables

2.2 Materials: (Continuation of the tables is provided on the next page.)

Material Type	**Purpose**
5.00 grams of Eggshell	As a model used for tooth enamel to investigate the effects of different beverages.

100 ml Cola	Test beverage to observe its acidity and the impact of sugar on eggshells.
100 ml Energy Drink	Test beverage to observe its acidity and the impact of sugar on eggshells.
100 ml Milk	Test beverage to observe its acidity and the impact of sugar on eggshells.
100 ml Water	Control group.
100 ml Orange Juice	Test beverage to observe its acidity and the impact of sugar on eggshells.
Transparent Plastic Cup	Used for storing eggshells in beverages during the entirety of the experiment.
Digital Balance (Δ= smallest division = ± 0.01 g)	Used to measure the mass of eggshell samples before and after exposure.
1000 ml Graduated Cylinder (Δ= $\frac{\text{smallest division}}{2} = \frac{10\text{ ml}}{2} = \pm 5$ ml)	Establish an equal volume of beverages in each cup
Smartphone	Used to visualize photos of eggshells for analysis.
Gloves and Tweezers	Used to handle eggshells.
Computer	Used to document data, and results.
Timer	Used to measure 4 weeks of time.

Table 4: Materials

2.3 Method Development:

2.3.1 Selection of Beverages Used in The Experiment:

The drinks used in the experiment were chosen with different acidity and sugar content. Since the experiment investigates the effect of acid and sugar on dental health, it is very important that the drinks used in the experiment have different acidity and different sugar ratios. In addition, when looking at the effect of acidity and sugar on dental health, instead of working directly with acid or sugar, the reason for examining the effect of the acidity and sugar of the drinks on dental health is to obtain more realistic results because the drinks used in the experiment are drinks that people frequently consume in daily life. The reason for using cola and energy drinks in the experiment is that the pH value of cola and energy drinks is very low, their sugar content is very high, and they contain acids such as phosphoric and citric acid. The reason for choosing orange juice in the experiment is to investigate the effect of citric acid, which is naturally present in oranges, on dental health. The reason for choosing milk in the experiment is that milk is high in calcium, just like the calcium found in the tooth structure. Water was chosen as the control group in the experiment and when analyzing the results of the experiment, all results will be compared with the control group (water).

2.3.2 The Reason for Using eggshells in The Experiment:

While investigating the effect of drinks with different acid and sugar ratios on dental health, eggshells were chosen instead of real teeth in the experiment. The reason for choosing eggshells instead of real teeth in the experiment is that the use of real animal teeth is ethically inappropriate, and it is very difficult to access real animal teeth. In addition, the enamel of a real tooth and eggshell are remarkably similar. While real tooth enamel is composed of calcium and phosphorus, eggshells are composed of calcium carbonate. In addition, the enamel is as thin as the eggshell and is the outermost layer of the tooth. This allows us to estimate the effect

of different beverages on tooth enamel by looking at the results of eggshells soaked in different beverages in the experiment.

2.3.3 The Reason for Choosing 4 Weeks as The Duration of The Experiment:

In the experiment, eggshells were exposed to different beverages and kept in the beverages for 4 weeks. This is because the acids and sugars in the drinks can cause permanent damage to the teeth if consumed continuously. In the human mouth, the drinks do not stay in the mouth for 4 weeks, but if the teeth are not brushed, the acid and sugar that affect the teeth from the drinks remain in the mouth. Therefore, in the experiment, the eggshells were kept in the drinks for 4 weeks. At the end of the 4-week period, the experiment was completed because the drinks used in the experiment started to deteriorate.

2.4 Experiment Steps:

2.4.1 Preparation:

1. Gather 50 comparable-sized eggshells, ensuring they are neat and free from cracks.
2. Label five transparent plastic cups with the following names of the beverages: Cola, Energy Drink, Milk, Water, and Orange Juice.
3. Use a measuring cylinder to dispense an identical volume of each beverage into labeled transparent plastic cup.

