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A Comparative Study on the Effects of Varying Concentrations of Eggshell Tea Fertilizer on *Capsicum annum* (Bell Pepper)

Anjanette Czyra L. Argonza
Alaissa Riobel D. De Chavez
Raquel B. Supan
Kerry P. Cabral

De La Salle University Integrated School

Abstract: With the increasing worldwide demand for eggs, the continuous accumulation of these poses environmental threats because of their support for microbiological action. However, the fact that eggshells have high calcium content motivated researchers to explore their potential use as fertilizer for various plant species. Despite this, most studies only focused on applying eggshell fertilizers in solid form. Meanwhile, research on boosting bell pepper production remains sparse in the Philippines despite its increasing demand. This study examined the capabilities of eggshell tea, a liquid form of eggshell fertilizer, by determining which concentration would be most effective and least effective in growing bell peppers in the Philippines. The plants were categorized into four groups with different mass/volume percentage concentrations of eggshell tea applied: 0% (EF-0), 2% (EF-2), 4.5% (EF-4.5), and 7% (EF-7). The effects of each concentration on the number of leaves, leaf surface area, height, and growth rate of the plants were analyzed accordingly. Results showed that eggshell tea was most effective on EF-4.5 while least effective on EF-7. The EF-4.5 exhibited the fastest growth and was the healthiest regarding the tested parameters, while the controlled and EF-2 groups demonstrated moderate growth. The EF-7 exhibited the slowest growth, along with leaf yellowing, damage, and curls, attributed to over-fertilization. Eggshell tea was revealed to have a generally positive effect on bell peppers; however, too much concentration could cause damaging effects as plants that did not receive any fertilizer demonstrated better results than EF-7.

Keywords: eggshell tea; fertilizer; bell pepper; growth rate, sustainability

INTRODUCTION

Eggs have long been part of the diet of a huge population in the world. In the past decade, a significant growth of 24% in egg production worldwide has occurred (McDougal, 2020). This is in line with the continuous projected rise in global egg consumption through the year 2029. As described by Conway (2020), the COVID-19 pandemic has resulted in more drastic changes in diets worldwide. This shift is rooted in the consumer's desire for cheaper yet nutritious diet options. Among all types of bird eggs, chicken eggs are the most commonly consumed. Considering that they account for a wide range of uses, the endless demand for eggs in the food and manufacturing industry contributes to a large amount of globally produced eggshell waste. In 2014, roughly 8 million tons of eggshell wastes were generated from around 70 million tons of eggs (De Angelis et al., 2017, as cited in Wijaya & Teo, 2019). With this, eggshell wastes, categorized under inedible, are considered one of the arising concerns of food waste. This type of waste is considered a "serious matter" in the industry (Penn State University, 2020). Since eggshells support microbiological action, continuous accumulation can induce environmental threats (Arabhosseini & Faridi, 2018). Despite this, improper disposal of large volumes of eggshell waste is still practiced by many because of challenges, including cost, availability of disposal sites, and odor (Phil & Zhihong, 2009, as cited in King'ori, 2011). As the rise in egg consumption leads to bigger environmental threats, the demand for a more sustainable approach to converting eggshell wastes into valuable products increases.

For the past years, exploring the potential of eggshells, such as being catalysts for biodiesel (Laca et al., 2017) and low-cost adsorbents for wastewater treatment (De Angelis et al., 2017), has been the focus of various researchers. Moreover, eggshells have a high calcium content of 98.2% while constituting 0.9% each of magnesium and phosphorus (Romanoff et al., 1949, as cited in

King'ori, 2011). A study in isolated intestinal epithelial cells concluded that calcium absorption in eggshells is 64% greater than in pure calcium carbonate (Arnarson, 2017). Aside from this, eggshell calcium contains low levels of toxic substances compared to other natural sources of calcium (Boron 2004, as cited in Arabhosseini & Faridi, 2018) and is described as the "best natural source of calcium" (Bee, 2011, as cited in King'ori, 2011). Since calcium is essential in plants, applying eggshells promotes plant growth (Arabhosseini & Faridi, 2018). A fertilizer is "a natural or chemical substance that is spread on the land or given to plants to make plants grow well," as defined by the Cambridge dictionary. An eggshell fertilizer also helped plants overcome plant blossom-end rot (BER) disease, usually occurring in tomatoes, peppers, squashes, and melons. This is due to its enrichment and provision of additional calcium and pH to the soil (Arabhosseini & Faridi, 2018). Thus, eggshells are cheap and effective calcium sources, giving them an excellent potential to enable biochemical functions and be an alternative fertilizer to plants.

