Abstract:

Cherry tomatoes have a short growth cycle consisting of three phases: growth, flowering, and fruiting. In this study, cherry tomatoes were watered using water and three different teas with varying acidities—chamomile tea, green tea, and black tea. Previous studies typically focused on tomato growth in controlled environments with consistent pH levels. They often aimed to maintain the appropriate pH in soil for plants that thrive in acidic or basic soils, rather than neutral ones. However, this experiment aimed to explore the use of tea to alter soil pH for more effective tomato growth. While there exist numerous studies on acidic teas, this research consolidated their effects into a single study. The experiment involved 40 pots organized into groups of 10, each receiving one of the three teas or water. Soil was filled in these pots, and 7 germinated seeds were planted in each pot, followed by daily watering with 20 mL of the designated liquid. Throughout the study, soil pH levels remained stable across the different groups tested, suggesting that the primary factor influencing variations in leaf yield and plant height was gallic acid. However, the findings regarding plant height and leaf production were statistically not significant. Future work will involve analyzing different teas with diverse properties to expand understanding in this area.

Introduction:

In modern times, the main issue regarding agriculture and food production is being unable to produce enough crops for the growing population. Competition for water and region-specific issues such as climate uncertainty and especially droughts contribute to the rising population being incapable of acquiring food (Pereira, 2017). By using tea to water plants, farmers can grow a more extensive supply of crops without using more water. Teas are an inexpensive way to increase food production by increasing crop yield: thus, helping feed the growing population.

Cherry Tomatoes and pH:

Tomatoes, specifically tomatoes, are essential to many cultures around the world: including several Asian and Latin American cuisines (González *et al.*, 2011). They also have several health and culinary benefits. For example, they are a rich source of vitamins A and C, potassium, and dietary fiber. Cherry tomatoes also contain antioxidants like lycopene, which are associated with potential health benefits such as reducing the risk of certain cancers and heart disease, are also present in them (González *et al.,* 2011). Additionally, cherry tomatoes are smaller, have a round or slightly oval shape, and are sweeter than regular tomatoes, which makes them essential to certain cuisines. Cherry tomatoes differ from regular tomatoes in a crucial way: cherry tomato plants often produce a higher yield per plant than ordinary tomato plants since they are smaller and can be packed more densely on the plant (Grover, 2019). Cherry tomatoes' ability to produce a higher fruit yield makes them beneficial for commercial growers who rely on maximizing their harvest to meet market demands and generate higher profits. In home gardens, a high fruit yield ensures an abundant supply of tomatoes for personal consumption or sharing with others. Therefore, cherry tomatoes were chosen for the experiment. The experiment conducted aimed to determine how to increase the fruit yield of cherry tomatoes using a readily available and cheap substance: tea (Grover, 2019).

Cherry tomatoes can reach up to 2 to 3 meters, have a diameter of 1.5-3 cm (about 1.18 in), and weigh around 30 g. They have a short growing time and three growth phases. The phases include the growth phase, the flowering phase, and finally, the fruiting phase (Anugraheni *et al.,* 2019). The aim of the experiment was to determine how different teas with varying pH levels affect cherry tomatoes' fruit yield. The measure of how acidic or basic a liquid is considered pH.

A basic solution has a pH level greater than 7, a neutral solution has a pH level of 7, and an acidic solution has a pH level less than 7 (Water Science School, 2019). Cherry tomatoes require the soil it is grown in to have a pH of 6.2-6.8 (Slusher, 2016). Soil with a pH higher than 6.8 and lower than 6.2 will not be sufficient to grow cherry tomatoes (Pokorny, 2021). The correct pH level is vital for the growth of plants because it allows them to obtain the nutrients necessary for their growth and health. The pH of the soil can be determined using a pH meter.

Teas:

Chamomile Tea:

The frequent usage of chamomile tea is due to its medicinal properties (Khanam *et al*., 2011). However, in this study, the tea's pH and other acidic properties are being studied. Chamomile tea has a pH level of between 6 and 7. The pH depends on the steeping time when brewing the tea. Chamomile tea is one of the least acidic herbal teas; however, its acidity is ideal for growing cherry tomatoes, as these tomatoes grow best in 6.3 to 6.7 pH soil (Ahmed *et al*., 2017). Other acids found in abundance in chamomile tea extracts are chlorogenic acid and vitamin C, otherwise known as ascorbic acid. During an experiment on chamomile tea that tested levels of different acids in chamomile using the UHPLC-MS/MS method, the discovery was that chamomile had high levels of chlorogenic acid (Gonçalves *et al*., 2010). Chlorogenic acid is the most abundant in chamomile tea extract and chamomile tea leaves themselves (Arak *et al*., 2011). This suggests that the steeping time affects both the pH level and the levels of chlorogenic acid.

Another acid in chamomile tea is ascorbic, more commonly known as vitamin C. When using an enzymatic biosensor, the enzymes of different teas were analyzed. In the analysis of chamomile tea, there was a substantial vitamin C component (Costa *et al*., 2021). Other acids found in great abundance are umbelliferone acid and apigenin acid (Gonçalves *et al*., 2010). Umbelliferone is used to fight infections like bronchitis and other bacterial infections. This suggests that chamomile tea may also be beneficial to the Tiny Tim tomatoes' bacterial health (Mazimba, 2017). Apigenin is an antioxidant, antioxidants aid in plant growth by acting as redox buffers that interact with the plants' cells, therefore influencing growth (Ali *et al*., 2017).

Green Tea:

Green tea has recently become a promising and environmentally friendly reactant as a natural organic matter (Wu, 2021). It has two properties that help with plant growth and development: vitamin C (ascorbic acid) and chlorogenic acid. Ascorbic acid (vitamin C) is synthesized by animals and plants but is absent from prokaryotes (Smirnoff, 2011). Additionally, in plants, ascorbic acid serves as a primary redox buffer and regulates various physiological processes controlling growth, development, signal transduction, and stress tolerance (Hossain *et al*., 2017). Chlorogenic acids (CQAs), the esters of caffeic acid and quinic acid, are biologically critical phenolic compounds in many plant species (Gil & Wianowska, 2017). When harvested for immediate use or the market, tomato plants show significant variability within a variety in ascorbic acid concentration, ranging from 7 to well over 40 milligrams per 100 grams of fresh tissue (Murneek *et al*., 1954). Some phenolics (chlorogenic acid and rutin) were suggested to regulate auxin (like indole 3-acetic acid) metabolism. The production of photoprotective compounds such as flavonols in the skins of tomato fruits may afford protection against UV-B-induced oxidative damage (Slimstad & Verheul, 2005).

