Malaysian Applied Biology (2023) 52(2): 13-20
https://doi.org/10.55230/mabjournal.v52i2.2648

Research Article

Enhanced Growth of Chili (*Capsicum annuum* L.) by Silicon Nutrient Application in Fertigation System

Suhaizan Lob[1,2]*, Nur Syakirah Sa'ad[1], Nurul Faziha Ibrahim[1,2], Norhidayah Che Soh[1], Ramisah Mohd Shah[1] and Muhammad Safwan Hafiz Zaudin[1]

1. Faculty of Fisheries and Food Science, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia
2. Institute of Marine Biotechnology, Universiti Malaysia Terengganu, 21030, Kuala Nerus, Terengganu, Malaysia

Corresponding author: suhaizanlob@umt.edu.my

ABSTRACT

Silicon (Si) is one of the most abundant elements naturally available in the soil. This element performs an essential function in improving plant growth. This present study was carried out to evaluate the impact of Si nutrient application on the growth performance of chili (*Capsicum annuum* L.). Chili plant grown using a fertigation system was subjected to manual application of a silicon nutrient solution in varying concentrations (0 ppm, 108 ppm, 180 ppm, & 360 ppm) via root application. Each treatment was replicated five times, with five plants in each replicate, and all plants were grown in a shade house. The growth performance parameters measured were the number of leaves, stem diameter, plant height, plant biomass (dry weight), and Si accumulation in the stem, leave, and chili fruit. Results showed that Si nutrient application significantly affected the growth performances of chili plants. Application of T3 (360 ppm Si nutrient) was able to produce the highest stem diameter (8.92 mm), fresh weight (129.63 g), dry weight (67.23 g), as well as Si accumulation in stem (54 ppm), and chili fruit (24 ppm). On the other hand, applications with T2 (180 ppm Si nutrient) also demonstrated the highest plant height (20.98 cm), number of leave (27), and Si accumulation in leave (87 ppm). In conclusion, the application of silicon nutrients has the potential to enhance plant growth in numerous crops, making it a beneficial supplement to traditional agricultural practices.

Key words: Abiotic stress, biomass, growth performance, root application, silicon accumulation

Article History
Accepted: 20 April 2023
First version online: 30 June 2023

Cite This Article:
Lob, S., Sa'ad, N.S., Ibrahim, N.F., Che Soh, N., Mohd Shah, R. & Zaudin, M.S.H. 2023. Enhanced growth of chili (*Capsicum annuum* L.) by silicon nutrient application in fertigation system. Malaysian Applied Biology, 52(2): 13-20. https://doi.org/10.55230/mabjournal.v52i2.2648

INTRODUCTION

Silicon (Si) is the second most abundant element in the Earth's crust after oxygen, comprising approximately 28.8% of its mass and found in the form of silicon dioxide (SiO_2), commonly known as silica (Xu *et al*., 2022). Silicon performs an essential function in increasing the tolerance towards heavy metals and improves plant growth and yield, especially in stress conditions (Fauteux *et al*., 2005; Yan *et al*., 2018). Ma & Yamaji (2006) reported that the presence of Si in the leaves tissue leads to a decrease in the rate of transpiration from the cuticle and will increase the resistance to radiation, lodging, high and low temperature, UV, and drought stress (Tayade *et al*., 2022). In addition, the deposition of Si under the cuticle contributed to the toughness and strength of the cell wall of the plants (Ma & Yamaji, 2008). Silicon is taken up by plant roots in uncharged molecule form, known as soluble monocyclic acids (H_4O_4Si) (Ma & Yamaji, 2006). Plants can simply absorb and digest the Si in the form of monocyclic acids. It can be absorbed from the roots through passive uptake and transported to other parts required by plants via the process called transpiration (Datnoff *et al*., 2007).