Figure 3: Evenly Separating Different Beverages into Transparent Plastic Cups

2.4.2 Preliminary Measurements:

4. Measure the mass of each eggshell by using a weighing scale (±0.01g precision) and document the initial mass.

5. Capture initial photos of each eggshell for subsequent visual comparison.

2.4.3 Exposure Procedure:

6. Place one eggshell into each transparent plastic cup, ensuring complete submersion in the beverage.

7. Maintain all samples in the same room with consistent temperature, light exposure, and humidity.

Figure 4: Equally Weighted Eggshells in Transparent Glasses Filled with Different Beverages

2.4.4 Observation & Data Collection:

8. Weekly, extract the eggshells from the beverages using tweezers and monitor alterations in:

    - Color (discoloration or staining)
    - Surface texture (smoothness, erosion, or softening)
    - Cracks or observable structural impairment

9. Capture weekly photographs to document alterations.

10. Measure the mass of each eggshell sample weekly and document the mass loss.

11. After observation, return each eggshell back into its labelled transparent plastic cup.

2.4.5 Final Measurements and Evaluation:

12. After four weeks, extract the eggshells and allow them to dry for a consistent period.
13. Measure the mass of the dried eggshells to determine the total mass loss.
14. Examine the surface erosion and discoloration of the eggshells.
15. Evaluate the results between different beverages and examine the correlation between acidity/sugar content and eggshell deterioration.

2.4.6 Conclusion and Interpretation:

16. Analyze the outcomes by comparing mass loss, color alterations, and surface degradation among beverage subtypes.
17. Formulate conclusions regarding which beverages inflict the most and least damage, correlating results to their possible impacts on tooth enamel.
18. Display data using graphs, tables, and images for comprehensive analysis.

2.5 Evaluation of Ethical Issues and Risks:

- While examining the eggshells, I removed the eggshells from the drinks with the help of tweezers so that the eggshells would not break.
- I used gloves while drying the surface of the eggshells to examine the eggshell's appearance because the beverages had started to deteriorate.
- I did not harm any organisms during my work, and I worked with eggshells that mimicked dental enamel instead of real animal teeth.

3. DATA COLLECTION AND PROCESSING:

3.1 Qualitative Data:

Qualitative data includes visual observations of the eggshells over the 4-week period. These observations focus on color changes, surface texture, cracks, and overall structural integrity. Quantitative data is analyzed through photographs taken over 4 weeks using a smartphone.

3.1.1 Photographs of The Eggshells Soaked in Beverages: (Continuation of the tables is provided on the next page.)

Beverage Type	**Photographs of The Eggshells in Week 1**	**Photographs of The Eggshells in Week 2**	**Photographs of The Eggshells in Week 3**	**Photographs of The Eggshells in Week 4**
Water (Control Group)				
Cola				
Orange Juice				

Energy Drink				
Milk				

Table 5: Photographs of The Eggshells Soaked in Beverages

3.1.2 Observations of The Eggshells Soaked in Beverages: (Continuation of the tables is provided on the next page.)

Beverage Type	**Week 1 Observations**	**Week 2 Observations**	**Week 3 Observations**	**Week 4 Observations**
Water (Control Group)	There was no change in the color or structure of the eggshell. It was the same as when it was first put in water.	No difference from the first week. No change or color change on the surface of eggshell.	No discoloration, no cracking or erosion on the surface of the eggshell.	Surface remains smooth and unchanged.

Cola	Small cracks appear on the surface of the eggshell. There is also a color change in the eggshell. The color of the eggshell turns brown. The surface is still smooth, and the eggshell remains hard.	The color of the eggshell has darkened and is considerably brown. The cracks on the surface of the eggshell have started to deepen. Visible erosion is appearing on the surface	The eggshell starts to shatter. The cracks on the surface of the eggshell have deepened, which causes the eggshell to disintegrate.	The eggshell is thoroughly shattered. In addition, the eggshell has become quite soft and has lost its former smoothness and hardness. The color of the eggshell is a very dark brown. The surface of the eggshell is eroded.
Orange Juice	The color of the eggshell is slightly turning yellow. There are also small cracks on the surface of the eggshell but no abrasion. The eggshell	The color of the eggshell is now more yellow and there is a big difference in the color of the eggshell compared to how the eggshell used to be. The surface	The color of the eggshell has not changed much compared to week 2, but the eggshell has lost its hardness and smoothness.	There is a significant difference in the color of the eggshell. The color of the eggshell is orange. In addition, the number of abrasions on the eggshell has increased. The

	remains smooth and hard.	of the eggshell is beginning to show abrasions.		eggshell is no longer as hard as before.
Energy Drink	Staining has started to appear a little but only slightly. In addition, the surface hardness has decreased compared to the first week.	The amount of staining on the surface of the eggshell increased. The eggshell has started to soften and there is significant abrasion on the surface of the eggshell.	The surface of the eggshell is now very softened. There is considerable abrasion and staining of the eggshell.	The surface of the eggshell is completely softened. The color of the eggshell is more orange compared to week 3. Abrasions on the surface are evident.
Milk	The surface of the eggshell is hard and smooth. There is no change in color of the eggshell.	The eggshell structure and appearance were like the first week.	The eggshell retains its hardness. There is no abrasion on the surface of the eggshell	The eggshell is hard. There is no abrasion or discoloration. Results in week 4 are like the first week.

			and no visible discoloration.	