Black Tea:

Black tea is one of the most popular teas worldwide. Black tea accounts for 78 percent of the world's tea consumption, and black tea is most prominent in westernile tea which contains both ascorbic acids, chlorogenic acid, antioxidants, and the correct pH level.

Novelty:

This experiment is novel because it addresses using tea to change soil's pH range to be more efficient in growing tomatoes. Other experiments do not address these factors together. Some experiments focus solely on tomato growth in a controlled environment, where the pH can be changed (Anugraheni, 2019). Other studies focus on keeping correct pH in soil for all plants that are better grown in acidic or basic soils rather than neutral (Pokorny, 2021). However, there are many studies on the acidic properties of teas (Ribeiro *et al.*, 2021). This information has never been put together in a single experiment to test if tea can shift the pH to a more favorable range to increase growth and yield in tomato plants.

Methods:

Material setup:

The acquisition included Tiny Tim Tomato seeds, 6x6 pots, and soil with a pH of 5.5-6.5 sourced from Francis Lewis High School. Next, green tea (pH 7-10), chamomile tea (pH 6-7), and black tea (pH 4.9-5.5) were ordered from Amazon.com. Subsequently, cut-up pieces of fabric were added to the bottom of the pots to catch any leaking liquid. Four groups of Tiny Tim

Tomato plants were assigned: control (only watered with water), green tea, chamomile tea, and black tea. Consequently, the pots were labeled based on the intended tea infusion.

Experimental setup:

Adhering to lab safety guidelines, hair was securely tied up, and goggles, gloves, and lab coats were worn prior to handling the plants. Furthermore, the surface was wiped with disinfecting wipes and allowed to dry before proceeding. Subsequently, a newspaper was positioned on the surface to facilitate easy cleanup of any spills. The presence of small drainage holes at the bottom of each pot was checked to prevent waterlogging and promote unrestricted growth of the plants.

Procedure:

In the experiment, ten pots were prepared on a newspaper surface. Three paper towels were moistened with deionized water, and seventeen seeds were placed in each towel. A large Ziplock bag was lightly sprayed with water, and paper towels were placed inside. The Ziplock bag was then put in a cabinet, providing a dark and warm environment for germination. Daily checks were made on the seeds, excluding weekends, and they were removed once they sprouted.

To prevent soil loss during watering, a 10x10 cm piece of fabric was placed at the bottom of each pot. All materials were set up, and a trowel (soil shovel) was used to fill the ten pots with soil. Carefully, 50 grams of soil were compressed into each pot, gently pushed down to a depth of 2.5 inches, and measured. The sprouted seed was placed in the center of the soil, and another 50 grams of soil was added on top, also compressed. These steps were repeated for all four trials. Lastly, the pots were placed on a tray and rotated based on their proximity to the window to receive sunlight.

Making the Tea:

The teas were prepared by pouring 500 mL of deionized water into a beaker and heating it in the microwave for 2 minutes and 30 seconds or until the water reached a temperature of 32-35°C. Once the water boiled, the beaker was carefully removed from the microwave using a pair of oven mittens. The tea bags were opened, and the tea bag was placed into the beaker following the provided instructions. The tea was allowed to steep for the instructed duration and then stirred with a small spatula. An additional 3 minutes of steeping time was given. Subsequently, the tea was cooled in the fridge for 10 minutes. Any remaining tea was labeled, stored in a sealed container, and refrigerated for two weeks.

Each group of watering mediums (chamomile tea, green tea, black tea, and water) comprised 10 pots, each containing two sprouting seeds, and daily watering was carried out with 20 mL of green tea, black tea, chamomile tea, or water, as indicated in the table. On weekends, the plants were watered with 30 mL of tea. Monitoring and checking the plants were conducted every 10 days to observe new leaves, while the leaf yield of the tomatoes was measured. Additionally, the pH level of the soil was checked every 10 days using a pH meter. After 60 days, the total tomato yield was measured.

Measuring Yield and Chlorophyll

The dry and fresh weights were obtained from each tomato plant. Three tomatoes were selected from a plant and removed from the soil. The excess dirt and debris present on the tomatoes were then washed off and the tomatoes were blotted dry to provide more accurate data. The tomatoes’ fresh weight was then determined by placing them on an analytical balance and recording the weight grams. This process was repeated for every plant in each group (chamomile tea, green tea, black tea, and control). Subsequently, the average weight of one tomato per group was calculated.

Next, the tomatoes were cut in half and placed in a dehydrator set at 42 °C overnight. The following day, their dry weight was measured. It was ensured that the origin of each tomato was noted according to its respective group. The dry weight was measured using a digital weighing balance, and the grams were recorded.

For the chlorophyll content measurement, the leaves of each plant were dehydrated overnight in an incubator at 42°C. Subsequently, the leaves were crushed using a mortar and pestle. A mixture of 0.5 g of the crushed leaves and 14 mL of deionized water was prepared, and the solution was poured into cuvettes using a funnel. The chlorophyll content was measured using a spectrometer. The spectrometer was set to a maximum wavelength of 663 nm to measure chlorophyll, and the recorded wavelength was noted in a table. Likewise, for chlorophyll b, the spectrometer was set to a maximum wavelength of 645 nm, and the measured wavelength was recorded.

Throughout the monitoring process, pictures were taken of each tomato plant, documenting the progress of the plants in each tea group and the control. These photographs serve as figures, visually illustrating the development of the tomato plants.

