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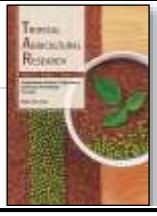

RESEARCH

Impact of Plant Growth Regulators on Salad Cucumber (*Cucumis sativus* L.) Vine Length and Yield

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ARTICLE INFO

Article history:
Received: 20 June 2024
Revised version received: 10 November 2024
Accepted: 17 December 2024
Available online: 01 January 2025

Keywords:
Cucumis sativus
Ethephon
Paclobutrazol
Sodium Nitrophenolate
Cucumis sativus
Salad cucumber

Citation:
Perera U.D.T. and Kumarasinghe H.K.M.S (2024). Impact of Plant Growth Regulators on Salad Cucumber (*Cucumis sativus* L.) Vine Length and Yield. Tropical Agricultural Research, 36(1): 28-38.

DOI:
https://doi.org/10.4038/tar.v36i1.8785

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ABSTRACT

Training of salad cucumber vines is a very labour and time-consuming task. Therefore, this study was conducted to investigate the impact of plant growth regulators(PGRs) on the length and yield of salad cucumber vines. The experimental design used was a Completely Randomized Design with four replicates. T1=Cycocel (0.4375 ml/L water), T2=Sodium Nitrophenolate (0.4 ml/L water), T3=Ethephon (0.325 ml/L water), T4=Paclobutrazol(250 mg/L water), and T5=Without PGRs (control) were the five treatments. Treatments were applied once a week. Growth parameters were recorded weekly while yield parameters were recorded at harvest. Data were analyzed by ANOVA using the SAS software. Subsequently, means were separated by Dunnett's test. Results revealed that the vine lengths were significantly low from the treatments T3 (Ethephon, 251 cm) and T4 (Paclobutrazol, 166.33 cm). The number of leaves per vine was significantly highest from T3 (Ethephon, 56 leaves) and T4 (Paclobutrazol, 42 leaves) produced the significantly lowest number of leaves per vine. Additionally, the significantly lowest length of internodes for the 14th and 21st internodes resulted from T3 (Ethephon, 3.36 cm, 3.33 cm) and T4 (Paclobutrazol, 2.96 cm, 3.33 cm). The significantly lowest leaf area in the 15th leaf resulted from T4 (Paclobutrazol, 321.86 cm^2) while the significantly highest leaf area in the 30th leaf resulted from T3 (Ethephon, 303.64 cm^2). Furthermore, a significantly higher number of nodes per 1 m of vine length was reported from T3 (Ethephon, 17.66 nodes) and T4 (Paclobutrazol, 20 nodes). In terms of yield parameters, the significantly lowest fruit weight (530.33 g), length (13.45 cm), and number of fruits (5.66) were recorded from T3 (Ethephon). Thus, T4(Paclobutrazol) is suitable for shortening the vine length along with a greater yield of salad cucumber vines.

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INTRODUCTION

Salad cucumber (*Cucumis sativus* L.) is a vital and commercially popular vegetable crop, which holds an attractive place in the vegetable market. Its main stem grows straight and then becomes prostrate. Therefore, the modification of the canopy architecture through training, pruning, and suitable spatial arrangements are necessary management strategies for achieving maximum, marketable yields from greenhouse cucumber cultivation. Training enhances the plant's capacity to absorb sunlight required for growth and sufficient air movement surrounding the plant reducing the risk of fungal and pest attacks while enhancing the quality and vegetative development of fruits (Samba et al., 2023). However, training the vines is a very labour and time-consuming task in salad cucumber cultivation. Therefore, use of alternative methods to reduce the vine length with better yields will be advantageous.

Plant growth regulators (PGRs) have been suggested as a commercial crop production technique to enhance growth and development and thus boost crop quantity and/or quality (Ngatia et al., 2003). These are synthesized organic chemical substances, which are used to regulate the growth and development of a plant. It has the potential to either promote or inhibit growth. Small quantities of PGRs can induce specific physiological changes in specific parts of the plant. Plant growth regulators have the potential to impact on a broad range of physiological parameters, such as modified plant architecture, improved nitrogen metabolism, increased uptake of nutrients (mineral ions), assimilate partitioning, enhanced flowering, increased mobilization of assimilates to specific sinks, enhanced seed quality, induction of flowering synchrony, and delayed leaf senescence (Marimuthu and Surendran, 2015). Therefore, PGRs can be used to increase crop yields and enhance quality by applying as a foliar spray or a soil drench at the right concentration (Marimuthu and Surendran, 2015). Asgarian et al. (2013) also stated that PGRs may be helpful in regulating plant growth and modifying the size and shape of plants, resulting in compact, short, and aesthetically pleasing plants.

