Improving the growth of cherry tomatoes (*Solanum lycopersicum L. var. Cerasiforme)* using irradiated carrageenan

SOPHIA THERESE L. PAMATI-AN, CHRISTINE A. MIRAFLORES, JOHN A. HENRY GALINO, and ZENNIFER L. OBERIO
Philippine Science High School - Western Visayas Campus, Brgy. Bito-on, Jaro, Iloilo City 5000, Department of Science and Technology – Science Education Institute, Philippines

Abstract

This study determined the effects of irradiated carrageenan on the plant growth and yield of cherry tomatoes. The irradiated carrageenan solution used in the study was provided by the Philippine Nuclear Research Institute. Irradiated carrageenan (experimental), commercial foliar fertilizer (positive control) and tap water (negative control) were used in foliar spraying the plants. Stem length, stem diameter, leaf area, number of days to flowering, number of days to priming, number of branches and number of harvested fruits were recorded. The diameter, length, and weight of the fruits were also recorded. Plants sprayed with irradiated carrageenan were found to have longer and bigger stems compared to plants in the other setups, more primary branches and number of harvested fruits, and earlier to first priming. Overall, these results indicate that irradiated carrageenan primarily improves the growth of cherry tomatoes during its vegetative state, which could lead to earlier harvests and improved production.

Keywords: *cherry tomatoes, plant growth, plant yield, irradiated carrageenan, growth promoters*

Introduction. Some plants are unable to thrive due to certain environmental factors such as temperature, rainfall, and wind, which could lead to the stunting of their growth. In these cases, plant growth stimulants are used to promote the growth and development of plants [1]. One stimulant that has been a recent subject for research is carrageenan which has undergone various methods of depolymerization, such as gamma-radiation [2]. Several studies have been made testing the effects of irradiated carrageenan as a plant growth promoter or stimulant [2,3,4,5].

Carrageenans are sulfated anionic polymers that are derived from various species of red seaweed (phylum Rhodophyta) [6]. Carrageenans are composed of D-galactose units linked alternately with a(1,3)-D-galactose-4-sulfate and b(1–4)-3,6-anhydro-D-galactose [3]. They are usually used for food, pet food, personal care, and pharmaceutical products [3].

Irradiated carrageenan is a type of oligomer degraded through radiation processing of the polysaccharides to produce lower molecular weights, which has been found to be more effective for stimulating biological activities in plants [3]. Abad et al. [5] tested irradiated carrageenan plant growth promoter that they produced on rice which showed significant increase in the yield, stem sturdiness, and extensiveness in root system. It was also able to increase the number of leaves, leaf area, and plant fresh and dry weight of rosas de baybayon (*Catharanthus roseus*) [2]. There have also been studies testing the effects of different forms of carrageenan on different plants, such as pechay [4], garbanzos (chickpea) and corn (maize) [7], tobacco [1], blue gum eucalyptus (*Eucalyptus globulus*) [8], and radiata pine (*Pinus radiata*) [9] which also resulted in significant positive effects on the growth in general. Naeem et al. [2] investigated the biochemical activities involved in the leaf area of *C. roseus*. Their study quantified the net photosynthetic rate and stomatal conductance, total contents of chlorophyll and carotenoids, activity of nitrate reductase (NR), activity of carbonic anhydrase (CA), activity of tryptophan decarboxylase (TDC), and total alkaloid content in leaves. These suggest that irradiated carrageenan applied through foliar application may act as catalyst in the biological reactions in the leaves of the plant which are often correlated with growth and yield of plants. Although some studies have been conducted on leafy vegetables, legumes, and trees, such as those mentioned previously, no existing study on the effects of irradiated carrageenan has been done on fruit-bearing vegetables.

According to Ahmad et al. [10], cherry tomatoes, which are becoming more popular in supermarkets, have limited fruiting especially in the tropics when temperatures rise. They also affirmed that the use of growth promoters can promote its fruiting.