However, despite having numerous benefits, it is important to apply plant fertilizers moderately. Plants that receive too much fertilizer can manifest damaging effects such as yellowing and wilting of lower leaves, browning leaf tips and margins, browned and blackened limp roots, defoliation, and very slow or no growth (Moorman, 2011). Aside from these observable effects on plants, too much fertilizer harms the environment as excess nutrients can leach into the groundwater, rivers, and oceans (Restuccia, 2021).

Different forms of eggshell fertilizers are commonly used: crushed, granular, pulverized, and liquid. Among these, the liquid organic eggshell-based fertilizer is most recommended because it is more evenly distributed and easily absorbed (Indrarosa, 2018). Grounded by this finding, eggshell tea, a liquid fertilizer from boiling the crushed eggshells with water, is more advantageous

than other eggshell-based fertilizers. Boiling the eggshells will release their nutrients into the water (Wijaya & Teo, 2019).

Despite the need to meet the nutritional requirements of plants, farmers often disregard fertilizer usage, possibly because of its expensive cost of providing an adequate amount to crops (Barcellos et al., 2008, as cited in Silveira et al., 2015). Furthermore, ammonium nitrate fertilizers, one of the most common commercial fertilizers, pose environmental risks in terrestrial and aquatic ecosystems due to ammonia. Containing more ammonia than plants can damage their cell membranes and potentially lead to necrosis. Hence, fertilizers made from eggshells address issues on accessibility, waste reclamation, and the environment.

Exploring the potential use of eggshell tea as fertilizer could benefit many sectors of society, especially those looking for cheaper alternatives to commercially available and expensive plant growth enhancers. Below are some benefits that each sector could benefit from this research.

To the agricultural sectors, this study will provide ample information to reduce the production cost spent on commercialized fertilizers by using an eco-friendly eggshell tea fertilizer instead.

To the farmers and garden owners, this study will provide knowledge on generating an instantly available fertilizer that could efficiently improve the production and growth of bell peppers. Along with this, knowledge of the best concentration of eggshell tea fertilizer is beneficial for them to maximize the growth periods of plants and predict the trends.

To the environment and community, this research will help reduce food waste each year. Mismanagement in the disposal of eggshells could lead to worse effects of pollution. Therefore, using it as a fertilizer can reduce eggshell waste and help eliminate this problem. Moreover, eco-

friendly eggshell fertilizers can be used instead of ammonium nitrate fertilizers. Thus, the risk of damaging the environment can be reduced.

To future researchers, this experiment will pave the way for a new research idea. This study could serve as secondary data to support future researchers' study and explore other aspects not covered here.

Moreover, past studies have examined usual test plants like tomatoes, basils, peanuts, and peas. Minimal findings on exploring eggshell tea fertilizer (a specific type of liquid eggshell fertilizer) on bell peppers are present. In addition, bell peppers are produced only in limited quantities in the Philippines despite the country being tropical and rich in agricultural settings. Although the demand for bell peppers increases because of their highly nutritious and delicious content and their potential to protect cells from free radicals that could prevent cancer, only minimal research is done for more efficient growth and production of the stated plant.

This study aims to fill these research gaps by focusing on bell peppers as test plants considering that they have a high calcium demand, fast growth rate, and an ideal growth period from October to December in the country, which matches the duration of the experiment. The geographical location was delimited to Laguna, Philippines, in the South Luzon area. The experimental concentrations are derived from the mass of eggshell/volume of H_2O percentages, specifically 20 g/L (2%), 45 g/L (4.5%), and 70 g/L (7%). The effect of these tested concentrations was compared to the controlled set-up. These given concentrations were mostly not yet investigated before. Additionally, for the scope of this study, household chicken eggshell wastes were used. Bell pepper seeds were collected from the researchers' personal supply of bell peppers, and loam soil was bought from online garden stores. To determine the most effective and least effective concentration on bell peppers, the effects of different mass/volume percentages of the

eggshell tea fertilizer were demonstrated and compared on the number of leaves, leaf surface area, height, and growth rate of the test plants.

Table 1 shows the key terms used in the study, including some technical definitions of terms in the field of agriculture.

Table 1

Definition of Terms Used in the Study

Term	Definition
● **Eggshell Tea**	This is a liquid fertilizer made from boiling the crushed eggshells with water. Boiling it will release the nutrients of the eggshell into the water (Wijaya & Teo, 2019).
● **Growth Rate**	This is the speed of the increase of an organism in a population given a period of time (Biology Online, 2020).
● **Maturity**	This is the complete stage of natural growth and development of the plant (Reid, 1992).
● **Seedlings**	This is the growth of a young plant coming from its seed stage (Merriam-Webster, 2020).
● **Vegetative stage**	This is the period between the germination stage and flowering stage when the plant executes photosynthesis the most for accumulating resources needed for flowering and reproduction (Vegetative Growth, n.d.).