Table 6: Observations of The Eggshells Soaked in Beverages

3.2 Quantitative Data:

3.2.1 Weekly Variation of The Mass of Eggshells: (Continuation of the tables is provided on the next page.)

Beverage Type	**Trials**	**Initial Mass (g)**	**Mass of the Eggshell (g) (Δt = ± 0.01 g) in Week 1 Mass**	**Mass of the Eggshell (g) (Δt = ± 0.01 g) in Week 2 Mass**	**Mass of the Eggshell (g) (Δt = ± 0.01 g) in Week 3 Mass**	**Mass of the Eggshell (g) (Δt = ± 0.01 g) in Week 4 Mass**
Water (Control Group)	Trial 1	5.00	5.00	5.00	5.00	5.00
	Trial 2	5.00	5.00	5.00	5.00	5.00
	Trial 3	5.00	5.00	5.00	5.00	5.00
	Trial 4	5.00	5.00	5.00	5.00	5.00
	Trial 5	5.00	5.00	5.00	4.99	5.00
	Trial 6	5.00	5.00	5.00	5.00	4.99
	Trial 7	5.00	5.00	5.00	4.98	4.98

	Trial 8	5.00	5.00	5.00	4.99	4.98
	Trial 9	5.00	5.00	5.00	5.00	5.00
	Trial 10	5.00	5.00	5.00	5.00	5.00
Cola	Trial 1	5.00	4.94	4.90	4.79	4.69
	Trial 2	5.00	4.96	4.92	4.80	4.69
	Trial 3	5.00	4.97	4.88	4.78	4.70
	Trial 4	5.00	4.95	4.89	4.80	4.68
	Trial 5	5.00	4.98	4.87	4.79	4.67
	Trial 6	5.00	4.97	4.87	4.80	4.70
	Trial 7	5.00	4.95	4.86	4.80	4.68
	Trial 8	5.00	4.94	4.89	4.80	4.67
	Trial 9	5.00	4.95	4.89	4.81	4.67
	Trial 10	5.00	4.98	4.89	4.80	4.68
Energy Drink	Trial 1	5.00	4.95	4.90	4.85	4.79
	Trial 2	5.00	4.96	4.92	4.88	4.79
	Trial 3	5.00	4.95	4.92	4.86	4.80
	Trial 4	5.00	4.95	4.90	4.85	4.81
	Trial 5	5.00	4.95	4.92	4.85	4.80
	Trial 6	5.00	4.96	4.93	4.85	4.79

	Trial 7	5.00	4.96	4.90	4.86	4.78
	Trial 8	5.00	4.95	4.90	4.87	4.79
	Trial 9	5.00	4.96	4.91	4.84	4.80
	Trial 10	5.00	4.96	4.90	4.85	4.79
Orange Juice	Trial 1	5.00	4.98	4.95	4.90	4.85
	Trial 2	5.00	4.97	4.96	4.89	4.86
	Trial 3	5.00	4.97	4.95	4.89	4.85
	Trial 4	5.00	4.98	4.95	4.87	4.84
	Trial 5	5.00	4.98	4.94	4.90	4.84
	Trial 6	5.00	4.97	4.95	4.87	4.85
	Trial 7	5.00	4.98	4.94	4.88	4.84
	Trial 8	5.00	4.99	4.93	4.89	4.86
	Trial 9	5.00	4.98	4.95	4.87	4.84
	Trial 10	5.00	4.97	4.94	4.88	4.83
Milk	Trial 1	5.00	4.99	4.98	4.98	4.98
	Trial 2	5.00	4.99	4.99	4.99	4.99
	Trial 3	5.00	4.98	4.98	4.97	4.97
	Trial 4	5.00	5.00	4.98	4.98	4.98
	Trial 5	5.00	4.99	4.99	4.99	4.98

	Trial 6	5.00	4.98	4.98	4.98	4.98
	Trial 7	5.00	4.99	4.99	4.99	4.98
	Trial 8	5.00	5.00	5.00	5.00	4.99
	Trial 9	5.00	5.00	5.00	5.00	4.99
	Trial 10	5.00	5.00	5.00	5.00	5.00

Table 7: Weekly Variation of The Mass of Eggshells

3.3 Organizing and Summarizing Data:

By taking the mean of 10 trials per week, the data from the effect of different beverages on the eggshell can be better analyzed. In this way, errors in measurement are stabilized and the systematic effect of a beverage on the eggshell can be understood. In addition, graphical and statistical analysis can be performed by taking the mean of 10 trials of each week.