Some PGRs used in crop cultivation are Cycocel, Sodium Nitrophenolate, Ethephon, and Paclobutrazol. Cycocel consists of 11.8% Chlormequat (2-Chlorethyl) Trimethylammonium Chloride (Cycocel, 2021). It is designed to stop excessive vegetative growth and to enhance photo-assimilate translocation to increase yields. In addition, Cycocel lowers plant water stress. Crops treated with Cycocel have stronger stems, shorter internodes, and greener leaves, making them more compact. In addition, Cycocel reduces stem elongation in herbaceous crops.

Sodium Nitrophenolate is a versatile regulator of plant development. It is a powerful cell activating agent and can quickly permeate in the plant body, promote cytoplasm flow, improve cell vitality, and enhance photosynthesis to increase plant growth. Purba et al. (2019) mentioned that Sodium Nitrophenolate is a plant growth stimulant made up of Sodium Orthonitrophenol, Sodium Dinitrophenol, Sodium Paranitrophenol, and Sodium 5-Nitroguaiacol, (0.2%).

Ethephon (2-Chloroethyl Phosphonic acid) is an ethylene-releasing substance, and it is commonly used to control plant growth (Khuankaew et al., 2009). It is used to encourage fruit ripening, abscission, flower induction, and other reactions. Ethephon formulations can also comprise soluble liquids/ concentrates and formulation intermediates (Takenaka, 2002).

Paclobutrazol is one of the most effective plant growth inhibitors which has been used in farming for many years. It is said to shorten stems, reposition the distribution of assimilates to balance sources and sinks, and boost yield (Mehmood, 2021). According to the results of several studies, Paclobutrazol could be sprayed on plants to prevent them from growing above ground, reduce the amount of assimilates that accumulate in the leaves, and encourage their transport and distribution to the roots and seeds, which would result in thicker, more robust roots and stems (Senoo and Isoda, 2003).

Therefore, PGRs can have a big impact on crop growth and development. However, little is

known about PGRs and their effects on growth and yield of salad cucumber. Therefore, this study aimed to identify the impact of PGRs on vine length and yield of salad cucumber to reduce the labour cost and time spent on plant training and to achieve a greater yield simultaneously.

METHODOLOGY

This research was conducted in an automated protected house at the Faculty of Agriculture, University of Ruhuna, Sri Lanka from January to April 2023. After the nursery period of seven days, salad cucumber (Var: EFDAL F1) seedlings were planted in coir grow bags at one plant per bag. They were placed on the floor of the protected house with a spacing of 60.96 cm x 60.96 cm (2 x 2 ft^2) (DOA). Plants were fertilized with Albert fertilizer 1 g/plant/day and irrigated with 1 L of water/plant/day. Management of pests and diseases were done according to the recommendations of the Department of Agriculture, Sri Lanka (DOA). Pruning of tendrils, removing of aborted and misshapen fruits and old and diseased leaves were done as required and plants were trained weekly. Microclimatic parameters inside the protected house were maintained within ideal ranges with the help of the automation system.

The experimental design used was a Completely Randomized Design (CRD) with four replicates. The five treatments were T1=Cycocel, T2=Sodium Nitrophenolate, T3=Ethephon, T4=Paclobutrazol and T5=Without PGRs(control). To prepare the solutions of PGRs, 0.4375 ml of Cycocel(T1), 0.4 ml of Sodium Nitrophenolate(T2), 0.325 ml of Ethephon(T3) and 250 mg of Paclobutrazol(T4) were dissolved in 1 L of water as mentioned in the labels of the PGRs. The prepared solutions were applied as a foliar spray for each plant 320 L/ ha basis once a week starting from one week after transplanting.