Due to the limitations brought about by the COVID-19 pandemic, the soil composition of the plants was not analyzed. Given this, the untested soil composition of the loam soil may influence the results of the study considering that soil composition tests are essential to inspect the

existing nutrients in the soil used. However, the researchers used the same type of soil. In addition, since laboratory tests are restricted, the manifestation of calcium in the bell peppers was not analyzed through these means. Hence, the alternative external manifestation of calcium was observed through the number of leaves, leaf surface area, height, and growth rate, as supported by the study of Parvin et al. (2015), where calcium was revealed to affect the said parameters.

With this, it is hypothesized that the bell pepper plants that receive eggshell tea fertilizer will affect the number of leaves, leaf surface area, height, and growth rate compared to the control group, which does not receive any eggshell tea fertilizer.

METHODOLOGY

Experimental

This study aims to explore the effects of varying concentrations of eggshell tea on bell pepper plants. The data were based on a mixed qualitative and quantitative research design. However, the study leaned more toward collecting quantitative data. The number of leaves, leaf surface area, height, and growth rate of each plant were measured using numerical data as the plants received the concentration of eggshell tea respectively assigned to them. The growth rate was based on the height of the plants measured every month. The formula used to calculate the growth rate is $\frac{\Delta H}{\Delta t}$, where ΔH is the difference in the measurement of the height of the plant in the first month period and second month period (t = 1), respectively. On the other hand, t is the difference in time between the previous and current measurements, which is the number of months between them (Agrawal, 2014). The leaf surface area was measured by tracing each bell pepper's small, medium, and large leaves using ImageJ. The average of these was then based on the generated surface area by ImageJ. The primary data were analyzed to determine which concentration performed best. As the plants were grouped according to the eggshell tea concentration they received, each plant group was composed of three bell peppers. Having multiple plants per group was important in discerning outliers in collected data, thus improving accuracy. Table 2 details the codes followed per plant group.

Table 2

Codes Used for Plant Groups That Received Respective Eggshell Tea Fertilizer Concentration

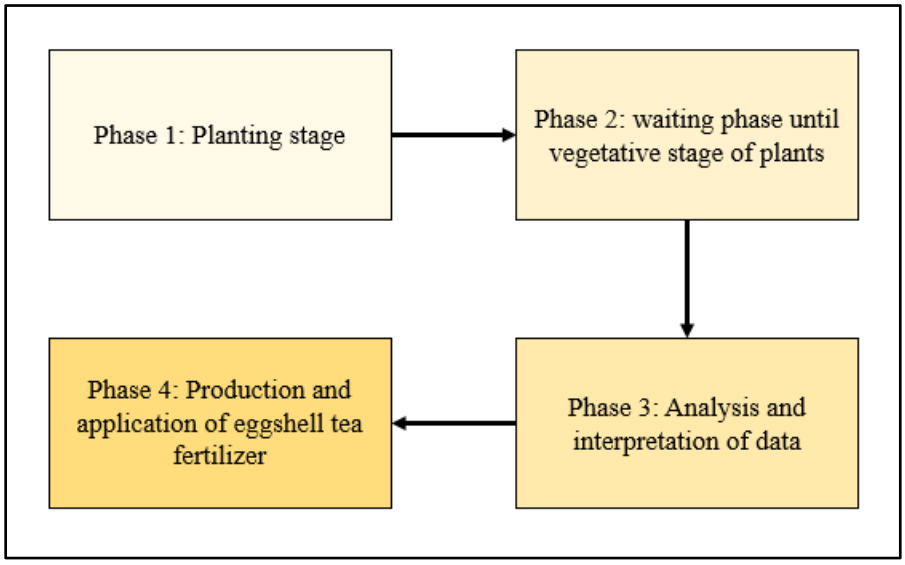
Code	Description
EF-0	Controlled Group
EF-2	2% Eggshell Fertilizer
EF-4.5	4.5% Eggshell Fertilizer
EF-7	7% Eggshell Fertilizer

Moreover, qualitative data were used to describe the effects of the varying concentrations of eggshell tea. To obtain these, the concentrations of the eggshell tea fertilizer were controlled and manipulated.

Furthermore, due to the COVID-19 pandemic, science laboratory tests were restricted to examining the conditions of the plants. Thus, the interpretations were based on the data gathered at the respective homes of the researchers. There are other methodological approaches to fertilizing plants with eggshells. Pulverized, granular, and liquid eggshell fertilizers may be used. However, the chosen experimental approach was the standard methodology used in other studies, which is using liquid fertilizer. Additionally, considering that this research was purely subjected to plants, no ethical issues were considered.