Data Analysis:

The tomato yield was assessed by counting the number of new leaves every 2 weeks. The data was recorded in a table, documenting the total number of leaves yielded by each plant and the bi-weekly leaf yield. All plants were measured on the same schedule. Subsequently, the average plant yield was compared using a line graph, illustrating the leaf yield every 2 weeks. Each group (control, chamomile tea, green tea, and black tea) had a dedicated line graph displaying the number of leaves grown on each plant within that group. A line of best fit was drawn to determine the average leaf yield every 2 weeks.

Additionally, a graph was created to compare the fresh weights and dry weights of the yielded fruit. A double line graph was utilized to illustrate the fresh weight and dry weight for each plant. The website https://astatsa.com/OneWay_Anova_with_TukeyHSD/ was employed to analyze the differences between the fresh weight and dry weight across the groups. Moreover, graphs were generated to compare the average fresh weights and dry weights of all plants. ANOVA analysis was performed on these graphs to evaluate the quality of leaf yield for different tea groups.

Furthermore, five additional graphs were created to measure the height of the plants. Four-line graphs represented the measurements of each plant over the monitoring period, while one bar graph compared the heights of all plants. In total, there were fifteen graphs. These graphs compared the heights, fruit yield within groups, the average yield across all groups, and the fresh and dry weights for each group separately. Other graphs assessed the pH and growth of each plant in every group, along with one graph comparing the averages for each plant group. Lastly, a graph was generated to compare the chlorophyll levels between each group, including chlorophyll a, chlorophyll b, and total chlorophyll levels.

Results:

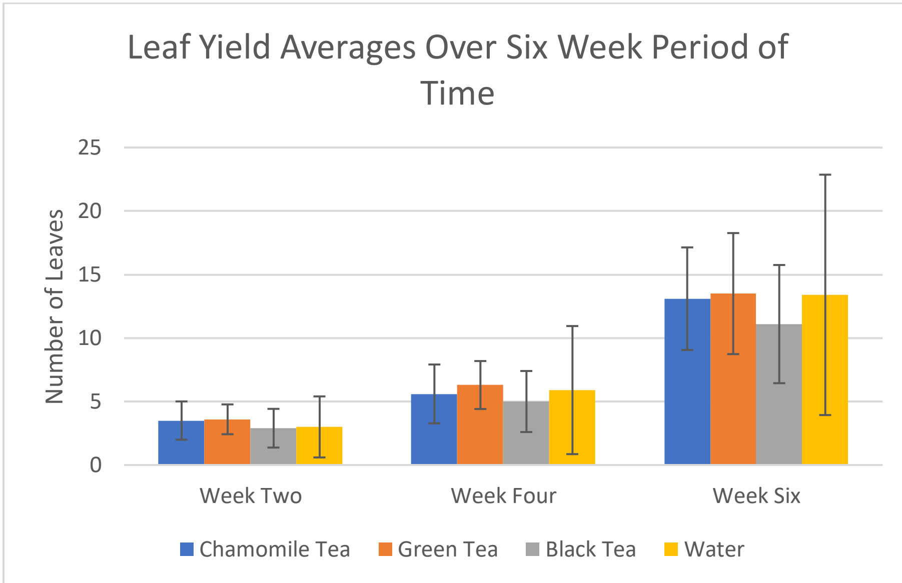

Figure 1: Leaf yield relative to biweekly intervals for all groups, Values represent +/- SD

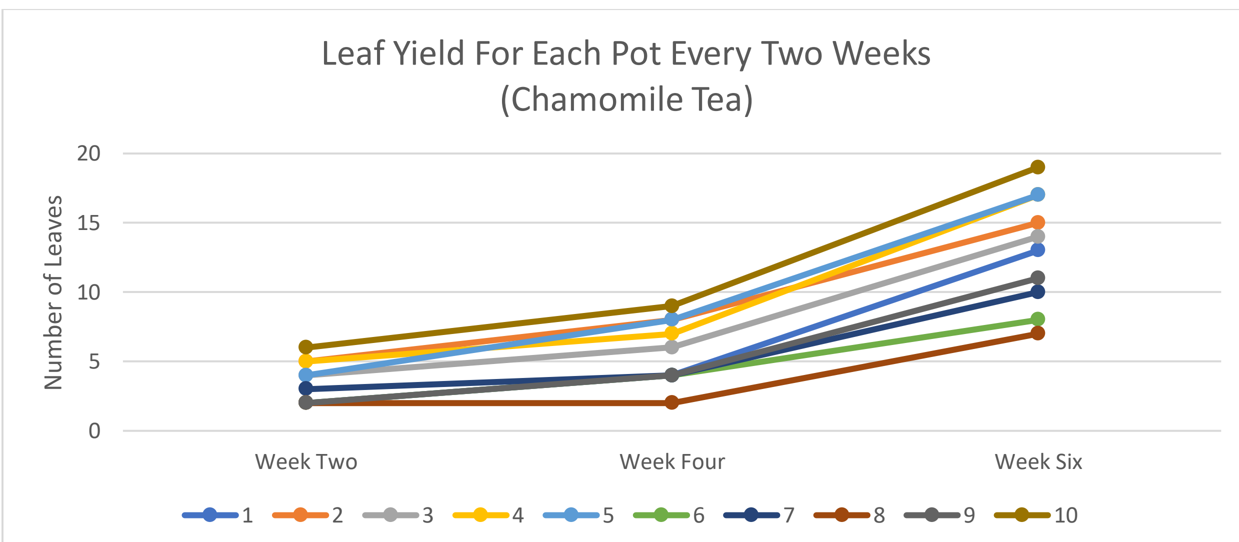

Figure 2: Leaf yield relative to biweekly intervals for each pot watered with chamomile tea; there are 10 pots that were watered with chamomile tea, and they were numbered 1-10