Vine length, number of leaves per vine, length of 7th, 14th and 21st internodes, nodes per 1 m of vine length, and leaf area of the 15th and 30th leaves were recorded as growth characteristics. Length of the 7th, 14th and 21st internodes, at three different stages of the crop life-cycle, were selected to obtain the internodal length. In addition, the 15th and 30th leaves were selected to obtain leaf area, which are at the vegetative and reproductive stages of the crop cycle to evaluate the impact of plant growth regulators at these stages. As yield parameters, fresh weight, length, and number of fruits were measured at harvesting. Salad cucumber fruits were harvested when the center diameter of the fruit was 30 mm, according to the international grades of the export market (Seminis grow forward, 2018). Data were analyzed by ANOVA using the SAS software. Subsequently, means were separated by the Dunnett's test.

RESULTS AND DISCUSSION

Results revealed that all the growth and yield parameters were significantly influenced by PGRs.

Vine length

The plants treated with T3 (Ethephon, 251 cm) and T4 (Paclobutrazol, 166.33 cm) recorded significantly lower vine length compared to the control treatment (without PGRs, 381.66 cm) (Figure 1). As mentioned by Ngatia et al. (2003), Ethephon is a synthetic chemical growth inhibitor. Hayashi et al. (2001) recorded height reduction by 23, 42, 46, 40, and 46% in the herbaceous perennials *Achillea*, *Echinacea*, *Leucanthemum*, *Monarda*, or *Physostegia,* respectively, compared to the control plants when Ethephon was applied three times at 1000 mg L^{-1}. Ngatia et al. (2003) found that spraying four levels of Ethephon 0, 100, 200 and 300 mg/L at 7, 14 and 28 days after emergence reduced the plant height of beans. Wees (1993) also recorded that even the lowest rate (12.5 mg) of Ethephon application significantly decreased plant height when compared with the control in Easter Lily plants. Furthermore, Dhakal et al. (2019) reported plant height reduction in cucumber with the application of 400 ppm Ethephon compared to control. Moreover, Yadava (2001) recorded that compared to the control, foliar spray of 400 ppm Ethephon significantly reduced plant height (29.5%) of cape gooseberry. As stated by them both Ethephon and Paclobutrazol are basically retardants that have a considerable effect on

plant height. Further they stated that the reduced plant height by Paclobutrazol, is the result of inadequate cell elongation, due to the inhibition of the biosynthesis of gibberellins.

Paclobutrazol is also one of the most effective plant growth inhibitors (Mehmood et al., 2021). As mentioned by Tesfahun (2018), the most important morphological result of applying Paclobutrazol is thought to be the reduction in plant height. Asgarian et al. (2013) reported a significant reduction in the height of zinnia plants by using Paclobutrazol at 10, 20, 30 mg/l concentrations. They further mentioned that the main stem height was reduced compared to control plants when Paclobutrazol concentration increased. According to them, the stem height suppression was primarily linked to the control of internode elongation, rather than a reduction in the number of nodes. As stated by Karimi (2020), growth retardants prevent the cellular splitting and growth of the apical meristem, thus the plant does not grow normally and remains short. Furthermore, Soliman et al. (2022) stated that the application of growth retardants appears to have a significant effect on limiting cell expansion and slowing down cell division, which in turn reduces plant height. Salad cucumber vines treated with Ethephon and Paclobutrazol were not trained throughout the whole crop cycle since they recorded a remarkably lower vine length. Therefore, results of the present study agree with past findings that both Ethephon and Paclobutrazol act as growth retardants to reduce the vine length of salad cucumber vines.