Figure 1

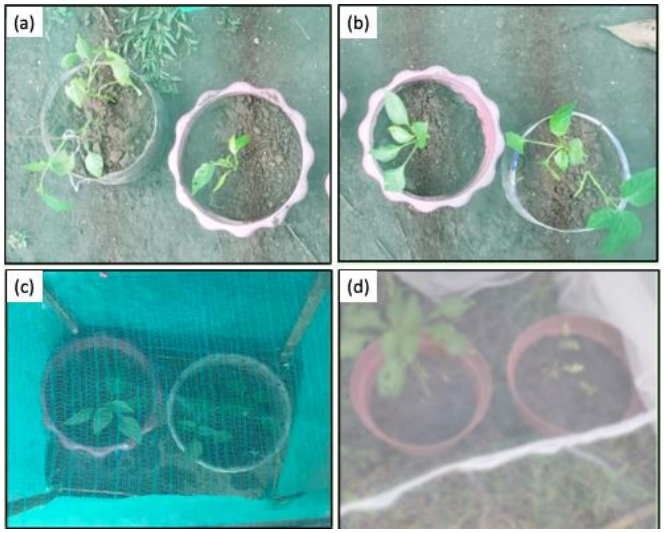
Four Phases of the Experimental Procedures



To complete this study, the experiment underwent four phases. Figure 1 shows the phase map of the study. The first phase is for the planting stage and enclosing the plants in the insect mesh. Four groups of bell pepper seeds, obtained from bell peppers bought from the local market, were planted on medium-sized pots with a height of 6 inches and a diameter of 8.25 inches. Overall, a total of 12 bell pepper plants were used for all four groups. Three of these groups were the experimental group, and the remaining was the controlled group. Since the experiment was limited to the respective houses of the researchers, the plant groups were randomly divided among the members. All plants were exposed to the same conditions. After the bell pepper seeds were planted, an insect mesh surrounded the plants. Four wooden sticks with a length of 1-meter act as its base wall. Surrounding the plants with insect mesh prevented pest infestation pesticides. Through this, the possibility of pests affecting the results was reduced. Figure 2 presents the experimental setup for different plant groups.

Figure 2

Experimental Set-up of Each Plant Group: (a) EF-0, (b) EF-2, (c) EF-4.5, and (d) EF-7.



Moreover, phase 2 was allotted for the waiting period until plants reached the vegetative stage. In a related study conducted by Indrarosa (2018), the start of fertilizer application was during the vegetative stage of the plants. No intervention was done until the plants reached the vegetative stage to ensure they were mature enough to receive the eggshell tea fertilizer. After reaching the vegetative stage, the three experimental groups were applied different concentrations of eggshell tea fertilizer assigned respectively. The control group, on the other hand, did not receive any fertilizer throughout the experiment.

Furthermore, the third phase was for producing and applying eggshell tea. There are two ways to apply eggshell fertilizer. It can be applied in solid form through pulverized eggshells or liquid form through the eggshell tea directly poured into the soil. However, the latter method is more convenient for the absorption of nutrients (Indrarosa, 2018) and was chosen as the type of fertilizer used.

Figure 3

Production Phases of the Eggshell Tea Fertilizer: (a) Collection of Eggshells, (b) Measurement of the Mass of Eggshells, (c) Boiling Process, and (d) Eggshell Tea Production.

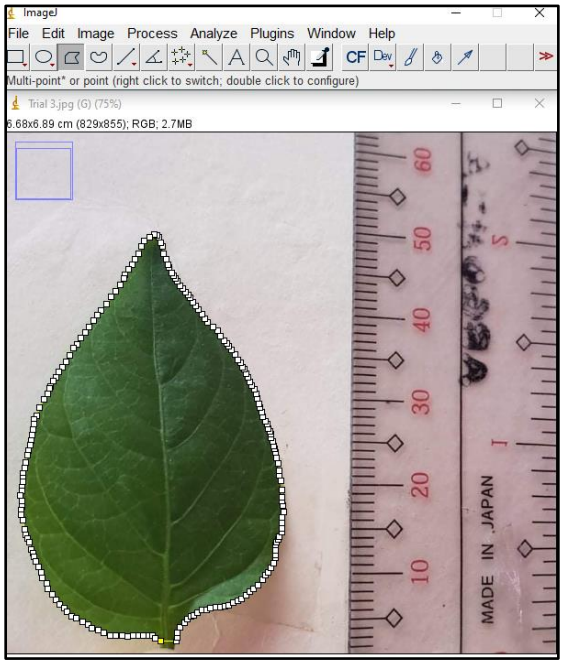
The eggshells, a tray, a heating pan, water, three empty bottles, and a precision lightweight platform scale were needed to make the eggshell tea. Figure 3 portrays the steps needed to produce the eggshell tea fertilizer. First, the eggshells were spread evenly on a tray and were exposed to the sun for a few hours to dry. Once the eggshells were all dried, they were crushed into smaller pieces. Using a lightweight scale, 20 g, 45 g, and 70 g of eggshells were measured. Each was heated separately in a pan with 1 L of water. The waiting period for the boiling of water was 1-2 min. This is in line with the study of Wijaya and Teo (2019), where boiling the eggshells was described as releasing the nutrients of eggshells in the water. After boiling, the eggshells were left in the water for 24 h before draining. The eggshell tea fertilizer was poured into the bottles while the eggshells drained from the mixture were disposed of properly.