Mean Mass of Eggshells Soaked in Different Beverages was calculated with the following equation:

$$\bar{x} = \frac{\sum x_i}{n}$$

$\bar{x}$ = Arithmetic mean

$\sum x_i$ = Sum of all measurements

n = Total number of measurements

(equation 1)[23]

Taking the standard deviation of 10 trials of eggshells soaked in beverages for 4 weeks helps us to understand how distributed the measurements are. Data with large standard deviations are

[23] Admin. "Mean Formula: Formulas, Methods and Solved Examples." *BYJUS*, BYJU'S, 6 Sept. 2022, byjus.com/maths/mean-formula/.

more variable, while data with small standard deviations are more coherent. In this way, by taking the standard deviation, it is possible to understand in which beverage the change in the eggshell is more consistent. Standard deviation is also needed for statistical analysis and error bars.

Standard Deviation of The Mass of Eggshells Soaked in Different Beverages was calculated with the following equation:

$$s = \frac{\sqrt{\sum(x_i - \bar{x})^2}}{n-1}$$

s = Sample standard deviation

$\bar{x}$ = Arithmetic mean

x_i = Each data point

n = Total number of data points in the sample

(equation 2)[24]

3.3.1 Mean Mass of Eggshells Soaked in Different Beverages:

Week Number	**Mean mass of eggshells soaked in Water (g)**	**Mean mass of eggshells soaked in Cola (g)**	**Mean mass of eggshells soaked in Energy Drink (g)**	**Mean mass of eggshells soaked in Orange Juice (g)**	**Mean mass of eggshells soaked in Milk (g)**
Week 1	5.0	4.959	4.955	4.977	4.992
Week 2	5.0	4.886	4.910	4.946	4.989
Week 3	4.996	4.797	4.856	4.884	4.988

[24] Admin. "Standard Deviation Formula for Population and Sample." *BYJUS*, BYJU'S, 16 Sept. 2020, byjus.com/standard-deviation-formula/.

Week 4	4.995	4.683	4.794	4.846	4.984

Table 8: Mean Mass of Eggshells Soaked in Different Beverages

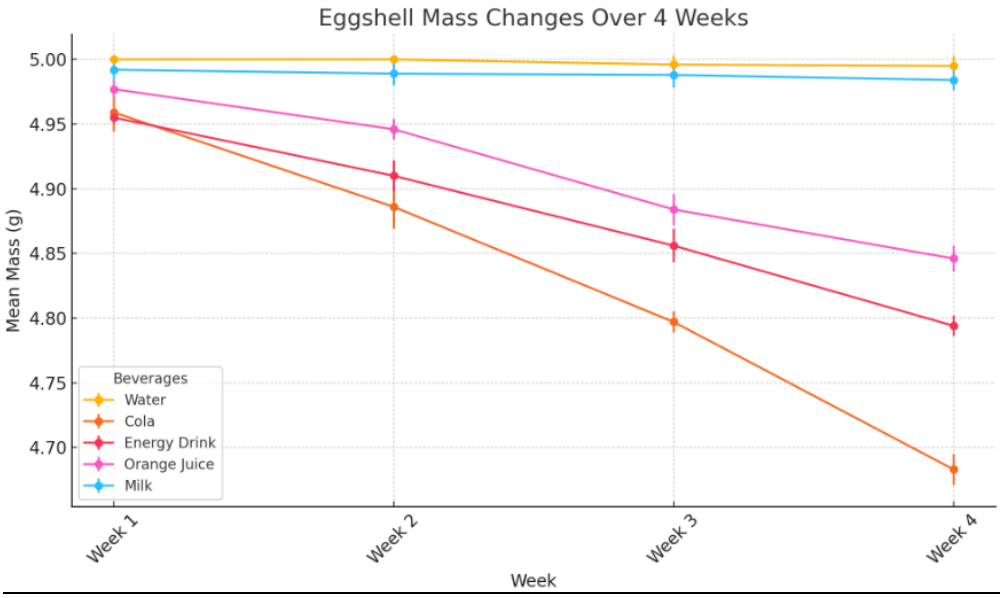
3.3.2 Standard Deviation of The Mass of Eggshells Soaked in Different Beverages:

Week Number	**Standard deviation of the mass of eggshells soaked in Water (g)**	**Standard deviation of the mass of eggshells soaked in Cola (g)**	**Standard deviation of the mass of eggshells soaked in Energy Drink (g)**	**Standard deviation of the mass of eggshells soaked in Orange Juice (g)**	**Standard deviation of the mass of eggshells soaked in Milk (g)**
Week 1	0.0	0.015	0.005	0.007	0.008
Week 2	0.0	0.017	0.012	0.008	0.009
Week 3	0.007	0.008	0.013	0.012	0.010
Week 4	0.008	0.012	0.008	0.010	0.008

Table 9: Standard Deviation of The Mass of Eggshells Soaked in Different Beverages

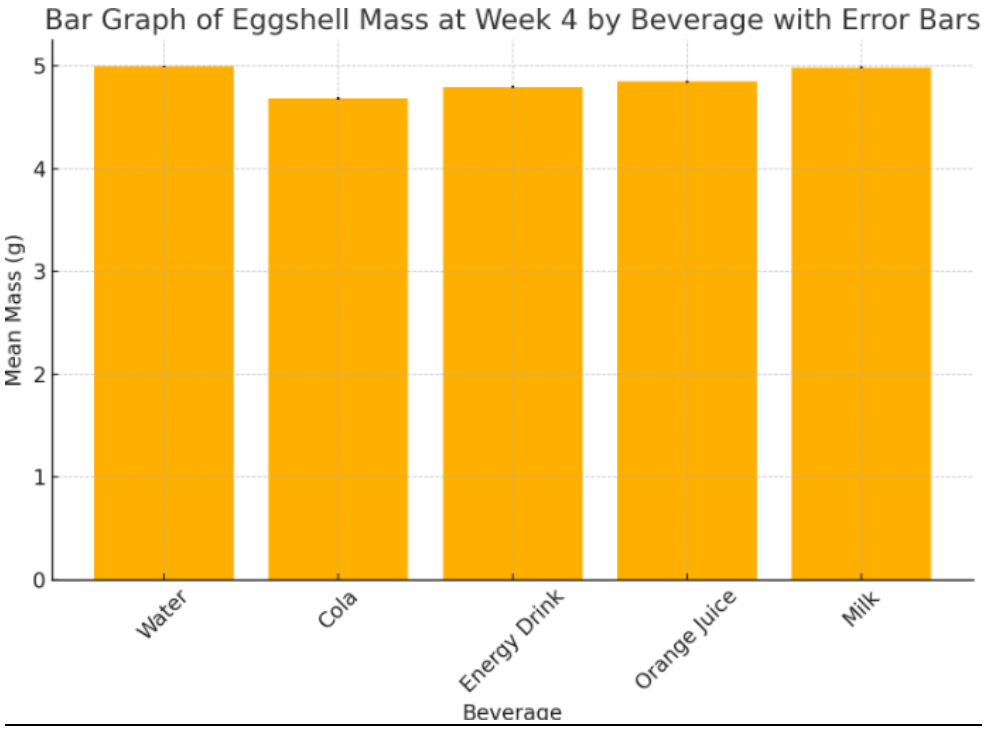
3.4 Data Visualization:

3.4.1 Line Graph:



Graph 1: Line Graph of Eggshell Mass Changes Over 4 Weeks with Error Bars

3.4.2 Bar Graph:



Graph 2: Bar Graph of Eggshell Mass at Week 4 by Beverage Type with Error Bars

3.5 Statistical Analysis:

3.5.1 T-Test: (Continuation of the tables is provided on the next page.)

By taking a T-Test, the difference in mean between two data can be understood in more detail. The T-Test shows whether the difference between two groups is significant.[25] We will compare the control group of water with the other groups to see if the change in eggshell is significant in different drinks. We obtained the T-Test with python code.[26]

Comparison	**T-Statistic**	**P-Value**	**Statistically Significant?**
Cola vs Water	-35.8271	0.000000	Yes ($p < 0.05$)
Milk vs Water	-1.0000	0.343436	No ($p > 0.05$)
Orange Juice vs Water	-23.7667	0.000000	Yes ($p < 0.05$)
Energy Drink vs Water	-15.8114	0.000000	Yes ($p < 0.05$)