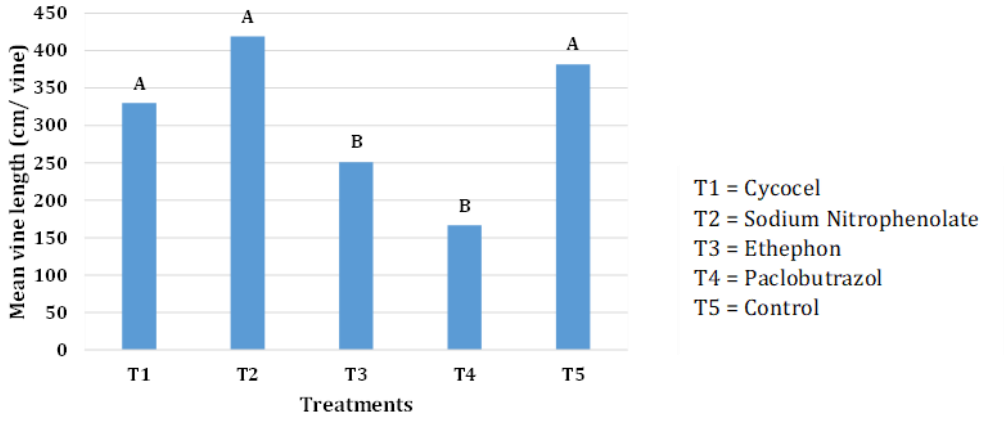

Figure 1: Impact of PGRs on vine length of salad cucumber plants

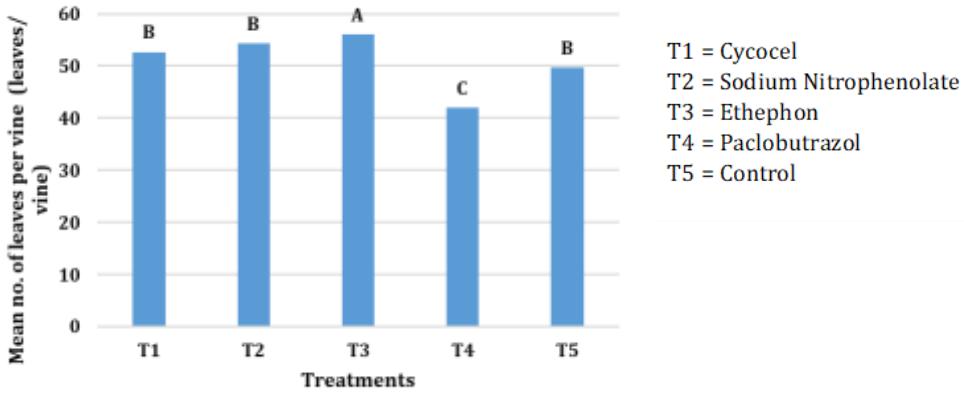

Figure 2: Impact of PGRs on number of leaves per salad cucumber vine

Number of leaves per vine

The plants treated with T3 (Ethephon) recorded significantly the highest number of leaves per vine (56) while the plants treated with T4 (Paclobutrazol) recorded significantly the lowest number of leaves per vine (42) (Figure 2). Yadava (2001) also reported significant increase of number of leaves in cape gooseberry with the application of 400 ppm Ethephon as a foliar spray. Helal (2000) reported enhanced branch numbers/plant in Ethephon treated Christmas Pepper. He mentioned that Ethephon treatments may enhance branching through its direct or indirect role on the apical dominance. Bharadwaj et al. (1988) also reported an increment in the number of lateral branches in *Capsicum annuum* plants treated with Ethephon making the plants bushier in appearance.

Nazarudin et al. (2007) stated that Paclobutrazol is a widely used growth retardant to regulate the vegetative growth of a variety of angiosperms. Tesfahun (2018) also indicated that vegetative growth of rice plants was significantly inhibited by the administration of Paclobutrazol. In agreement with the results of the present study, Navarro et al. (2007) recorded that when Paclobutrazol was applied to strawberry seedlings, the number of leaves per plant reduced by 12-19 compared to untreated plants.

Length of the internodes

The internodal lengths of the 14th and 21st internodes treated with T3 (Ethephon, 3.36 cm, 3.33 cm) and T4(Paclobutrazol, 2.96 cm, 3.33 cm) were significantly low (Table 1). However, the length of the 7th internode was not significantly affected by PGRs. When developing the 7th internode, plants were very young and have not adapted for the treatments. Therefore, the delay of adaptation of plants for the treatments might be the reason for the length of the 7th internode being not significantly influenced by the treatments. However, when developing the 14th and 21st internodes, plants had a substantial time to adapt for the treatments.

These findings are also supported by earlier findings of Sadhu and Das (1978), who recorded a reduction of internode length in *Momordica charantia, Luffa acutangula, and Cucumis melo var. utilissimus* with the application of Ethephon. Zhang et al. (2020) also recorded that internode elongation rate was decreased in maize plants when Ethephon was applied. Furthermore, Zhao et al. (2021) reported that internode lengths in maize was reduced by Ethephon. Asgarian et al. (2013) have reported that the application of Paclobutrazol decreased the main stem height of Zinnia plants significantly and the main stem height suppression was associated with control of internode elongation. Therefore, Paclobutrazol being a growth retardant, decreases the vegetative growth of plants. Navarro et al. (2007) also reported a 24% reduction in internode length when compared to control plants in strawberry tree seedlings by the application of Paclobutrazol. Tesfahun and Menzir (2018) stated that the application of Paclobutrazol in *Eragrostis Tef* , mainly caused a decrease in the elongation of internodes instead of decreasing the number of internodes.