Thus, this study investigated the effects of irradiated carrageenan solution on the plant growth and yield of cherry tomatoes by determining the effects of the foliar application of carrageenan on the stem, leaves, growth, and yield of cherry tomatoes. Specifically, it aims to:

(i) Measure the a) stem length b) stem diameter, and c) leaf area every two weeks after transplanting to fruition of cherry tomatoes treated every 14 days with irradiated carrageenan solution, with commercial fertilizer (positive control), and with tap water (negative control)

(ii) Determine the a) number of days to flowering b) number of days to first priming c) total number of harvested fruits at one priming d) number of primary and secondary branches e) individual fruit weight of mature cherry tomatoes f) fruit length of mature cherry tomatoes, and g) fruit diameter of mature cherry tomatoes of cherry tomato plants treated every 14

days with irradiated carrageenan solution, with commercial foliar fertilizer (positive control), and with tap water (negative control)

(iii) Determine if there is a significant difference in each of the parameters from cherry tomatoes treated with irradiated carrageenan solution, with commercial foliar fertilizer (positive control), and with tap water (negative control) for one priming

(iv) Determine which of the cherry tomato plants treated with irradiated carrageenan solution, with commercial foliar fertilizer (positive control), and with tap water (negative control) is significantly different from each other in terms of the parameters

Studying the effects of irradiated carrageenan on cherry tomatoes might lead to the use of irradiated carrageenan in a broader range of crops and can also contribute to the understanding of the effects of carrageenan on plants. The findings of this study may also become basis for future research on the mechanism for its effects.

Methods. Ninety cherry tomato seeds were germinated, transplanted, randomized, and grouped into three setups, namely experimental, positive control, and negative control which were foliar sprayed with irradiated carrageenan solution, commercial foliar fertilizer, and tap water, respectively. Stem length, stem diameter and leaf area were measured every 14 days until 70 days after transplant, while the number of primary and secondary branches, number of days to flowering, number of days to priming, number of harvested fruits, individual fruit weight, fruit length, and fruit diameter were also recorded. The data gathered were analyzed using One-Way ANOVA and Least Significant Difference (LSD) was used as post-hoc.

Germination and Transplant. Red Plum cherry tomato seeds, verified by the Department of Agriculture as true to the species that is named, as well as its hybrid and variety, were sown in an 8 in x 13 in seedling tray using a soilless medium, Klasmann K TS1, which is mainly composed of white peat [11]. Two to three cherry tomato seeds were sown in each cell of the seedling tray, to a total of approximately 260 cherry tomato seeds sown in 104 cells. After 2 days, the seeds sprouted. The seedlings with the best growth attributes, indicated by the plant height, stem diameter, and number of healthy true leaves were chosen for transplanting. Twenty-two (22) days after sowing the cherry tomato seeds, the seedlings produced true leaves. The seedlings were then transplanted to polyethylene pots with a diameter of 30 cm and height of 27.5 cm that were placed on pallets at the PSHS-WVC Academic Building rooftop.

Randomization. Each plant was randomly assigned to a block of 10 plants. After sorting, the first three blocks were assigned to experimental group, the second three blocks were assigned to positive control, and the last three blocks were assigned to negative control.

Foliar Application. One percent solution (g/L) of irradiated carrageenan was foliar sprayed every 14 days after transplant for 70 days. The positive control setup was sprayed with commercial foliar fertilizer based on the manufacturer's recommendation of dose and frequency, a commercial fertilizer known to be used by cherry tomato farmers, and the negative control setup was sprayed with tap water every 14 days.

Measuring Growth Parameters. The stem length was measured from the surface of the soil to the leaf of the growing tip. The stem diameter was measured at 15 cm from the surface of the soil [12]. Leaf area was determined by selecting three of the largest leaves in each of the replicate and measuring its area with the use of ImageJ.

The number of days to flowering was counted from transplanting to the day where 50% of all cherry tomato plants in each replicate had at least three open flowers. The number of days to first priming was counted from transplanting of the cherry tomatoes to first priming of 50% of the plants have one fruit ready for harvest per replicate. Numbers of primary and secondary branches were counted separately at harvest period. Cherry tomatoes were harvested and counted at one priming. The fruit length, fruit diameter, and fruit weight were measured.

Data Analysis. The data gathered on the ten parameters for the three different setups (irradiated carrageenan solution, commercial fertilizer, and tap water) were computed and analyzed using One-Way ANOVA in Statistical Test for Agricultural Research (STAR) to determine if there was any significant difference between the means of the measured parameters. LSD was used as post-hoc test.

Safety Procedure. Researchers wore protective gear such as gloves during spraying. Excess irradiated carrageenan and commercial foliar fertilizer were disposed properly.