In cultivation, water and fertilizers are the two most crucial inputs and their effective management is significant for higher productivity and sustaining environmental quality. The fertigation system is the modern cultivation method using soilless media which has proven to improve the growth and yield of many high-cash crops including chili (Mohd *et al*., 2016). Fertigation allows the application of the right amounts of plant nutrients equally to the wetted root volume zone (Hu *et al*., 2021; Kapoor *et al*., 2022). The use of fertigation technology is crucial in improving the growth and yield of chili besides increasing the income of farmers (Mohd *et al*., 2016). This is because, in a fertigation system, both fertilization and irrigation occur simultaneously and directly to the plant's root area. This cultivation system has been very useful for chili farmers. The benefit of Si application as a foliar spray on chili planted in a hydroponic system has been well-documented in previous studies (Sukkaew *et al*., 2016; Magaña-López *et al*., 2022). The study conducted by Sukkaew *et al*. (2016) revealed that the application of Si fertilizer at a rate of 2 g L^{-1} resulted in the highest plant growth and total silicon accumulation in plants. This finding was further supported by Magaña-López *et al*. (2022) recent study, which reported an increase in seedling length of up to eight times with Si application. However, the ability of chili plants to absorb Si nutrient through root application, especially in fertigation systems are still limited. Thus, to fill the gap, this study has been designed to investigate the benefit of combining a fertigation system and Si application in chili cultivation. The optimum Si concentration in enhancing chili plant growth was also evaluated.

MATERIALS AND METHODS

Seedling preparation

In this experiment, chili plants were cultivated using a fertigation system and were conducted in Bukit Kor, Marang, Terengganu. Two shade houses were fitted with a fertigation system and covered with nets to prevent insect or pest infestation. Chilli variety Kulai was obtained from Bumi Agro Enterprise at Kuala Terengganu. Chili seeds were soaked in varying concentrations of Si nutrient solution overnight, as prepared below. For the control group, chili seeds were only soaked in sterile distilled water (SDW). After soaking, the treated seeds from varying Si nutrient concentrations including the control group, were placed between two layers of tissue paper that were wetted with the corresponding Si nutrient solution concentration. The seeds were left to germinate for approximately 4 - 7 days. Once germinated, the seed was transferred into a germination tray filled with moist peat moss. The germination trays were placed under the shade house to avoid direct sunlight on the new emerging seedling. All seedlings were allowed to grow until 3-4 true leave before transplanting into the shade house. Seedlings were watered daily.

Silicon nutrient preparation and application of chili seedling

In this experiment, chili seedlings were supplied with fertilizer AB using a fertigation system, while varying concentrations of Si nutrients were applied to the roots of the plants. The Si nutrient in the form of Silicic acid (H_4O_4Si: 72%) used in this study was obtained from Siben Agriculture Company, Taiwan. The Si nutrient was prepared in four different concentrations and labeled as Treatment 0 (T0): control with 0 ppm of Si, Treatment 1 (T1): 108 ppm of Si nutrient, Treatment 2 (T2); 180 ppm of Si nutrient, and Treatment 3 (T3); 360 ppm of Si nutrient. The Si concentration prepared in this study was modified from Jayawardan *et al*. (2014). The Si stock solution was diluted with SDW to get the desired concentration and freshly prepared on the day of application to avoid crystallization. The experimental design used in this study was a randomized complete block design (RCBD), where each treatment was replicated five times, with five plants in each replicate.

Chilli seedlings in the germination tray were supplied with 1 mL of varying concentrations of Si nutrient prepared above every week. After transplanting into the fertigation system, Si nutrients continued to supply but with a higher volume of 40 mL to each plant according to the respective concentration every week.

Data collection

Growth performance determination

In this experiment, non-destructive growth parameters namely stem diameter, plant height, and the number of leaves were assessed (Gallegos-Cedillo *et al*., 2021). All the assessments were done fortnightly. The diameter of the stem (mm) was measured in the middle stem by using a carbon fiber composite digital caliper. The height of the plant (cm) was measured starting from the ground until the plant shoot by using a measuring tape. The number of leaves was counted manually starting from the new shoot. The last parameter measured for growth performance was Absolute Growth Rate (AGR). AGR is the rate of increase in growth variable at time 't'. To measure AGR, the differential coefficient of the growth variable concerning time 't' was calculated. In this study, three growth variables as described above were calculated by using the following equation (Hunt *et al*., 2003):

$$AGR = \frac{P_2 - P_1}{T_2 - T_1}$$

where, P_1 and P_2 refer to the growth variable at the time T_1 and T_2, respectively. AGR is expressed in cm/week and number/week.