Table 1: Impact of PGRs on length of the 14th and 21st internodes of salad cucumber vines

Treatments	Length of 14th internode (cm/ vine)	Length of 21st internode (cm/ vine)
T1 = Cycocel	8.54^{a}	5.96^{a}
T2 = Sodium Nitrophenolate	10.26^{a}	7.43^{a}
T3 = Ethephon	3.36^{b}	3.33^{b}
T4 = Paclobutrazol	2.96^{b}	3.33^{b}
T5 = Control	7.70^{a}	8.23^{a}

Leaf area

In the 15th leaf, T4 (Paclobutrazol) recorded the lowest leaf area of 321.86 cm^2, whereas T3 (Ethephon) recorded the significantly highest leaf area of 303.64 cm^2 in the 30th leaf (Figure 3). Yadava (2001) also reported a significant reduction in leaf area with Paclobutrazol at 50 ppm for cape gooseberry (*Physalis peruviana* L.). According to him reduced intercellular spaces and spongy mesophyll cells near the leaf margin in leaves, caused by Paclobutrazol, might be the reason for the reduction in leaf area. Roseli et al. (2012) also reported significant decrease in leaf area with Paclobutrazol application as compared with the control in *Syzygium myrtifolium*. According to them this might be due to the ability of Paclobutrazol to prevent leaf cell elongation. As cited by them, Tonkinson et al. (1995) have reported that Paclobutrazol reduced wheat leaf size by reducing cell length instead of reducing number of cells. Moreover, Wu et al. (2022) reported that Paclobutrazol application reduced the leaf area of Herbaceous Peony. Thus, it is clear that Paclobutrazol reduces the size of leaves in plants.

Khan et al. (2008) reported that application of Ethephon increased the leaf area of mustard plants. Fatma et al. (2021) also reported that leaf area of mustard plants under salt stress was increased by 40.8% by the application of Ethephon. According to Chumthong et al. (2023), leaf area was considerably affected by the frequency of Ethephon spraying in Stevia plants. The highest leaf area (1,030 cm^2) was observed after spraying Ethephon thrice, and the lowest (585 cm^2) after a single spraying of Ethephon. Pahwa and Ghai (2015) have stated that although Ethephon has long been known as a growth inhibitor, there is much evidence that it can also stimulate growth. Saxena et al. (2007) discovered that applying a lower dose of Ethephon resulted in an increase in the leaf area of chickpea at all stages. As mentioned by them, when Ethephon is sprayed during the pre-flowering stage, it promotes cell division, which increases leaf expansion. Lone (2001), Mir (2002), and Mir et al. (2009) reported that applying Ethephon to mustard plants increased the number of leaves and leaf area per plant. According to Pahwa (2013), the leaf area of pigeon pea increased when Ethephon (100 ppm) was applied during the pre-flowering stage. Therefore, results of the present study are in agreement with previous studies.

Number of nodes per 1 m of vine length

The number of nodes per 1 m of vine length was significantly higher in T3 (Ethephon, 17.66 nodes) and T4 (Paclobutrazol, 20 nodes) applied treatments (Figure 4). Dhakal et al. (2019) recorded the highest number of nodes in cucumber with 300 ppm Ethephon application. They stated that inhibiting cell division due to Ethephon application may have reduced internodal distance, which then contributed to the increased number of nodes. According to the findings of Rafeekher et al. (2001), Christopher and Loy (1982), and Arora et al. (1994), applying Ethephon to cucumbers, watermelon, and long melons reduced the internodal distance. Sadhu and Das (1978) also recorded that the total number of nodes were increased in *Luffa acutangula, Momordica charantia and Cucumis melo var. Utilissimus* with the application of Ethephon.