Results and Discussion. From the data gathered, it was found that the stem length, stem diameter, number of primary and secondary branches, and number of days to first priming were improved when compared to plants sprayed with either commercial foliar fertilizer or tap water. The improvement in the parameters is supported by the increased rates of activity of plant biochemical mechanisms due to stimulation by irradiated carrageenan.

Stem Length. The mean stem lengths (measured in cm) of plants sprayed with irradiated carrageenan were found to be significantly ($P \leq 0.05$) higher compared to the stem lengths of other plants during the sixth week after transplant. The bi-weekly increment of stem length in plants sprayed with irradiated carrageenan were found to be significantly ($P \leq 0.05$) higher compared to plants sprayed with tap water, but significantly ($P \leq 0.05$) lower compared to plants sprayed with the commercial foliar fertilizer during the 4th to 6th week after transplant (Table 1). Afterwards, the bi-weekly increment of stem length in plants sprayed with tap water became significantly ($P \leq 0.05$) higher compared to other plants during the sixth to eighth week after transplant(Table 1). No other significant findings on irradiated carrageenan were

Table 1. Bi-weekly Stem Length Increment of Cherry Tomato Plants Sprayed with Irradiated Carrageenan, Commercial Fertilizer, and Tap Water.

	Bi-weekly Stem Length Increment (cm)					
Treatment	Week 0-2	Week 2-4	Week 4-6	Week 6-8	Week 8-10	Week 10-12
Irradiated Carrageenan	23.44[a] ± 7.308	34.53[a] ±6.780	35.79[a] ± 7.022	15.54[b] ±6.620	12.66[a] ± 7.152	2.350[a] ± 7.141
Commercial Fertilizer	23.96[a] ± 4.126	33.49[a] ± 7.248	39.44[a] ±8.610	17.70[b] ±8.447	10.03[a] ± 7.642	3.560[a] ± 7.358
Tap Water	26.39[a] ±5.366	31.34[a] ± 6.811	30.49[b] ± 6.819	20.98[a] ±6.119	12.78[a] ±6.872	3.460[a] ±10.33

Means within a column followed by the same letter(s) are not significantly different (P ≤ 0.05). Means of three replicates ± SD.

Table 2. Bi-weekly Stem Diameter Increment of Cherry Tomato Plants Sprayed with Irradiated Carrageenan, Commercial Fertilizer, and Tap Water

	Bi-weekly Stem Diameter Increment (mm)				
Treatment	Week 2-4	Week 4-6	Week 6-8	Week 8-10	Week 10-12
Irradiated Carrageenan	3.81[a] ± 2.152	0.72[a] ± 0.6619	0.67[a] ±0.6244	0.60[a] ± 0.7263	-0.10[b] ±0.9359
Commercial Fertilizer	2.31[b] ± 1.193	0.82[a] ± 0.4860	0.39[a] ±0.5350	0.20[b] ± 0.6891	0.38[a] ±0.4700
Tap Water	3.02[b] ± 1.276	0.86[a] ± 0.4264	0.55[a] ± 0.7078	0.58[a] ± 0.6335	0.05[b] ± 0.6727

Means within a column followed by the same letter(s) are not significantly different (P ≤ 0.05). Means of three replicates ± SD.

found during the other two-week periods.

Stem Diameter. It was found that the stem diameters of plants sprayed with irradiated carrageenan and tap water were significantly ($P \leq 0.05$) higher than plants sprayed with the commercial fertilizer for the whole data gathering period except for the sixth week after transplant. Plants sprayed with irradiated carrageenan were also found to have a significantly ($P \leq 0.05$) higher bi-weekly increment in stem diameter compared to the other plants during the second to the fourth week (Table 2) and during the eighth to the tenth week after transplant. No significant findings on irradiated carrageenan were found on the other weeks (Table 2).

Leaf Area. The measured leaf areas of plants sprayed with irradiated carrageenan were not found to be significantly ($P \geq 0.05$) different than the leaf areas of the other plants.

Number of Days to First Flowering. The mean number of days to flowering of the plants sprayed with irradiated carrageenan, commercial foliar fertilizer, and tap water were 26.67, 27.00, and 27.33, respectively. These means were not significantly different from each other at $P \geq 0.05$.