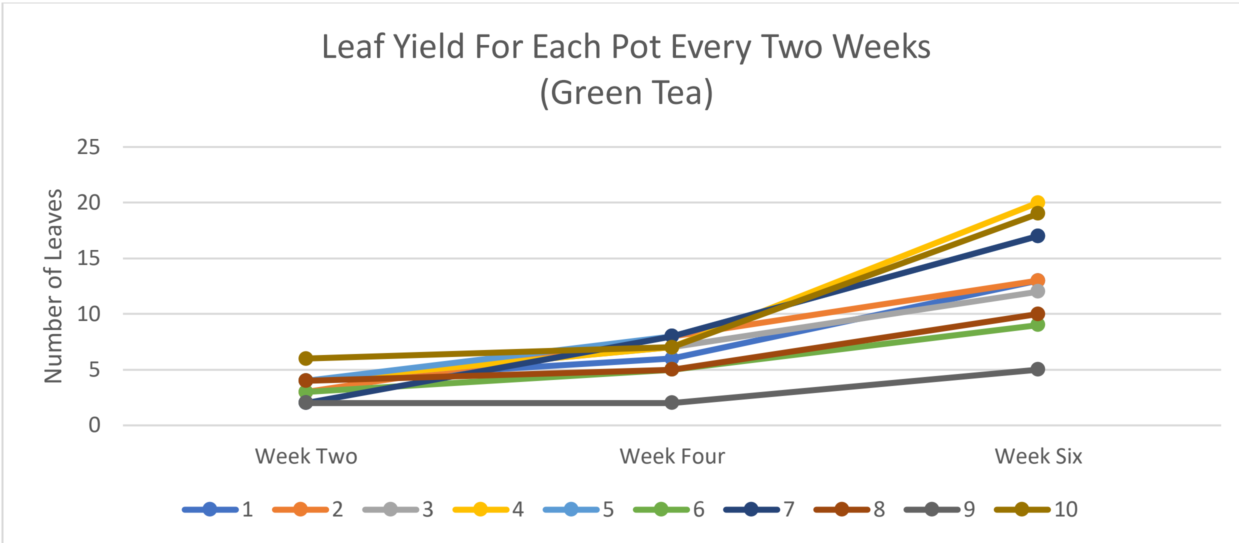

Figure 3: Leaf yield relative to biweekly intervals for each pot watered with green tea; there are 10 pots that were watered with green tea, and they were numbered 1-10

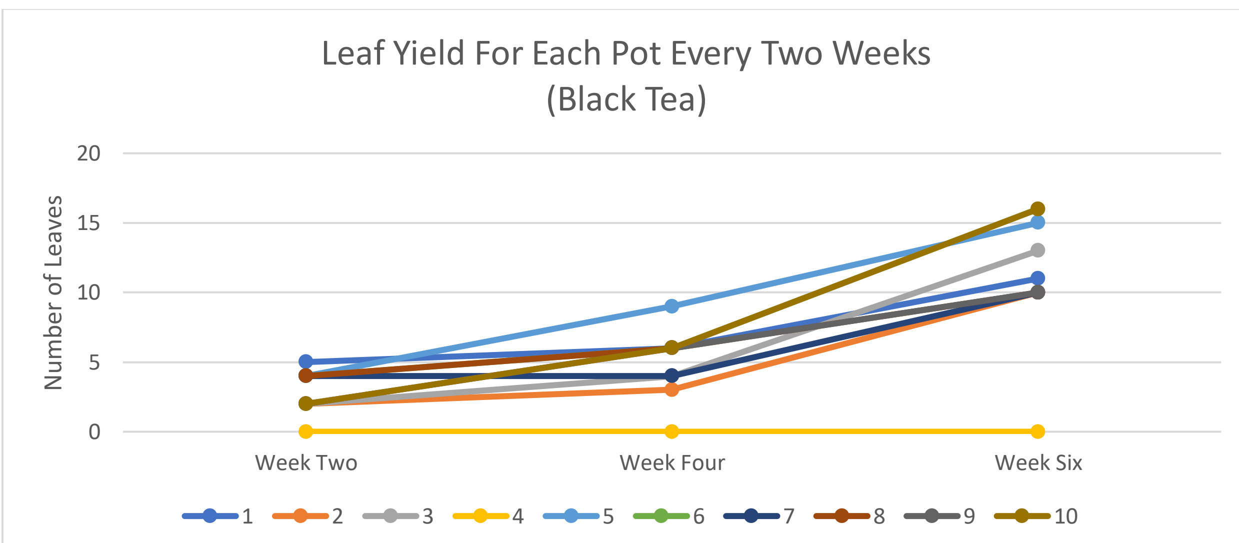

Figure 4: Leaf yield relative to biweekly intervals for each pot watered with black tea; there are 10 pots that were watered with black tea, and they were numbered 1-10

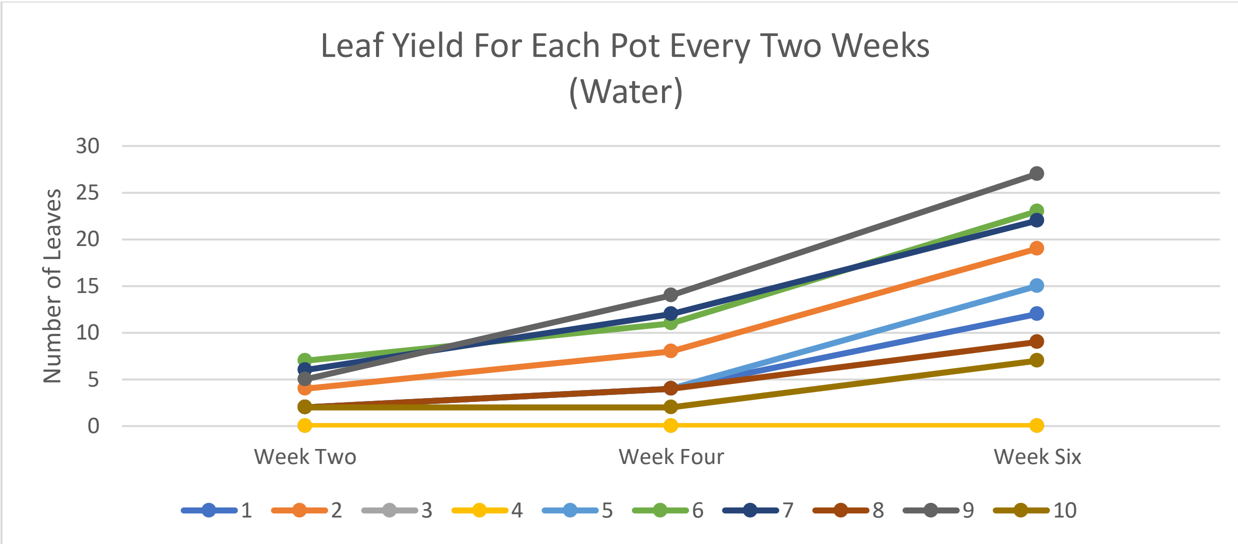

Figure 5: Leaf yield relative to biweekly intervals for each pot watered with water (control group); there are 10 pots that were watered with water, and they were numbered 1-10