The dry weight was measured after drying all harvested plant materials in an oven at 65 °C for 72 h recorded by using a digital balance.

The dry digestion method was used to prepare the plant samples (stem, leave, & fruit) for Si content determination using inductively coupled plasma optical emission spectrometry (ICP-OES). A total of 1 g of sample was dried in a furnace at 500 °C for 8 h. The dried sample was then treated with 2 mL of HCl (37% v/v) until it was evaporated. A total of 10 mL of HNO_3 (20% v/v) was added to the samples, and the mixture was heated slowly in a water bath for 1 h at 70 °C to dissolve the residue. The mixture was transferred into a 100 mL volumetric flask and made up to the volume before being filtered through Whatman No. 2 filter paper. The resulting filtrate was then ready to be analyzed using ICP-OES. Blanks were prepared in the same way as the sample, but the sample was omitted.

Statistical data analysis

The results were analyzed for statistical significance at a significance level of $P \leq 0.05$ using ANOVA in SPSS statistical software (version 20.0 for Windows). Tukey's test was subsequently used for pairwise comparisons of the mean values.

RESULTS AND DISCUSSION

The average stem diameter of chili plants after 19 weeks is presented in Figure 1A. There was a significant effect

($P \leq 0.05$) of Si concentration on the stem diameter. All the plants treated with Si were significantly different from the control. The greatest stem diameter showed by treatment T3 (8.92 mm), followed by T2 (8.23 mm), T1 (8.05 mm), and T0 (5.96 mm). Therefore, the highest Si concentration leads to an increased diameter of the stem due to an increase in the experimental period. Moreover, the development of stem diameter by applying Si concentration was better than the control plant (T0) as shown in week 19. Si content in the stem could help in strengthens the cell walls of the chili plant and help the plant to build stronger stems. A greenhouse study by Magaña-López *et al*. (2022) has also found that the application of Si has improved seedling performance through the induction of plant defense indicators and improvement in the physiological functions during cultivation that leads to better growth and tolerance to abiotic stress. In separate studies, other researchers have reported that Si application contributed to the hardness of the stem of rock melon plant to support fruits weight Isbell (2021), and also acts as a plant defense mechanism (Epstein, 2009). Xylem and phloem play a vital role in the translocation of water and nutrients in the plant system (Lucas *et al*., 2013). Related to the current study, the Si treatment might increase the stem diameter and contribute to improving plant growth due to the transport of water and nutrients from the root through the stem and finally spread to the whole plant parts (Hosseini *et al*., 2012).

Figure 1B showed the average chili plant height from week 1 to week 19 after transplanting. There was a significant effect ($P \leq 0.05$) of Si concentration on plant height. The result showed that the chili plant height treated with Si was significantly higher than the control plant. The highest plant height was observed from plants treated with T2 (20.98 cm), followed by T1 (18.26 cm), T3 (17.00 cm), and T0 (11.81 cm). Starting from week 13, the height of chili plants in treatment T2 increased faster than other treatments and control plants. Because of the supply of Si in plants, the increase in plant height could be due to the stem elongation process. Balakhnina & Borkowska (2013), and Epstein (2009), in separate studies, reported that Si could deposit in the cell wall and thus strengthens the wall structure of the plants. Besides, the previous work by Yoshida *et al*. (1962) stated that the deposition of Si in cell walls can enhance rice plant height by making the leaves and stems straighter.