Papageorgiou et al. (2002) found that Paclobutrazol increased the number of nodes within lateral shoots of lavender. As stated by Lal et al. (2023) Paclobutrazol shortens the distance between nodes, thus increasing the number of nodes per unit length. Similarly, Paclobutrazol increased the number of nodes per 1 m of vine length in salad cucumbers. Therefore, results of the present study agree with past findings. In the context of salad cucumbers, nodes are the crucial locations from where leaves and fruits emerge. Therefore, higher number of leaves and fruits can be obtained per unit length of vine if the number of nodes per 1 m of vine length is increased.

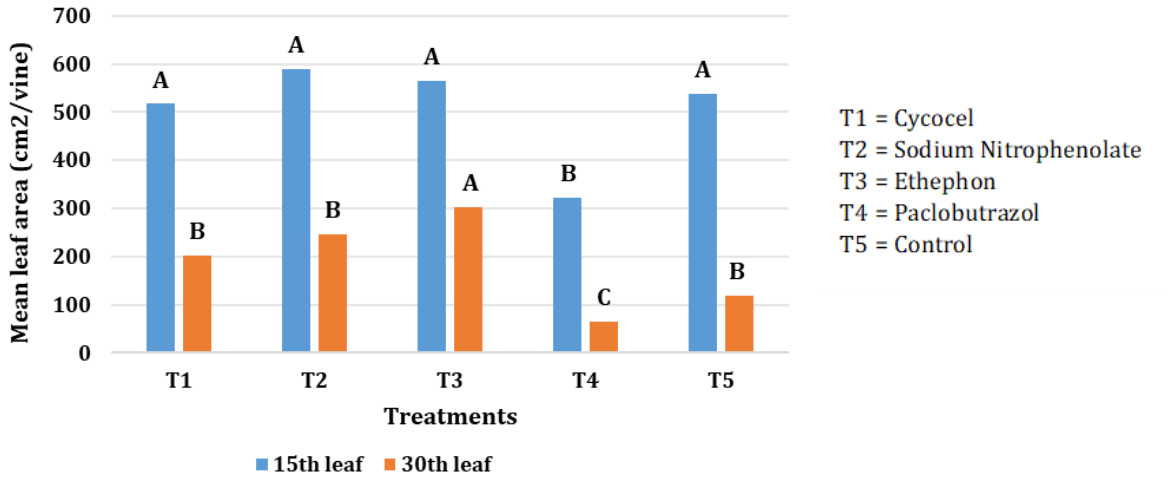

Figure 3: Impact of PGRs on leaf area of salad cucumber vines

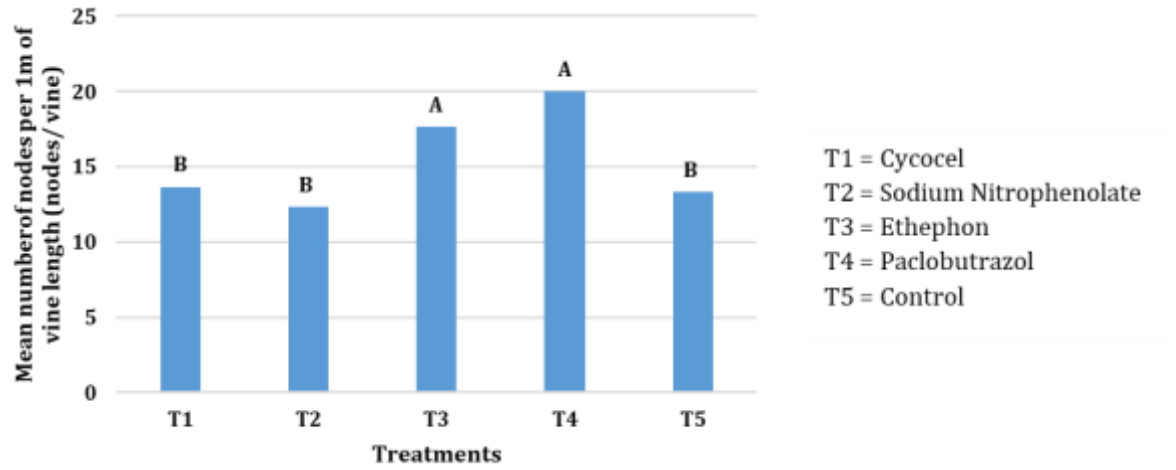

Figure 4: Impact of PGRs on number of nodes per 1 m of salad cucumber vine length