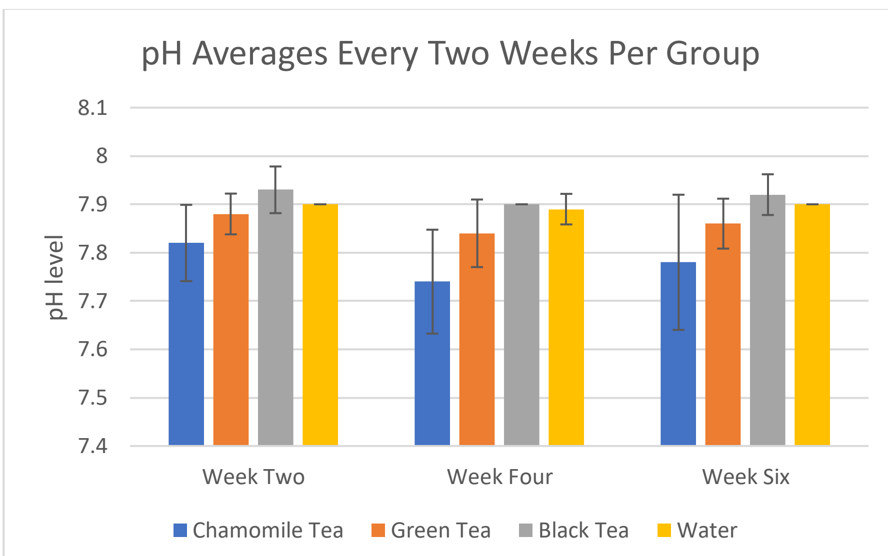

Figure 6: pH Level Relative to Biweekly Intervals for all tea groups, Values represent +/- SD

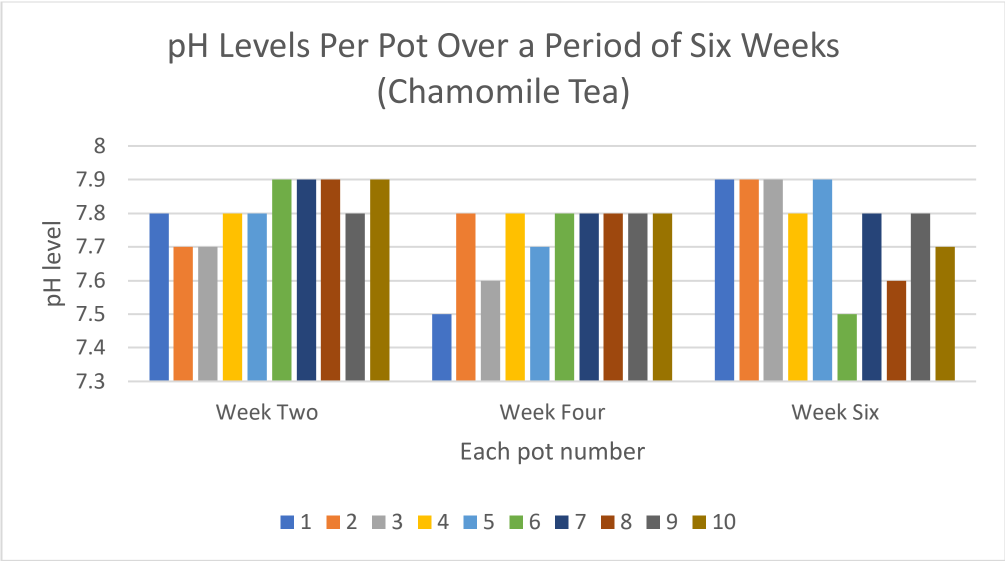

Figure 7: pH level relative to biweekly intervals for each pot watered with chamomile tea; there are 10 pots that were watered with chamomile tea, and they were numbered 1-10

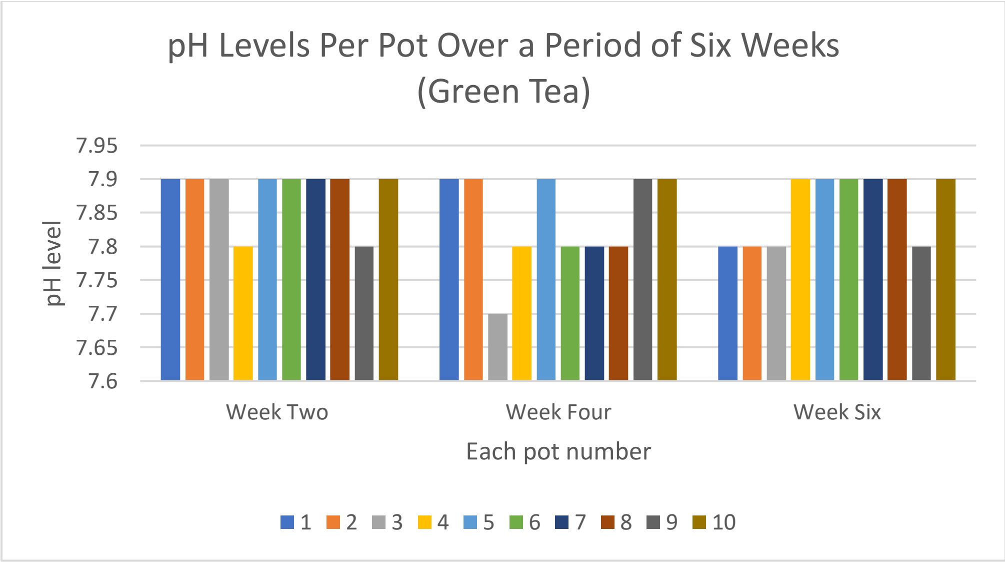

Figure 8: pH Level relative to biweekly intervals for each pot watered with green tea; there are 10 pots that were watered with green tea, and they were numbered 1-10