Figure 1C showed the number of leave after 19 weeks. There was a significant effect ($P \leq 0.05$) of Si concentration on the number of leave. The treatments of T2 (27) had significantly the highest leave number compared to T0 (18), and other treatments, T1 (22) and T3 (21). Thus, the greatest number of leaves produced by plants will improve the growth and development of plants by conducting more photosynthesis. According to Tominaga & Kawamitsu (2015), Si supplements enable the plant to collect more sunlight as an energy source to improve the photosynthesis process. Si treatment can lead to a reduction in leaf senescence (Sarto *et al*., 2014), resulting in a higher total number of leaves at the end of the assessment period compared to the control group, and it is also important to note that the leaf count will continue to increase with an increase in the amount of time.

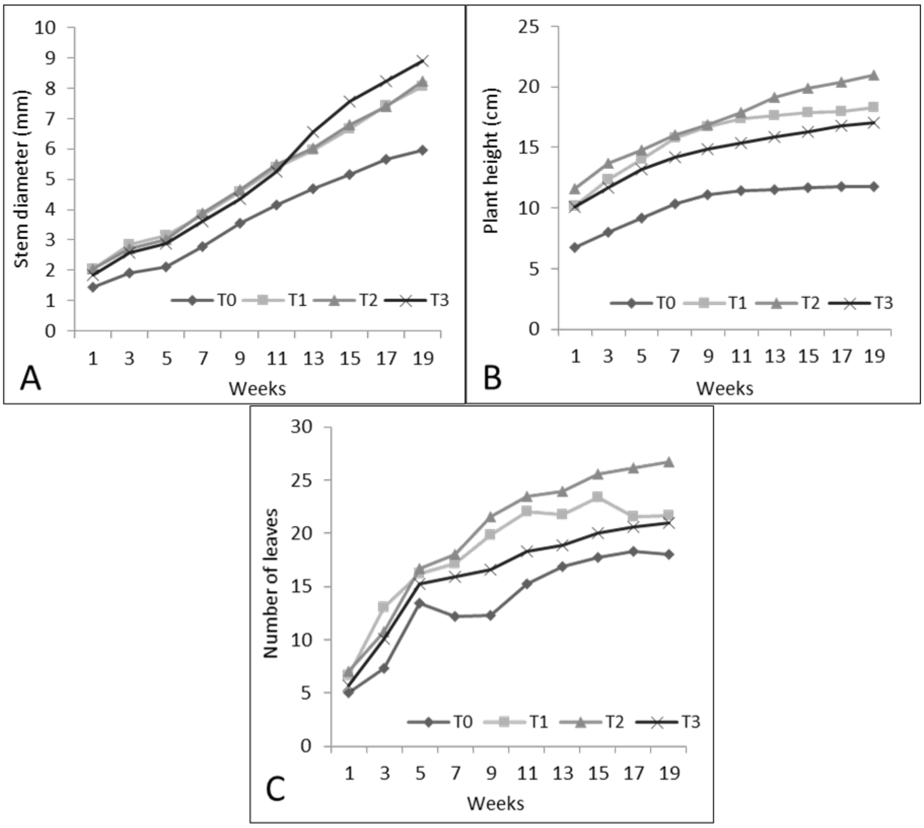

Fig. 1. Effects of varying concentrations of Silicon nutrient application on; A) stem diameter, B) plant height, and C) the number of leaves of chili. The means were significantly different at $P \leq 0.05$ using Tukey's test.

Table 1 presents the mean values of absolute growth rate (AGR) for chili plants from week 1 to week 19 after transplanting. As shown in the table, the application of Si had a significant effect on both stem diameter and plant height, as evidenced by their AGR. Specifically, the use of T3 resulted in the highest AGR (0.42 cm/week) for stem diameter, which was significantly different from the other treatments. For plant height, T2 showed a significantly higher AGR (0.52 cm/week) compared to T0 (0.28 cm/week), but no significance compared to T1 (0.45 cm/week) and T3 (0.39 cm/week).