Number of Days to First Priming. The mean number of days to first priming of cherry tomato plants sprayed with irradiated carrageenan, commercial foliar fertilizer, and tap water were 70.00, 81.67, and 74.33, respectively. Cherry tomatoes sprayed with irradiated carrageenan were found to have significantly ($P \leq 0.05$) fewer days to first priming compared to cherry tomatoes sprayed with the commercial foliar fertilizer and tap water.

Number of Branches. Plants sprayed with irradiated carrageenan were found to have a significantly higher number of primary branches (mean = 43.27) compared to plants sprayed with the commercial fertilizer (mean = 32.37) and tap water (mean = 33.00). The mean number of secondary branches of plants sprayed with irradiated carrageenan, commercial foliar fertilizer, and tap water were 71.97, 55.43, and 82.27, respectively. No significant difference was found between the number of secondary branches of plants sprayed with irradiated carrageenan and plants sprayed with tap water. Plants sprayed with the commercial fertilizer were found to have a significantly lower ($P \leq 0.05$) number of secondary branches compared to plants sprayed with irradiated carrageenan and tap water.

Total Number of Harvested Fruits. The mean of the total number of harvested fruits of plants sprayed with irradiated carrageenan, commercial fertilizer and tap water were 76.00, 34.33, and 70.03, respectively. Plants sprayed with irradiated carrageenan were found to have significantly ($P \leq 0.05$) higher number of harvested fruits than plants sprayed

with commercial fertilizer but have no significant difference ($P \geq 0.05$) with plants sprayed with tap water.

Individual Fruit Weights. The mean weight of individual harvested fruits of plants sprayed with irradiated carrageenan, commercial fertilizer, and tap water were 4.407 g, 4.208 g, and 3.950 g, respectively. There was no significant ($P \geq 0.05$) difference among these means.

Fruit Length. The mean fruit length of individual harvested fruits of plants sprayed with irradiated carrageenan, commercial fertilizer, and tap water were 24.58 mm, 24.32 mm, and 23.57 mm, respectively. There was no significant ($P \geq 0.05$) difference among these means.

Fruit Diameter. The mean fruit diameter of individual harvested fruits of plants sprayed with irradiated carrageenan, commercial fertilizer, and tap water were 17.55 mm, 17.35 mm, and 16.92 mm, respectively. There was no significant ($P \geq 0.05$) difference among these means.

Discussion. The results of the study suggest that the application of irradiated carrageenan to cherry tomatoes significantly enhanced the following parameters: stem length, stem diameter, number of primary and secondary branches, number of days to first priming, and number of harvested fruits. However, the application did not significantly affect the cherry tomatoes in terms of the leaf area, fruit length, fruit diameter, and fruit weight. The improvement of the stem length, stem diameter, numbers of primary and secondary branches, number of days to first priming, and number of harvested fruits might be due to the increased rate of activity of biochemical mechanisms such as photosynthesis, carbon fixation, pollen viability, and anther dehiscence resulting from the application of irradiated carrageenan [10,13,14]. The activation of cell division and elongation, and the addition of micronutrients from the application are also possible causes for the improvement [10,13,14].

The stem of plants sprayed with irradiated carrageenan was longer compared to the stem lengths of other plants during the sixth week after transplant. The elongation of the stem is aligned with the previous studies which reported an increase in plant height in *C. roseus* [2,15] and tobacco [1,13]. According to Muñoz et al. [13] and Castro et al. [1], this increase in plant height is the result of increased photosynthesis and carbon fixation due to the stimulation by carrageenans.

Plants sprayed with irradiated carrageenan have thicker stems compared to plants sprayed with the commercial fertilizer for the whole data gathering, except for the sixth week after transplant. This increase in the growth of stem diameter is supported by previous studies; notably, Abad et al. [6] found that rice plants treated with irradiated carrageenan had significantly increased stem diameters, leading to increased sturdiness. According to Zou et al. [16], the stem diameter in tomatoes is a parameter that can describe the growth of the plant under abiotic stress during its vegetative stage. During our data gathering, the plants experienced abiotic stress in the form of excessive rain and winds brought by a tropical depression during its vegetative growth, 10 weeks after transplant. As the stem is a water-storing organ for the plant, a larger stem diameter could enhance the growth of a plant under environmental stress. This suggests that the application of irradiated carrageenan on cherry tomatoes improves their resistance against possible abiotic factors.