The experimental groups received 2%, 4.5%, and 7% eggshell tea. This was done every Monday, Wednesday, and Friday. Every month, data was monitored and recorded in line with the objectives.

Phase 4, the last phase, includes the interpretation and data analysis. The number of leaves, leaf surface area, height, and growth rate of each set-up were calculated and interpreted to determine which concentration performs best in promoting a faster growth rate.

Figure 4

Data collection of Leaf Surface Area Through the ImageJ application



Moreover, Figure 4 shows how the leaf surface area was calculated through ImageJ. The large, medium and small leaves per trial were captured with a ruler beside them to collect the data. These pictures were then saved into the ImageJ application. To begin the process of determining the leaf surface area, the scale for measurement was adjusted accordingly. To get more accurate results, a 1 cm straight line was drawn using the ruler to get the known distance. Afterward, the leaves were traced using the Polygon section in the application. Then, the average of leaf surface areas that ImageJ generated was calculated.

Figure 5

Data Collection of Plant Height

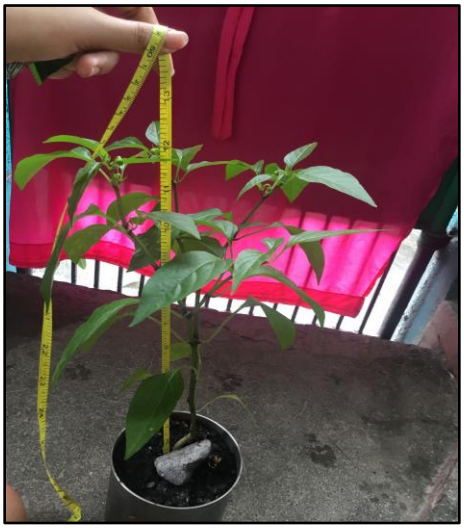


Figure 5 depicts the procedure for how the plant height was measured. A tape measure was used to record the height from the surface of the soil up to the leaf base of the highest and the most fully expanded leaf data. Thus, this measurement excludes the length of the roots in the soil.

RESULTS AND DISCUSSION

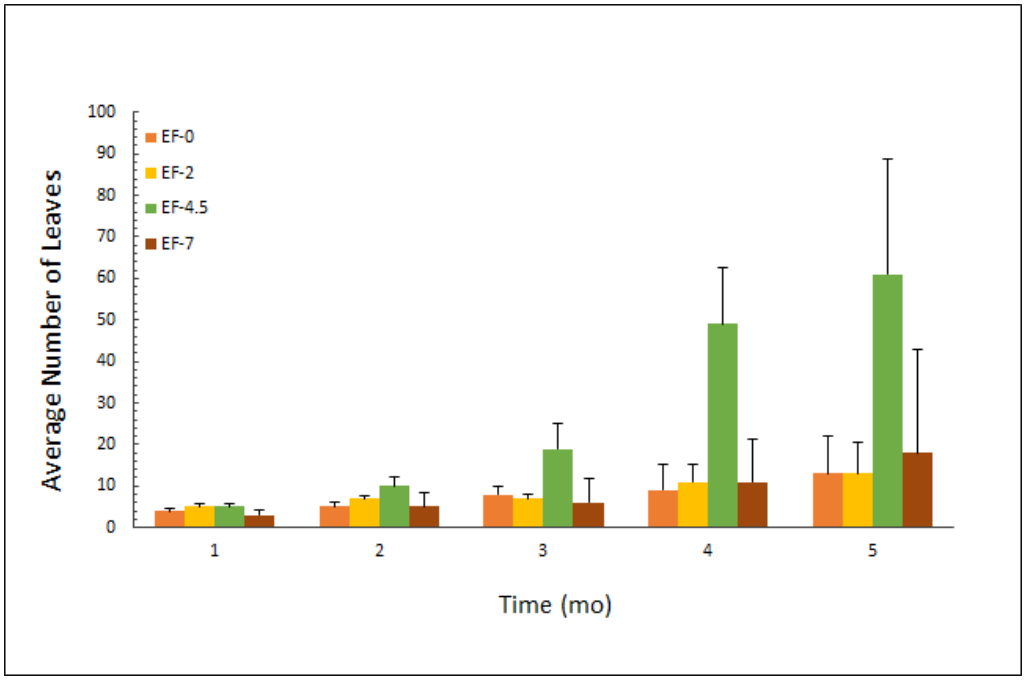
The number of leaves, leaf surface area, height, and growth rate were the specific parameters measured to analyze and compare the effects of the different concentrations of eggshell tea.