Yield parameters

In terms of yield parameters, T3 (Ethephon) reported significantly lower fruit weight (530.33 g), fruit length (13.45 cm), and number of fruits (5.66) (Figure 5, 6 and 7). Although T4 (Paclobutrazol) has recorded significantly lower fruit length (13.13 cm) like T3 (Ethephon), it has recorded significantly higher fresh weight (2542.33 g), and number of salad cucumber fruits (21.66), than T3 (Ethephon) treatment (Figure 5, 6 and 7). Even though, both Ethephon and Paclobutrazol reported significantly higher number of nodes per 1 m of vine length, which is a desirable attribute to increase the salad cucumber yield, only Paclobutrazol reported a yield comparable to other treatments and control. That may be due to the inability of Ethephon to develop fruits from salad cucumber flowers. Since variety EFDAL F1 used in this experiment is a hybrid variety there were almost pistillate flowers in salad cucumber vines in all treatments. However, a lot of flowers were aborted in Ethephon treated salad cucumber plants. Therefore, Ethephon treated salad cucumber plants recorded a significantly lower yield compared to the other PGRs treatments and the control.

These findings are supported by earlier studies. Ngatia et al. (2003) recorded that increase in Ethephon application led to a significant decrease in bean seed yield per plant. They further recorded that an increase in Ethephon level drastically decreased the number of pods produced by each plant. Ton (2021) also reported that seed yield of Faba

Bean was decreased with increasing Ethephon dose. Thomas and Rankin (1982) also recorded a reduction in average bulb weight and total yield of onion by the application of Ethephon at 1000 and 3000 mg/L concentration.

Since the objective of the present study was to investigate the most appropriate PGR to reduce the vine length to minimize training practices along with a greater yield, application of Paclobutrazol can fulfill this objective. However, salad cucumber fruits obtained from Paclobutrazol treated plants showed a slight misshapen appearance deviating from the erect cylindrical appearance, which is commercially accepted. Therefore, further research should be conducted to evaluate the optimum concentration of Paclobutrazol to obtain commercially accepted type of salad cucumber fruits.