A significant growth rate compared to the control shows that the use of Si is very effective in plant growth. This result is in line with research by Sudradjat *et al*. (2016), where silicon application significantly increased photosynthesis rate, leaf length, fruit thickness, and reduced unmarketable yield. Norhasanah (2012) also reported Si from rice husk ash applied as bio-fertilizer on pepper (*Capsicum frustescents* L.) increased the production of the crop. For the observation of the number of leaves, even though there was no significant difference exist, the application of T2 treatment still indicated the highest AGR (1.09 leaves/week) compared to the other treatments. Therefore, the application of Si, particularly between the range 180 - 360 ppm obtained from T2 and T3 treatments, showed positive results in promoting the growth of chili plants in terms of stem diameter, plant height, and a number of leaves.

Table 1. Means for Absolute Growth Rate (AGR) of chili plant from week 1 to week 19 after transplanting

Treatment	Mean		
	Number of leaves AGR (number/week)	Stem diameter AGR (cm/week)	Plant height AGR (cm/week)
T0 (0 ppm Silicon nutrient; control)	0.72±0.08	0.25±0.01[a]	0.28±0.04[a]
T1 (108 ppm Silicon nutrient)	0.83±0.11	0.32±0.02[b]	0.45±0.07[ab]
T2 (180 ppm Silicon nutrient)	1.09±0.14	0.34±0.01[b]	0.52±0.06[b]
T3 (360 ppm Silicon nutrient)	0.85±0.15	0.42±0.01[c]	0.39±0.05[ab]
ANOVA between treatments	ns	*	*

*Means followed by the same letter within each treatment are not significantly different (P≤0.05) using Tukey's test, ns: not significant

The biomass represented by the dry weight of chili plants treated with varying Si concentrations were presented in Figure 2. The result indicated that the significantly highest (P≤0.05) dry weight was obtained from T3 (67.23 g), but no significant differences were recorded in the dry weight of chili treated with T2 (39.03 g), T1 (28.84 g), and T0 (16.72 g). Costa *et al*. (2016) found that higher concentrations of supplied Si led to a proportional increase in fresh plant biomass. This effect may be attributed to improvements in various growth performance parameters, such as increased number of leaves, stem diameter, plant height, and fruit production, observed in plants treated with Si. A study conducted by Sarto *et al*. (2014) found that the higher plant biomass in crops by the usage of Si concentration was about the alteration of plant structures, delay in senescence, and augmentation in stiffness of tissue structure, improvement of lodging and increase of photosynthesis. Moreover, Galindo *et al*. (2021) elaborate that Si amendment application enhanced leaf chlorophyll index, agronomic efficiency, and N-uptake in cereal plants, thus increasing the grain yield.

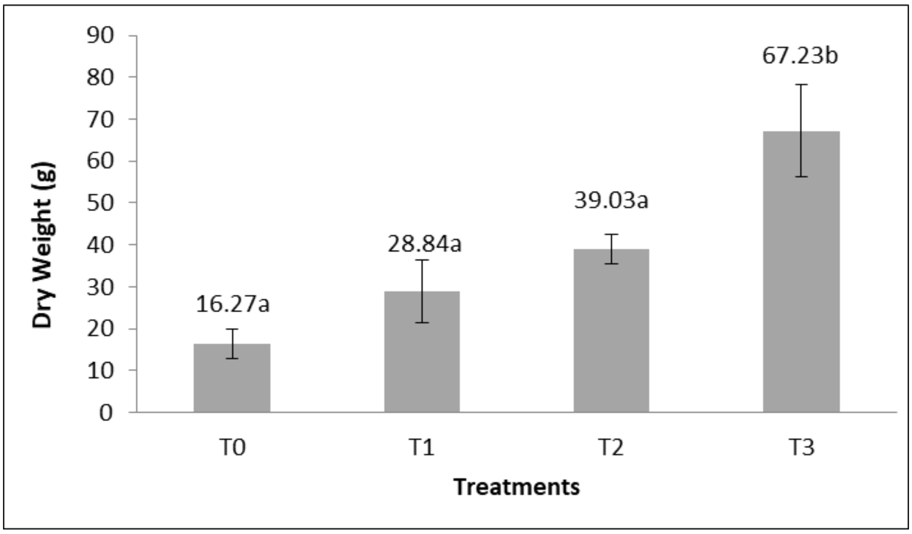

Fig. 2. Plant biomass represented in dry weight of chili plants treated with varying concentrations of Silicon nutrient assessed at week 19. Means followed by the same letter within each treatment are not significantly different (P≤0.05) using Tukey's test.