Average Number of Leaves

The number of leaves of all three bell peppers in each plant group with corresponding eggshell tea concentrations received was counted monthly. Figure 6 depicts the bar graph of the average number of leaves for all plant groups. The length of the error bars was based on the standard deviation of the average number of leaves.

Figure 6

Graph of the Average Number of Leaves Per Plant Group With Application of Eggshell Tea Fertilizer



As evident in Figure 6, the number of leaves significantly increased for the experimental groups starting from the third month and continued until the end of the experiment. Considering that the third month was December, the significant increase can be accounted for by the climate requirement of bell peppers. Mariano and Jimenez (n.d.), stated that bell peppers require cool weather to produce the best fruit quality, which was recommended to be planted from October to December in the context of the Philippine climate. Thus, this is one of the possible factors for the significant increase. Moreover, it can also be observed that the increase in the number of leaves in EF-0 was consistently the least among all the plant groups. However, in the fifth month, both EF-0 and EF-2 had an equal number of leaves. In general, these plant groups were the two with the least number of leaves compared to the rest.

On the other hand, EF-4.5 exhibited the greatest and most evident increase in the number of leaves throughout the experiment. Every month, the number of leaves in this group was significantly higher than the previous month and can also be described as the healthiest. Lastly, EF-7 was observed to have the second greatest-number of leaves towards the end of the experiment. Although this group initially had the least number during the first months, the increase in its leaves became increasingly significant from the third month onwards. Therefore, in general, Figure 7 displays the following trend in decreasing order of the number of leaves:

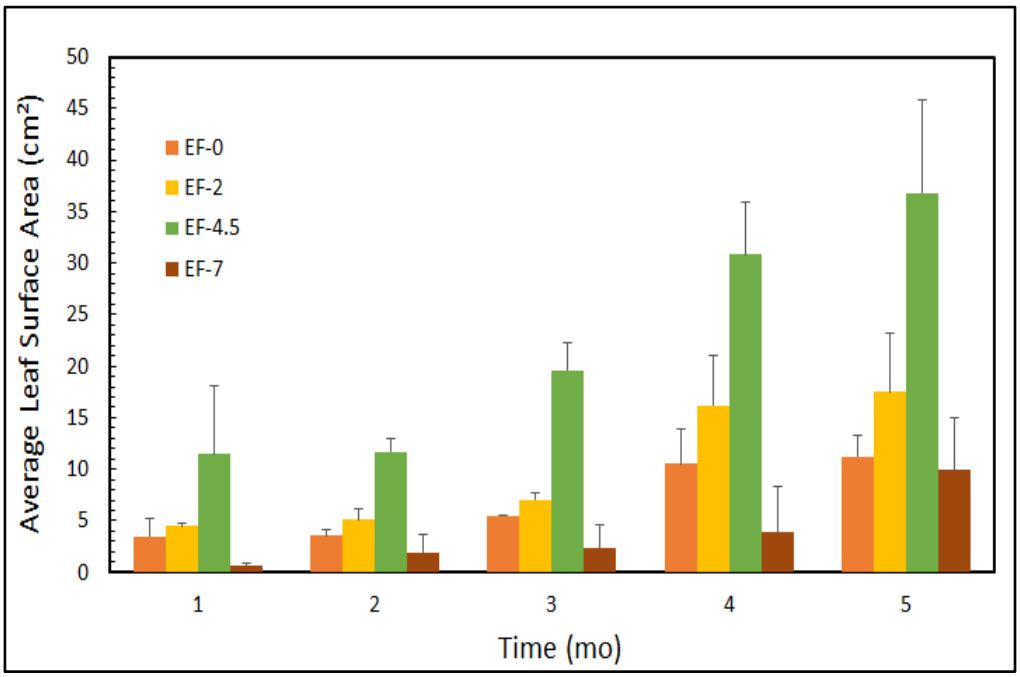
EF-4.5 > EF-7 > (EF-0 = EF-2).

Average Leaf Surface Area

The leaf surface area of all three bell peppers per group was calculated using ImageJ and averaged every month, as shown in Figure 7. These calculations are summarized in Figure 7 as it represents the average leaf surface area of the plant groups throughout the experiment.