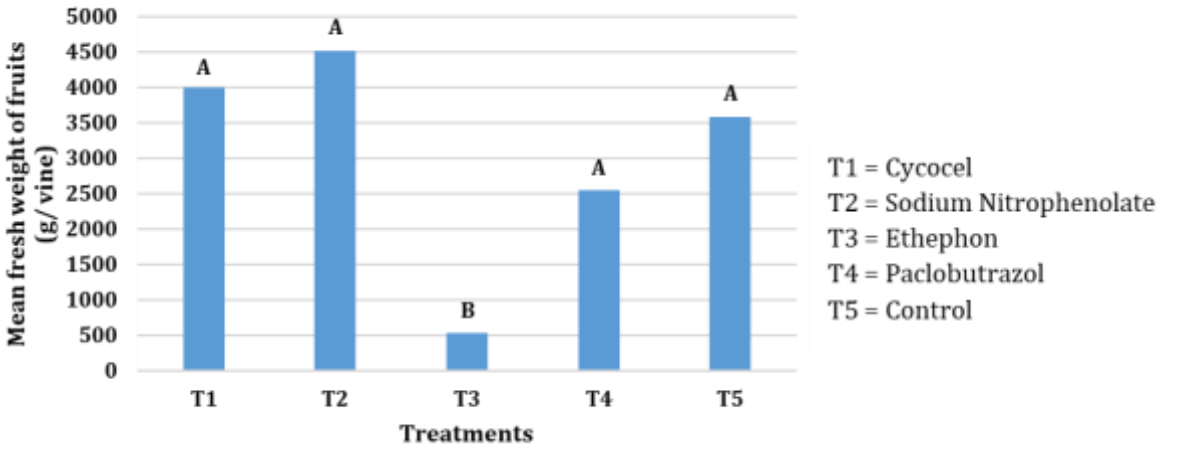

Figure 5: Impact of PGRs on fresh weight of salad cucumber fruits

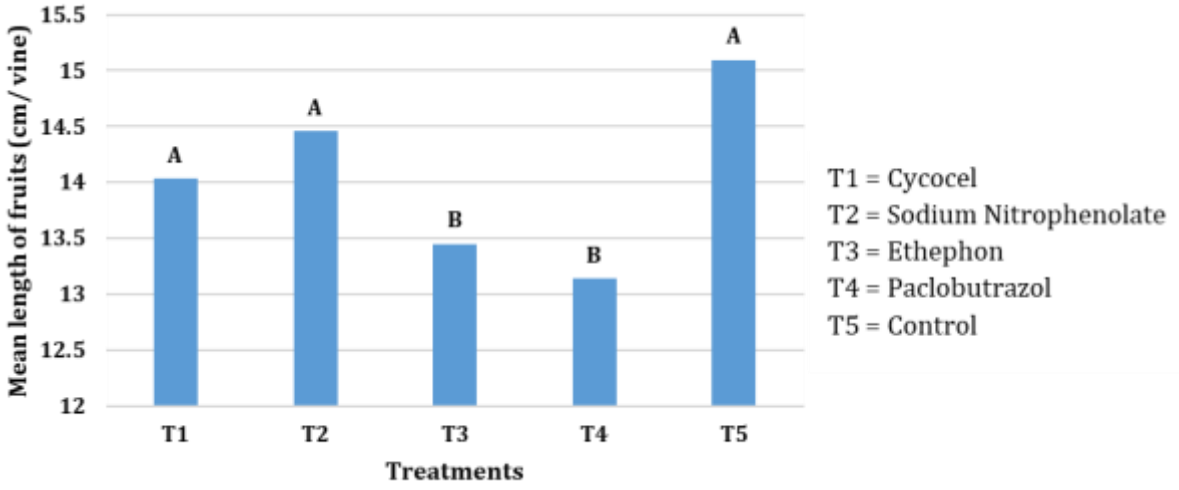

Figure 6: Impact of PGRs on length of salad cucumber fruits

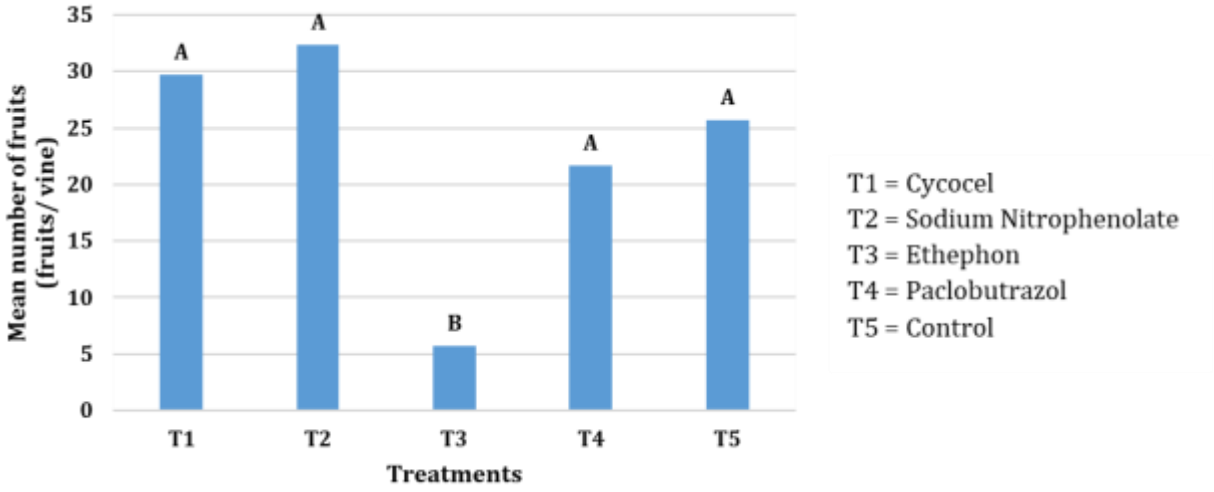

Figure 7: Impact of PGRs on number of salad cucumber fruits

CONCLUSION

Throughout the 120-day crop cycle, training of the vines was not required for T3 (Ethephon) and T4 (Paclobutrazol) applied salad cucumber plants since they reported significantly shorter vine lengths. Thus, time and labour were not utilized for training these plants. However, T3(Ethephon) recorded the significantly lowest yield parameters. Consequently, T4 (Paclobutrazol) can be suggested to shorten the vine length and simultaneously to achieve yield comparable to the conventional methods.

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