Silicon accumulation in chili stem and leaves are presented in Figure 3. The significant effect (P≤0.05) of different Si applications was observed in the Si content in the chili stem (Figure 3A). The highest accumulation of Si in the stem was found in the chili plant treated with T3 (54.26 ppm), followed by T2 (30 ppm), T1 (27 ppm), and

T0 (24 ppm). The lowest amount of Si deposition in the control plant could come from the fertilizer applied in the fertigation system. The increase of Si deposition in the stem could lead to an increase in the thickening of the cell wall and reduce crop stem lodging. Previous studies reported that the use of Si as a treatment could improve the integrity of the cell wall structure for crop organs besides increasing the mechanical strength of the stem (Zhang *et al*., 2015). A similar study by Rea *et al*. (2022) claimed that the concentration of Si was maximum in potato stem treated with a basal application of Si compared to foliar-applied Si and untreated control. The deposition of Si in plant tissue could enhance the strength of the stem by increasing the thickness of the culm wall, the size of the vascular bundles, and preventing lodging.

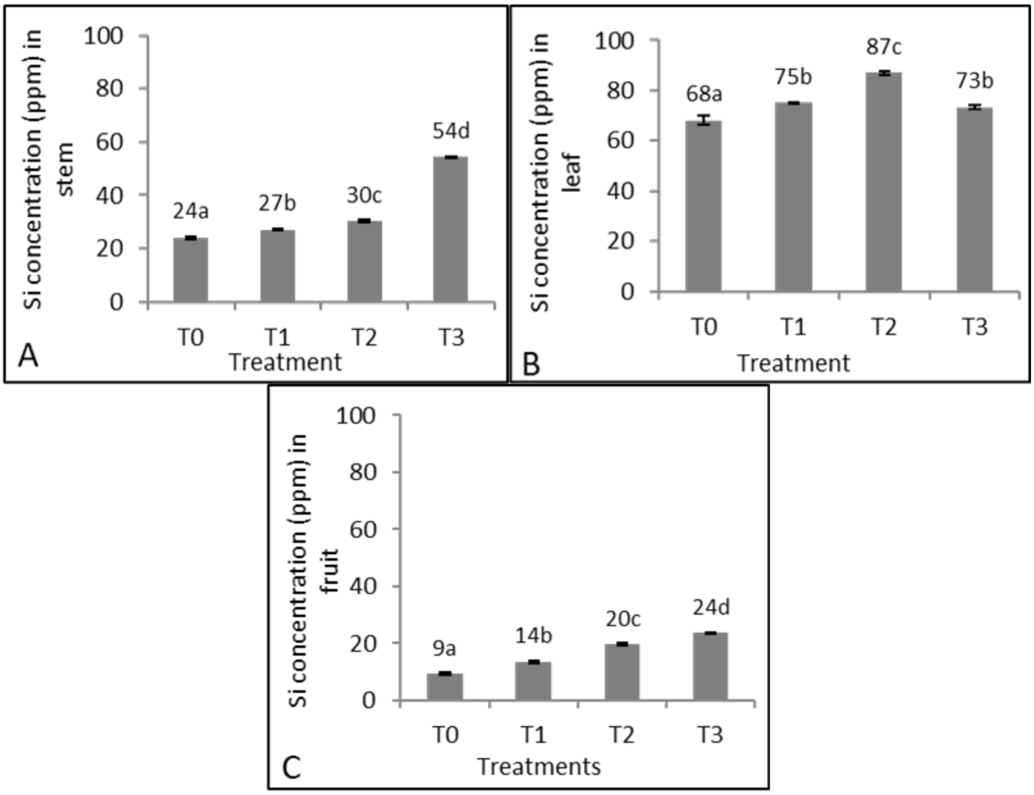

Fig. 3. Silicon content in chili plants treated with varying concentrations of Silicon nutrients after 19 weeks; A) Silicon content in chili stem, B) Silicon content in chili leaves, and C) Silicon content in chili fruit. Means followed by the same letter within each treatment are not significantly different ($P≤0.05$) using Tukey's test.