Figure 7

Graph of Average Leaf Surface Area Per Plant Group with Application of Eggshell Tea Fertilizer



The trend of the leaf surface area for all plant groups was observed to be increasing throughout the experiment. From the first to the last month, EF-7 consistently exhibited the smallest leaf surface area compared to the rest, while the opposite is evident for EF-4.5. The latter was revealed to have the largest increase, following the same trend of significant increase from the third month onwards (similar to the trend in their number of leaves) due to the cold weather. Furthermore, EF-2 showed the second-highest increase, followed by EF-0. It can also be noted that these two groups exhibited close results, having only a minimal difference between their leaf surface area. During the transition from the fourth to the fifth month, the surface area increase in EF-0 and EF-2 was only small compared to the drastic increase in EF-7.

Also, EF-0 showed a few small leaf holes from the third month onwards, while EF-7 consistently showed bigger holes starting the same month. EF-7 was the only group observed to

have evident leaf curls, yellowing, and leaf damage among all the plant groups. This explains its very minimal increase in leaf surface area throughout the experiment. These observations can be rooted from over fertilization. According to Smith (n.d.), this occurs due to the excess salt produced by the eggshell tea fertilizer, which potentially alters the salt concentration of the soil and affects the leaf surface area of the bell peppers. Thus, the general trend for the average leaf surface area following a decreasing order is the following:

EF-4.5 > EF-2 > EF-0 > EF-7.

Average Plant Height and Growth Rate

This experiment's third and fourth parameters are the plant height and growth rate. Like the other collected data, these were also averaged for all three plants per plant group. Figure 8 depicts the linear growth of the bell peppers for five months.

Figure 8

Graph of Average Plant Height Per Plant Group with Application of Eggshell Tea Fertilizer

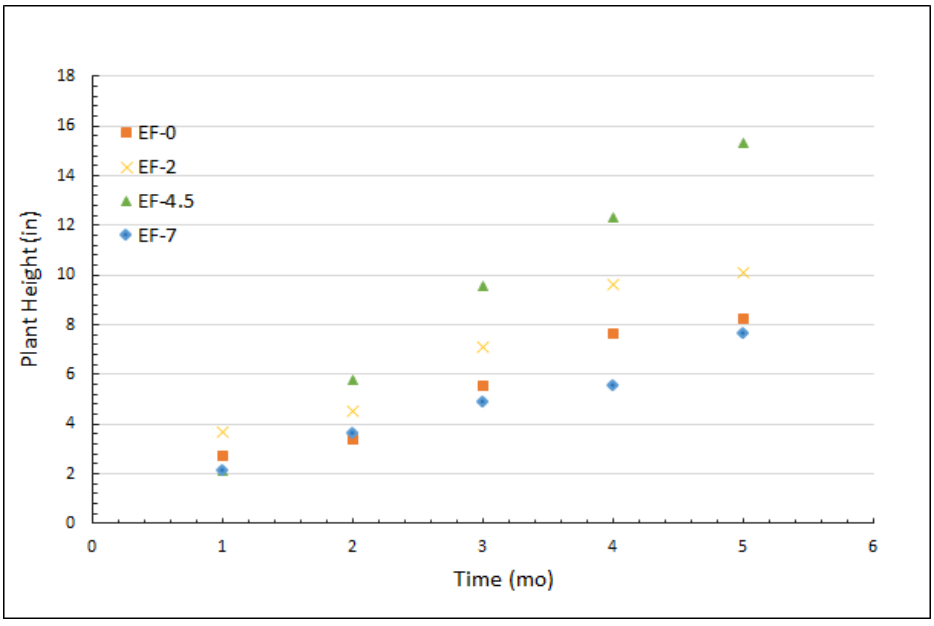


Figure 8 shows that the height of EF-4.5 consistently had the greatest increase in all months. With a final height of 15.3 recorded during the last month, it is evident that EF-4.5 rapidly and significantly outperformed all other plant groups. This was followed by EF-2 and EF-0, exhibiting the second and third greatest increase, respectively. On the other hand, EF-7 had the shortest height, reaching a final measurement of only 7.7 in. It was observed that this plant group also showed only a minimal increase throughout the months.

Moreover, the average growth rate of all plant groups was also shown through the slope indicated in the respective equations of the trendline, as detailed in Table 3.