Although the flowers of plants sprayed with irradiated carrageenan, commercial fertilizer, and tap water bloomed the same day, the fruits were viable to harvest earlier for plants sprayed with irradiated carrageenan than the others. Venkadeswaran et al. [17] suggested that the increase in fruit set, or the process in which flowers became fruits, at the earlier reproductive phase might be due to higher anther dehiscence and higher pollen viability. However, it was also observed that some of the plants from all setups (sprayed with irradiated carrageenan, commercial foliar fertilizer, and tap water) suffered from blossom drop, the loss of flowers due to abiotic stress.

Application of irradiated carrageenan increased the number of primary and secondary branches of cherry tomato plants in comparison to those applied with commercial foliar fertilizer and tap water. This agrees with the results of Bi et al. [7] in which the application of carrageenan increased the number of branches in chickpea and maize plants. Studies have shown that the number of branches can be increased by the activation of cell division and cell elongation, [5] or addition of micronutrients [14]. The sulfate groups present in carrageenan which were found to have biological functions were magnified through irradiation [3], and in the case of the number of branches, the increase could be caused by the mechanisms stated above. The leaf area, number of harvested fruits, fruit length, fruit weight, and fruit diameter of cherry tomato plants sprayed with irradiated carrageenan solution, commercial fertilizer and tap water were comparable. The results of the leaf area contradict the previous studies of Naeem et al. [2], Khan et al. [15], and Mousavi et al. [18], which claimed that irradiated carrageenan increase the leaf area as it increased the net photosynthesis, rubisco activity, and glutamate dehydrogenase activity.

The application of irradiated carrageenan on cherry tomato plants increased the number of harvested fruits in comparison to those sprayed with commercial fertilizer. Although there is no previous study on the application of irradiated carrageenan on fruit-bearing vegetables, previous studies on the application of seaweed extracts to tomato plants have shown that the application increases the number of harvested fruits [19,20]. According to Crouch and Staden [20], the increased number of fruits is due to the increased number of flowers of plants applied with seaweed extracts, which could be the result of the increased plant growth of the plant or the presence of various hormones that affect the flowering of the plant.

The leaf area, fruit length, fruit weight, and fruit diameter of cherry tomato plants sprayed with irradiated carrageenan solution, commercial fertilizer

and tap water were comparable. These results contradict with previous studies of Naeem et al. [2], Khan et al. [15], and Mousavi et al. [18] which claimed that irradiated carrageenan increase the leaf area as it increased the net photosynthesis, rubisco activity, and glutamate dehydrogenase activity.

However, as previous studies have not used cherry tomatoes or any comparable fruit-bearing vegetables, the exact mechanism which affected the yield of the cherry tomato plants is not yet known. Similarly, there was no significant difference observed in the fruit length, fruit weight and fruit diameter of cherry tomatoes of plants sprayed with irradiated carrageenan, commercial foliar fertilizer and tap water. The mechanism which resulted to such is also unknown.

Error Analysis. Human error in the measurement of stem length, stem diameter, leaf area, number of branches, and number of harvested fruits, and instrumental error in the measurement of fruit weight may lead to errors in the gathered data.

Conclusion. It is concluded that the application of irradiated carrageenan solution enhanced the growth of cherry tomatoes, in terms of stem and branches. No significant effect was observed in the yield of cherry tomatoes. The present study also suggests that irradiated carrageenan increased the number of fruits harvested in a period of one priming. However, more studies will be required on the topic especially on the biochemical mechanisms, to explain why plants sprayed with irradiated carrageenan had no difference with plants sprayed with commercial fertilizer and tap water on the leaf area, number of days to flowering, total number of harvested fruits, the size and weight of the fruits of cherry tomatoes.

Recommendations. It is recommended that the study be replicated in a plastic greenhouse to further reduce external factors (wind, insects, etc.) and the harvesting period of cherry tomatoes be extended. Increasing the parameters of cherry tomatoes to be measured (e.g. the number of flowers, flower cluster, percent of fruit set, sugar content, shelf life, and lycopene content of fruits, and fresh and dry weight of plant) is also recommended. Since temperature is said to affect the stem diameter, it is recommended that the temperature should be measured during data gathering.

Irradiated carrageenan is also recommended to be applied to cherry tomatoes using hydroponics or by mixing carrageenan with soil, using different concentrations, and testing at which frequency of spraying irradiated carrageenan is most effective in improving the growth and yield of cherry tomatoes.

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