Silicon accumulation in leaves is presented in Figure 3B. The results showed that there was a significant effect ($P≤0.05$) of Si application on the Si content in the leaves of chili plants. The leaves treated with Si regardless of the concentration accumulated higher Si compared to the control plant (T0). Treatment with Si in T2 (87 ppm) accumulated the highest Si content, followed by T3 (73 ppm), T1 (75 ppm), and T0 (68 ppm). Accordingly, in the present study, the highest Si deposition in each plant part depends on the different Si treatments. This is because, the higher total amount of Si availability in soil solution will influence the Si uptake in plants (Rea *et al*., 2022). The concentration of Si in the xylem sap is higher than in the external solutions, regardless of the external Si supply (Liang *et al*. 2005). A supporting study by Nikolic *et al*. (2007) reported that more than half of the Si taken up by roots was translocated to the leaves in cucumber. Reports also indicated that leaves that contain higher Si deposition could maximize carbon allocation to plant growth as it alleviates the stress of plants (Cooke & Leishman, 2011). In addition, the role of Si deposition in leaves increases the structural component of the plants and also creates a hard-outer layer (Bélanger *et al*., 2003). Also, previous studies reported that leaves with higher deposition of Si contribute to increasing mechanical strength and outer layer to enhance protection for the plants (Ma & Takahashi, 2002; Epstein & Bloom, 2005).

Figure 3C showed that the Si accumulation in chili fruit was significantly different ($P≤0.05$) between each treatment. Based on the data, the accumulation of Si was highest in fruits treated with T3 (24 ppm), followed by T2 (20 ppm), T1 (14 ppm), and T0 (9 ppm). Although Si is abundantly present in the soil, it is an insoluble form which makes the absorption by the plant low. In this study, the application of Si directly to the plant's root helped the plant to uptake more Si during the growth cycle. The plant must take up an adequate amount of Si because it provides numerous benefits to plants. For example, it contributes to the structural strength of the plant and plays an active role in various physiological processes, such as regulating the uptake of other plant nutrients. According to Yan *et al*. (2018), the application of Si fertilizers has become a common practice nowadays to improve the productivity and sustainable production of many crops. In addition, the application of Si to the plant can increase biomass accumulation and improve yield in both monocotyledonous and dicotyledonous crops including vegetables and fruits which absorb and retain high Si in their organs (Liang *et al*., 2006; Zhang *et al*., 2007; Liu *et al*., 2011; Al-Wasfy, 2012; Babini *et al*., 2012; Al-Wasfy, 2013). Laane (2018) also reported that the Si uptake by a plant's xylem will travel through the transpiration stream and can be deposited in various parts of the plant, such as the leaf, stem, and fruit. Uptake of Si by plants has also been reported to decrease the level of diseases caused by bacteria, fungal pathogens, and physiological disorders (Kaluwa *et al*. 2010; Marais, 2015 Helaly *et al*., 2017). Besides that, the accumulation of Si in fruits not only helps to extend their shelf life but also increases the size of the fruits (Costa *et al*., 2015).

CONCLUSION

Based on this study, it is evident that the application of Si through root has a positive impact on the growth and development of chili plants. Si is translocated from the root to the leaves and spreads throughout the plant, which makes root application an effective method. The Si nutrient applied in various concentrations promoted better growth performance of the crops. These findings can be useful for farmers and researchers in optimizing the growth of chili plants, ultimately leading to increased crop yield and quality.