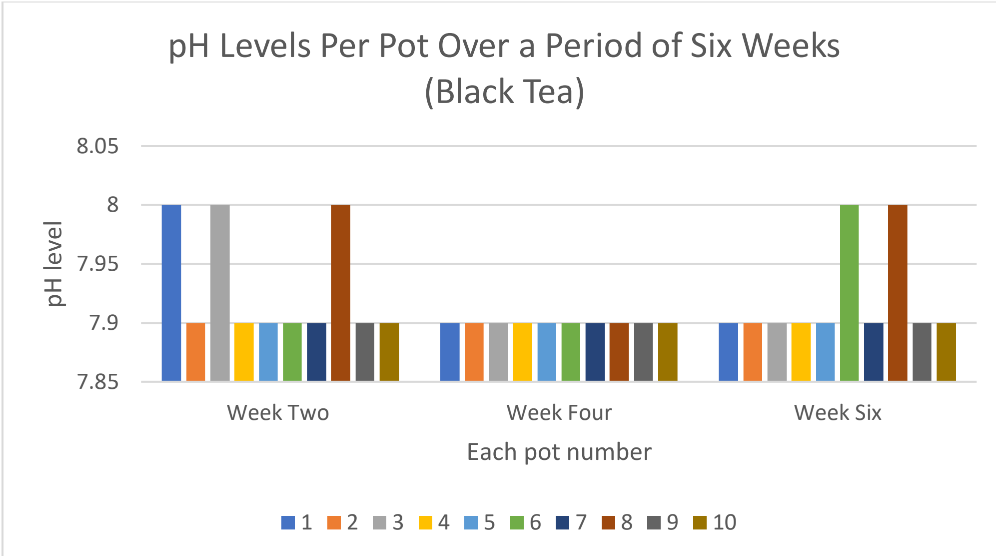

Figure 9: pH level relative to biweekly intervals for each pot watered with black tea; there are 10 pots that were watered with black tea, and they were numbered 1-10

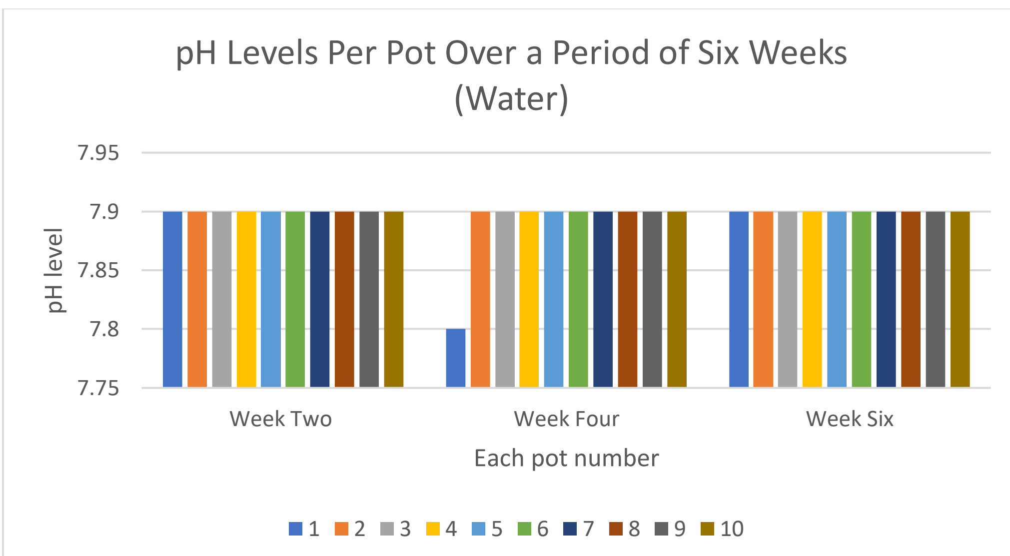

Figure 10: pH level relative to biweekly intervals for each pot watered with water; there are 10 pots that were watered with water (control group), and they were numbered 1-10

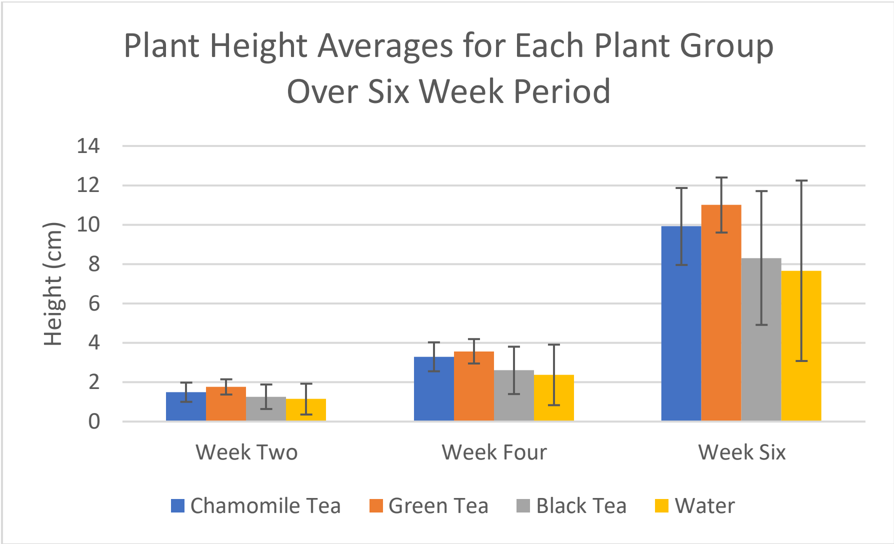

Figure 11: Plant height trends in each group over biweekly intervals, Values represent +/- SD