Table 10: T-Test

4. DISCUSSIONS:

In this experiment, 5 different drinks were selected. It was taken into consideration that these drinks are frequently used in daily life. Eggshells were used in the experiment to mimic real tooth enamel. Eggshells are very similar to dental enamel due to their content and structure. Therefore, with the results of this experiment, it is concluded that the effect of beverages with different acid and sugar ratios on the surface, color and abrasion of dental enamel. Eggshells soaked in the drinks were photographed and their mass was measured every week. The photographed eggshells showed the weekly color and surface changes of the eggshells kept in different beverages. In addition, measuring the mass of eggshells soaked in different beverages

[25] "T-Test, Chi-Square, ANOVA, Regression, Correlation..." *Datatab*, datatab.net/tutorial/t-test. Accessed 13 Mar. 2025.
[26] Python Code for T-Test is provided in the bibliographies section

on a weekly basis allowed us to understand the extent to which different beverages erode eggshells.

Table 5 shows the changes in the surface and color of the eggshells. Cola was the beverage that changed the color of the eggshell the most during the 4-week period. In addition, cola caused cracks in the eggshell and the eggshell kept in cola in the 4th week was completely disintegrated. Looking at the weekly change images of the energy drink, it is said that the eggshells kept in the energy drink are highly abraded and softened compared to the control group of water. Although it does not stain as much as cola, the energy drink also caused a significant color change in the eggshells. Another beverage that provides another color change in eggshells is orange juice. Orange juice turned the color of the eggshells orange at the end of the 4-week period. Although it did not soften the eggshells as much as the energy drink, the eggshells kept in orange juice also lost their hardness and abrasion occurred on their surfaces. Milk did not affect the eggshells. During the 4-week period, the eggshells kept in milk were hard and not eroded. There was also no change in the color of the eggshells placed in milk. If eggshells are to be compared in terms of color change, it is said that cola is the one that provides the most color change based on Table 5. Cola is followed by energy drink and orange juice. Water and milk did not cause any color change in the eggshells. The beverage that softens the eggshell the most and causes the most abrasion on the eggshell is energy drink from the data in Table 5. Energy drink abraded and softened the eggshells at a significant rate. Cola also caused fractures in the eggshells kept in the same way. The surface of the eggshells kept in orange juice was less abraded than the energy drink. Milk and water did not cause abrasion on eggshells.

When the average masses of the eggshells in Table 8 are examined, it is seen that the eggshell kept in cola is the least at the end of the 4-week period. Energy drink and orange juice are next. Milk provided the lowest mass change. Since water was the control group, it did not provide any mass change in eggshells. In Table 10, the masses of eggshells kept in different drinks are

compared with the masses of eggshells kept in water by t-test. The reason for the comparison with water is that water is the control group. The T-Statistic values in table 10 are negative. This is because the mass of eggshells decreases over the weeks. The p-values of the other beverages except milk were statistically significant. This indicates that there is no significant change in the mass of the eggshells kept in milk.

When Qualitative and Quantitative values are analyzed, it is seen that cola has the highest effect on eggshell, followed by energy drinks and orange juice. It can also be inferred that water and milk have no effect on the eggshell. When these results are summed up, it is seen that cola, which has the highest sugar and acid content, has the highest effect on eggshells. Based on these results, it can be inferred that as the sugar and acid ratio increases, the damage to the eggshell increases. Thus, it will be concluded that the cola with the highest sugar and acid ratio will have the most effect on the dental enamel. This confirms the H_A hypothesis.

According to the results of a study conducted by the Scientific Advisory Committee on Nutrition (SACN) in the United Kingdom in 2014[6], the statement that the surface, mass, or color of eggshells immersed in cola, energy drinks, orange juice, milk, and water for four weeks will change is confirmed by the results of the experiment.

5. EVALUATIONS:

5.1 Strengths:

Strengths	**Reason(s) to be Considered as a Strength**
Obtaining results by performing 50 trials in the experiment.	More accurate results were obtained
Conducting the experiment for 4 weeks.	The experiment lasted long, and thus more realistic results were obtained.

Photographing the results of the experiment during each week.	The results are better compared.
Taking the means of the data obtained.	The results are better compared.
Taking the standard deviation of the data obtained.	The result distribution is better understood.
Graphing the results obtained.	The results are better compared.
Making T- Test of the obtained data	More in-depth analysis provided.