Table 3

Average Growth Rate for EF-0, EF-2, EF-4.5, and EF-7 and Their Corresponding Coefficient of Determination Value

Plant Group	Equation of the Line	Growth Rate	R^2 Value
EF-0	y = 1.526x + 0.928	1.526	0.9621
EF-2	y = 1.801x + 1.607	1.801	0.9543
EF-4.5	y = 3.283x + 0.827	3.283	0.9954
EF-7	y = 1.296x + 0.914	1.296	0.9761

In Table 3, the linear equation of the graph is shown in the form of y = mx + b, where m is the slope of the line. From this, EF-4.5 was revealed to have the highest growth rate value, with a slope of 3.283 in per month. Following this plant group are EF-2 and EF-0, with an average growth rate of 1.801 and 1.526 in, respectively. On the other hand, EF-7 exhibited the most minimal

growth, as reflected by its smallest growth rate value compared to the other plant groups. Considering that a slower growth rate is also one of the symptoms of over-fertilization (Moorman, 2011), this effect can be attributed as the reason behind the slow growth of EF-7 compared to the other groups. Finally, the last column of the table shows the R^2 value, also known as the coefficient of determination. This value shows how well the data fit the regression line. The R^2 value may range from 0 to 1. An R^2 value closer to 1 indicates a better fit for the model. These values were generated through Excel and were important in observing accuracy. With this, the general trend observed in the plant height and growth rate following a decreasing order is EF-4.5 > EF-2 > EF-0 > EF-7.

CONCLUSIONS

Comparing all the concentrations of the eggshell tea fertilizer applied, EF-0 and EF-2 showed moderate growth, with EF-2 reaching the fruiting stage and demonstrating slightly better results on the tested parameters than to EF-0. Furthermore, EF-4.5 exhibited the greatest and fastest growth of bell peppers. It was also the first plant group to reach the fruiting stage. On the other hand, EF-7 exhibited the smallest leaf surface area, plant height, and growth rate. Leaf curling, leaf spots, yellowing of leaves, permanent damage of leaves, and minimal growth rate were also observed in EF-7. Considering that the given symptoms were present, over-fertilization could significantly contribute to these results. The data gathered revealed a generally positive effect of the eggshell tea fertilizer, such as faster and healthier growth on the bell peppers compared to those that did not receive any fertilizer. However, relatively high eggshell tea concentration led to destructive effects such as those observed in EF-7. Thus, of all the tested concentrations, the eggshell tea was most effective to be applied on bell peppers with 4.5% concentration and least effective with 7% concentration.

For future research, it is recommended to conduct laboratory testing and monitoring, to analyze the shelf life of eggshell tea fertilizer, to set a longer experimental period, and to add eggshell tea concentrations to be tested. Moreover, laboratory tests such as testing for soil pH and moisture content are recommended as these will help analyze the soil properties and the leaves of the plant (i.e., the presence of pests) and possibly discover other effects of the fertilizer. The soil content plays a huge role in the growth of plants, as it has microorganisms that may influence the growth of the plants. A faster growth rate may be derived from more nutritious soil; hence, studying this through laboratories is also recommended. Additionally, the shelf life of the eggshell

tea fertilizer is recommended to be tested and analyzed to determine the most effective duration to use the fertilizer. Doing this will also eliminate or minimize any negative influences from the fertilizer being spoiled. Moreover, a longer duration of the experimental period is important to generate a more accurate trend. The experimental period of this study was only conducted for five months, which limited the observed trend in the parameters to that time frame only. Extending the duration will help discern more observations and improve analysis. Lastly, additional eggshell tea concentrations to be tested are recommended to decrease the huge gap between each concentration. Adding tested concentrations will help in discovering a more precise concentration that is most effective for bell peppers. This will also be beneficial in eliminating outliers and making generalizations (i.e., lower concentrations may have a better effect than moderate to high concentrations).

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ABOUT THE AUTHORS

Anjanette Czyra L. Argonza

Anjanette Czyra Argonza is an incoming biomedical engineering freshman. In 2021, she presented a paper on waste reclamation for plant fertilizers in an international conference two years after receiving a research award. A multi-awarded STEM graduate of DLSU-Laguna, she hopes to become a significant figure in the engineering field someday.

Alaissa Riobel D. De Chavez

Alaissa Riobel De Chavez graduated high school at De La Salle University - Laguna Campus. Her past research focused on advancements in the medical field and plant growth enhancements. She is taking up BS in Medical Laboratory Science at De La Salle Medical Health and Science Institute.

Raquel B. Supan

A recipient of the Lasallian Institutional Gift to Adopted Pupils (LINGAP) scholarship, Raquel Supan is an incoming Civil Engineering freshman at De La Salle University. She is also an aspiring journalist and competed in feature writing contests at regional and district press conferences.

Kerry P. Cabral

Kerry Cabral earned his doctoral degree in International Development Engineering at the Tokyo Institute of Technology under the Monbukagakusho scholarship. His research focused on developing multi-dimensional nanostructures for water purification by photocatalysis. He currently teaches practical research and some basic science courses to SHS students at De La Salle University-Laguna.