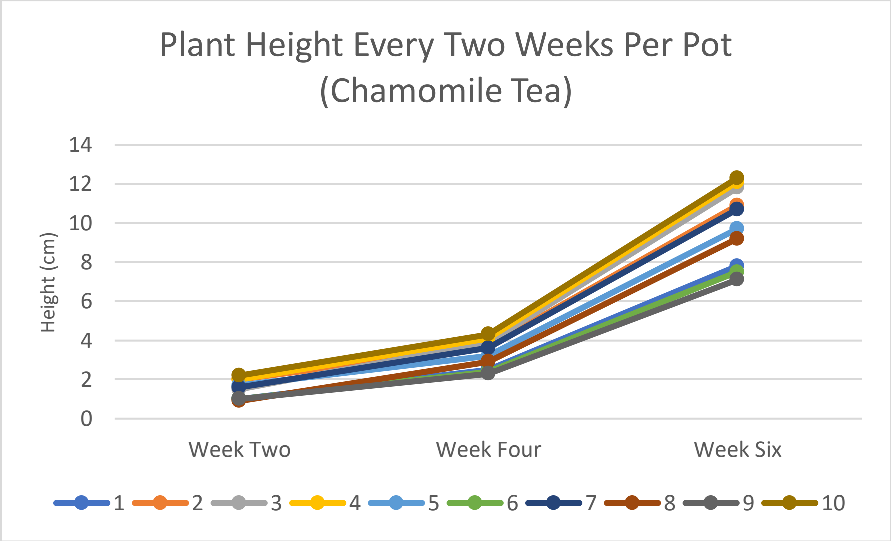

Figure 12: Plant height trends for the plants watered with chamomile tea

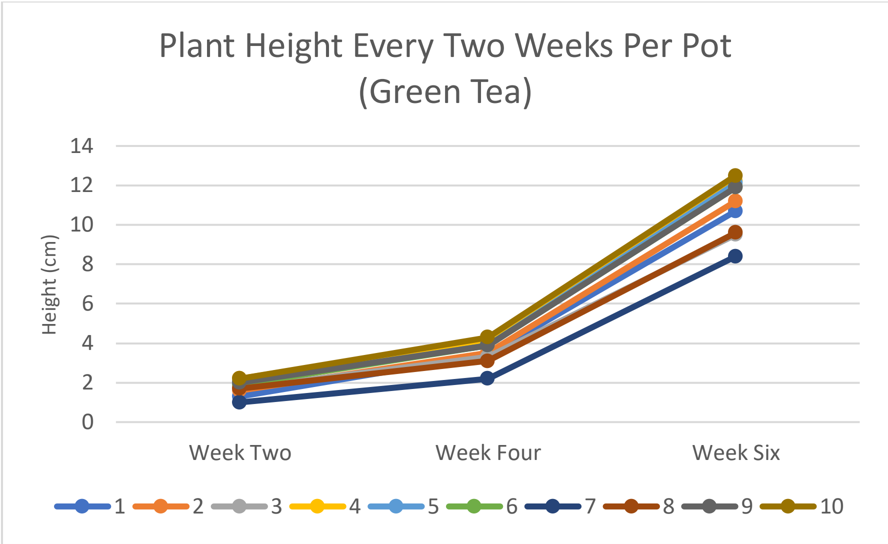

Figure 13: Plant height trends for the plants watered with green tea.

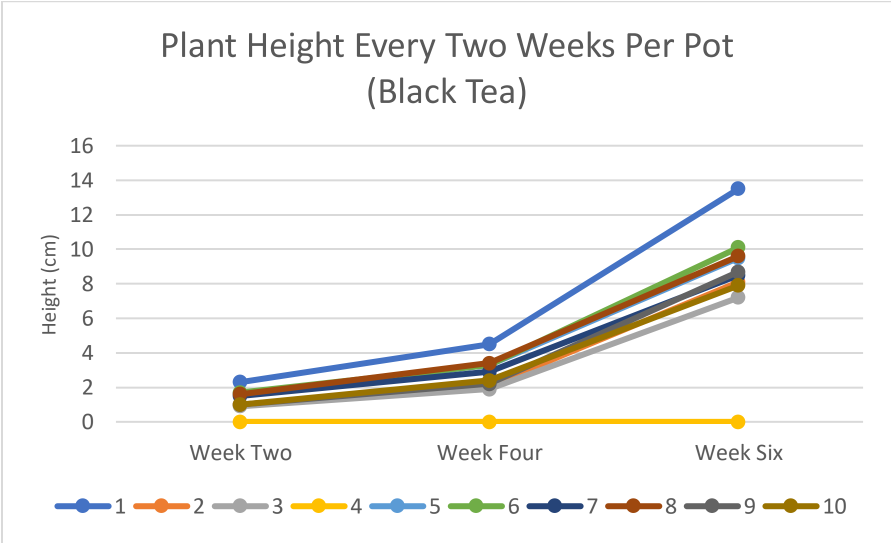

Figure 14: Plant height trends for the plants watered with black tea.

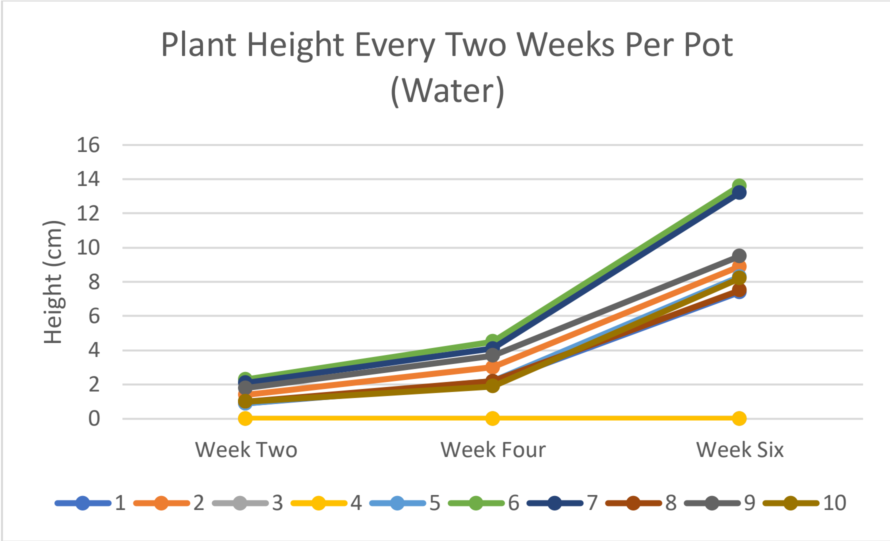

Figure 15: Plant height trends for the plants watered with black tea.