Table 11: Strengths

5.2 Limitations:

Real teeth were not used for ethical reasons. This reduces the accuracy of the result obtained.

6. CONCULUSION:

The data show that beverages high in sugar and acidity, especially cola, are the most damaging to tooth enamel. These results confirm that the higher the sugar and acid content, the greater the damage to tooth enamel. However, beverages with low pH values, such as milk and water, do not damage tooth enamel and appear to have less impact on dental health. This study highlights the negative effects of sugary and acidic beverages on dental health and reveals that excessive consumption of such beverages can damage tooth enamel.

7. BIBLIOGRAPHIES:

1: “Oral Health.” *World Health Organization*, World Health Organization, www.who.int/news-room/fact-sheets/detail/oral-health. Accessed 13 Mar. 2025.

2: by Nawon, Posted, and Nawon. “Top 10 Most Consumed Beverages in the World.” *Nawon Food and Beverage*, 4 July 2024, nawon.com.vn/top-10-worlds-most-consumed-beverage/?srsltid=AfmBOopFaPQinqafg2Z8hAkRF6bMA9pRfJHCDVLVlbg2hIRmPTr5NXfP.

3: Moore, Dr. Durning. “How Bottled Water Ph Impacts Dental Health.” *Smile Moore Dental*, 7 Jan. 2025, www.drdurningmoore.com/understanding-the-ph-of-bottled-water-and-its-impact-on-oral-health/#:~:text=The%20natural%20pH%20of%20your,consuming%20acidic%20foods%20or%20drinks.

4: “Action on Sugar.” *Sugars and Tooth Decay - Action on Sugar*, www.actiononsugar.org/sugar-and-health/sugars-and-tooth-decay/#:~:text=When%20sugar%20is%20consumed%20it,to%20be%20removed%20%5B2%5D. Accessed 13 Mar. 2025.

5: “Havuzların PH Değeri Kaç Olmalıdır?” *Havuzcu Market*, www.havuzcumarket.com/blog/icerik/havuzlarin-ph-degeri-kac-olmalidir. Accessed 13 Mar. 2025.

6: England, Public Health. “SACN Carbohydrates and Health Report.” *GOV.UK*, GOV.UK, 17 July 2015, www.gov.uk/government/publications/sacn-carbohydrates-and-health-report.

7: professional, Cleveland Clinic medical. “Tooth Enamel: What It Is & How to Preserve It.” *Cleveland Clinic*, 1 May 2024, my.clevelandclinic.org/health/body/24798-tooth-enamel.

8: “What to Know about the Ph of Water.” *Medical News Today*, MediLexicon International, www.medicalnewstoday.com/articles/327185#:~:text=In%20its%20purest%20form%2C%20water,somewhere%20between%206.5%20and%208.5. Accessed 13 Mar. 2025.

9: *The Harms of Acidic Beverages on Teeth | Dentevim Dental Clinic*, www.dentevim.com/en/the-harms-of-acidic-beverages-on-teeth. Accessed 13 Mar. 2025.

10: “What Are the Ingredients of Coca-cola Classic?” *What Are the Ingredients of Coca-Cola Classic?*, www.coca-cola.com/hk/en/about-us/faq/what-are-the-ingredients-of-coca-cola-classic#:~:text=Phosphoric%20Acid%20%E2%80%93%20The%20tartness%20of,the%20use%20of%20phosphoric%20acid. Accessed 13 Mar. 2025.

11: Forest Lake Family Dental. “Does Coke Ruin Teeth in General?” *Forest Lake Family Dental*, 16 Sept. 2024, www.forestlakefamilydental.com/does-coke-ruin-teeth-in-general/#:~:text=While%20enjoying%20a%20Coke%20now,and%20cause%20other%20dental%20problems.

12: “How Much Sugar Is in Coca-cola?” *How Much Sugar Is in Coca-Cola?*, www.coca-cola.com/hk/en/about-us/faq/how-much-sugar-is-in-coca-cola. Accessed 13 Mar. 2025.

13: *Tea Coffee Acids Soft Drinks*, www.beyondsmilesparkridge.com/wp-content/uploads/2019/12/pH-Values-of-beverages-and-drinks.pdf. Accessed 13 Mar. 2025.

14: “The Role of Citric Acid in the Soft Drink and Energy Beverage Industry.” *Total Ingredientes*, Total Ingredientes, 17 Feb. 2025, www.totalingredientes.com.br/en/post/the-role-of-citric-acid-in-the-soft-drink-and-energy-beverage-industry.

15: “Product Q&A.” *Red Bull Gives You Wings - RedBull.Com*, www.redbull.com/gb-en/energydrink/what-are-the-nutrition-facts-of-red-bull-energy-drink. Accessed 13 Mar. 2025.

16: “Citric Acid in Juices.” *ICIQ*, 11 Dec. 2024, iciq.org/outreach/schools-and-high-schools/from-the-laboratory-to-the-classroom/citric-acid-in-juices/.

17: “Freshly Squeezed Orange Juice.” *Calories in 100 Ml of Freshly Squeezed Orange Juice and Nutrition Facts*, www.fatsecret.com/calories-nutrition/generic/orange-juice-freshly-squeezed?portionid=1136675&portionamount=100.000. Accessed 13 Mar. 2025.

18: Abdela, Woubit, et al. “Effects of Orange Juice Ph on Survival, Urease Activity and DNA Profiles of Yersinia Enterocolitica and Yersinia Pseudotuberculosis Stored at 4 Degree C.” *Journal of Food Safety*, U.S. National Library of Medicine, Nov. 2011, pmc.ncbi.nlm.nih.gov/articles/PMC3212038/#:~:text=Undiluted%20orange%20juice%20(UD)%20%3D,and%20NaOH%20neutralized%3D%20pH%207.0.

19: “Milk.” *THE NUTRITIONAL COMPOSITION OF DAIRY PRODUCTS*, 22 Apr. 2021, milk.co.uk/nutritional-composition-of-dairy/milk/.

20: “Milk.” *Calories in 100 Ml of Milk and Nutrition Facts*, www.fatsecret.co.in/calories-nutrition/generic/milk?portionid=1136438&portionamount=100.000. Accessed 13 Mar. 2025.

21: “Ph Determination of Milk and Milk Products: A Smartphone-Based Method Using a Chemically Bound Ph Indicator.” *pH of Milk and Milk Products,* www.sigmaaldrich.com/US/en/technical-documents/protocol/analytical-chemistry/photometry-and-reflectometry/ph-of-milk-and-milk-products?msockid=1d441febf6296a2d04a90a92f7ec6b51. Accessed 13 Mar. 2025.

22: Johnson, Doug. “What Are the Similarities between Eggshells and Teeth?” *Sciencing*, Sciencing, 30 Aug. 2022, www.sciencing.com/similarities-eggshells-teeth-8427281/.

23: Admin. “Mean Formula: Formulas, Methods and Solved Examples.” *BYJUS*, BYJU’S, 6 Sept. 2022, byjus.com/maths/mean-formula/.

24: Admin. “Standard Deviation Formula for Population and Sample.” *BYJUS*, BYJU’S, 16 Sept. 2020, byjus.com/standard-deviation-formula/.

25: “T-Test, Chi-Square, ANOVA, Regression, Correlation...” *Datatab*, datatab.net/tutorial/t-test. Accessed 13 Mar. 2025.

26: Python Code for T-Test:

```
import pandas as pd

from scipy import stats


# Load the data from the file into a Pandas DataFrame

df = pd.read_excel("111.docx")


# Remove rows with missing values

df = df.dropna()


# Initialize an empty list to store the results

results =


# Beverages to compare with 'Water'
```

```
beverages = ['Cola', 'Milk', 'Orange Juice', 'Energy Drink']


# Weeks to compare

weeks = ['Week 1Mass ', 'Week 2Mass ', 'Week 3Mass ', 'Week 4Mass']


# Perform paired t-tests for each beverage against water

for beverage in beverages:

    water_data = df[df['Beverage Type'] == 'Water (Control Group)']

    beverage_data = df[df['Beverage Type'] == beverage]


    # Combine data from all weeks

    water_all_weeks = pd.concat([water_data[week] for week in weeks])

    beverage_all_weeks = pd.concat([beverage_data[week] for week in weeks])


    # Perform paired t-test

    t_statistic, p_value = stats.ttest_rel(water_all_weeks, beverage_all_weeks)


    # Append the results to the list

    results.append({

        'Beverage Comparison': f'{beverage} vs Water',
```

```
        't-statistic': t_statistic,
        'p-value': p_value
    })

# Convert the results list to a DataFrame
results_df = pd.DataFrame(results)

# Print the results DataFrame
print(results_df.to_markdown(index=False, numalign="left", stralign="left"))
```

The photos in figures 3 and 4 were taken by me.

The photos in table 5 were taken by me.

Graph 1 and graph 2 were created by me.