Discussion:

Experiment and Hypothesis:

The experiment examined teas with different pH levels to evaluate their influence on cherry tomato growth and fruit yield. The initial hypothesis was that chamomile tea would be the most suitable when growing cherry tomatoes since chamomile tea has a pH between 6 and 7 (depending on the amount of time spent brewing), and cherry tomatoes' ideal pH is 6.3 and 6.7. Additionally, chlorogenic acid and vitamin C, otherwise known as ascorbic acid, are found in substantial amounts in chamomile teas, thus increasing the likelihood of growth, including fruit yield, leaf yield, and height, regarding cherry tomatoes.

Tea comparisons for leaf yield and height:

In Figure 1, the plants watered with green and chamomile tea exhibited the highest overall leaf yield, although the quantities of leaves produced by the watering methods of green and chamomile tea were nearly identical. The cherry tomato plants watered with plain water produced, on average, fewer leaves than the plants that were watered with green tea and chamomile tea. Lastly, black tea produced the lowest overall mean leaf yield since one of the plants watered with black tea did not sprout or produce any leaves. Furthermore, Figure 4 reveals that the plants watered with black tea exhibited a leaf count of no more than 16 after 6 weeks, while figures 2, 3, and 5 illustrate that green tea, chamomile tea, and plain water all resulted in plant growth with 20-25 leaves after 6 weeks.

In Figure 11, the data illustrates that the group of plants receiving green tea consistently displayed the highest average plant height throughout the observation period. Following closely, the group watered with chamomile tea exhibited the second-highest plant heights. In contrast, the groups watered with plain water and black tea consistently showed the lowest average plant height. It is important to note that the exclusion of data points for one plant in the black tea group and two plants in the control group, which did not sprout, influenced the calculated means and, consequently, the overall results.

Control Group and Consistency:

The control group watered exclusively with plain water exhibited the highest leaf yield, with the highest leaf count reaching 26 for one of the plants. However, it is worth noting that two plants from the control group showed no growth at all. Therefore, considering the consistency of results, green tea appears to be a more suitable option.

On a related note, one plant in the black tea group did demonstrate the greatest height among all observations; however, it is essential to recognize that the heights of the plants watered with black tea displayed less uniformity compared to those watered with green tea. Consequently, the data continues to suggest that green tea remains the preferred choice as a medium for watering tomato plants.

The pH values among all the groups did not exhibit statistical significance ($p>0.05$), indicating a relatively stable pH level across the groups. These variations likely arose from other factors, such as gallic acid. Green tea had significantly more leaves and plant height due to green tea having gallic acid.

Factors Behind Green Tea Results:

Green tea produced these results although its pH is higher than the desired amount for cherry tomatoes (green tea typically has a pH between 7-10) because it contains epigallocatechin-3-gallate (EGCG or gallic acid). Green tea includes chlorogenic acid and ascorbic acid, both of which we have previously discussed as factors that greatly benefit cherry tomato growth. However, it also includes another acid specific to green tea, gallic acid. In humans, gallic acid has shown a significant increase in metabolism. Chamomile tea, containing very small amounts of gallic acid, explains why plants watered with chamomile tea produced fewer leaves and height overall compared to those watered with green tea despite it being in the desired pH range for cherry tomatoes (Puleteo, 2023).

Limitations:

While this study has provided insights into the relationship between soil pH levels, tea infusions, and the growth of Tiny Tim Tomato plants, several limitations should be acknowledged. Firstly, the relatively small sample size utilized in this study may restrict the generalizability of the findings to broader agricultural contexts. Additionally, the experiment's duration was limited to a specific timeframe, and further research could explore the longer-term effects of tea infusions on soil pH and plant growth. Furthermore, although the study suggests gallic acid's potential role in enhancing leaf yield and plant growth, it does not provide a complete analysis of the various compounds and mechanisms at play. Lastly, the temperature in the lab during the performance of the experiment was too high, resulting in the death and stunted growth of several plants. Recognizing these limitations, future investigations can build upon this foundation to offer a more comprehensive understanding of the complex interactions between soil conditions, tea infusions, and crop productivity. Finally, the experiment yielded no statistically significant data. Therefore, the revisions mentioned above should be implemented to increase the chances of statistically significant data that could aid future experiments.

Conclusions:

In this study, the relationship between soil pH levels and leaf yield in Tiny Tim Tomato plants under the influence of various tea infusions was investigated. Notable but ultimately statistically insignificant findings emerged concerning plant height and leaf production.

Soil pH levels remained relatively stable throughout the different groups, indicating that the primary factor contributing to the variation in leaf yield and plant height came from a separate source. The most likely source is gallic acid, as the group with the highest leaf yield and plant height, green tea, had significant levels of gallic acid and other beneficial acids, such as ascorbic and chlorogenic acid.

Implications:

Based on the study's findings, where soil pH levels remained stable across different tea treatments, implications for agriculture and plant cultivation become evident. The main factor influencing variations in leaf yield and plant growth appears to originate from a distinct source, with gallic acid standing out due to its association with the highest leaf yield and plant growth in the green tea group. These results emphasize the potential importance of specific compounds, such as gallic acid and related beneficial acids like ascorbic and chlorogenic acid, in enhancing crop productivity. Consequently, further research in this direction may yield valuable insights for improving agricultural practices and developing sustainable crop management strategies that foster healthier and more productive plant growth.

Future directions:

Considering the findings from this study, which revealed the consistent stability of soil pH levels across different tea infusion treatments, future research will focus on investigating the role of specific compounds, such as gallic acid and other beneficial acids like ascorbic and chlorogenic acid, in influencing leaf yield and plant height in Tiny Tim Tomato plants. The aim is to explain the precise mechanisms by which these compounds impact plant growth and productivity. Additionally, exploring the potential synergistic effects of these compounds when combined in tea infusions and their broader implications for sustainable agriculture practices and crop management is of interest.

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