ACKNOWLEDGEMENTS

The authors would like to express their deepest gratitude to the Ministry of Higher Education for granting financial support through FRGS-RACER (RACER/1/2019/WAB01/UMT//2) and Universiti Malaysia Terengganu for supporting this research. Our heartfelt thanks also go to all the field and laboratory staff of the Faculty of Fisheries and Food Sciences, Universiti Malaysia Terengganu for their technical support.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Al-Wasfy, M.M. 2012. Trails for improving water use efficiency and improving productivity in Williams banana orchards by spraying salicylic acid. Minia Journal of Agriculture Research and Development, 32(2): 139-160.

Al-Wasfy, M.M. 2013. Response of Sakkoti date palms to foliar application of royal jelly, silicon and vitamins B. Journal of American Science, 9(5): 315-321.

Babini, E., Marconi, S., Cozzolino, S., Ritota, M., Taglienti, A., Sequi, P. & Valentini, M. 2012. Bio-available Silicon Fertilization Effects on Strawberry Shelf-Life. In: XXVIII International Horticultural Congress on Science and Horticulture for People (IHC2010): International Symposium on Postharvest Technology in the Global Market. International Society for Horticultural Science, pp. 815-818. https://doi.org/10.17660/ActaHortic.2012.934.107

Balakhnina, T. & A. Borkowska. 2013. Effects of silicon on plant resistance to environmental stresses: Review. International Agrophysics, 27: 225-232. https://doi.org/10.2478/v10247-012-0089-4

Bélanger, R.R., Benhamou, N. & Menzies, J.G. 2003. Cytological evidence of an active role of silicon in wheat resistance to powdery mildew (Blumeria graminis f. sp. tritici). Phytopathology, 93: 402-412. https://doi.org/10.1094/PHYTO.2003.93.4.402

Cooke, J. & Leishman, M.R. 2011. Silicon concentration and leaf longevity: Is silicon a player in the leaf dry mass spectrum? Functional Ecology, 25(6): 1181-1188. https://doi.org/10.1111/j.1365-2435.2011.01880.x

Costa, B.N., Dias, G.D., Costa, I.D., Assis, F.A., Silveira, F.A. & Pasqual, M. 2016. Effects of silicon on the growth and genetic stability of passion fruit. Acta Scientiarum. Agronomy, 38(4): 503. https://doi.org/10.4025/actasciagron.v38i4.30939

Costa, I.J.S., Pereira, M.C.T., Mizobutsi, G.P., Maia, V.M., Silva, J.F., Oliveira, J.A.A., Oliveira, M.B., Souza, V.N.R., Nietsche, S., Santos., E.F. & Korndorfer, G.H. 2015. Influence of silicon fertilization on 'Palmer' mango tree cultivation. Acta Horticulturae, 1075: 229-234. https://doi.org/10.17660/ActaHortic.2015.1075.26

Datnoff, L.E., Rodrigues, F.A. & Seebold, K.W. 2007. Silicon and plant disease. In: L.E. Datnoff, W.H. Elmer & D.M. Huber (Eds.). Mineral Nutrition and Plant Disease. APS Press, Saint Paul MN. pp. 233-246.

Epstein, E. & Bloom, A.J. 2005. Mineral Nutrition of Plants: Principles and Perspectives. 2nd Ed. Sinauer Associates, Sunderland.

Epstein, E. 2009. Silicon: its manifold roles in plants. Annals of Applied Biology, 155(2): 155-160. https://doi.org/10.1111/j.1744-7348.2009.00343.x

Fauteux, F., Rémus-Borel, W., Menzies, J.G. & Bélanger, R.R. 2005. Silicon and plant disease resistance against pathogenic fungi. FEMS Microbiology Letters, 249(1): 1-6. https://doi.org/10.1016/j.femsle.2005.06.034

Galindo, F.S., Pagliari, P.H., Rodrigues, W.L., Fernandes, G.C., Boleta, E.H.M., Santini, J.M. K., Jalal, A., Buzetti, S., Lavres, J. & Filho, M.C. M.T. 2021. Silicon amendment enhances agronomic efficiency of nitrogen fertilization in maize and wheat crops under tropical conditions. Plants, 10(7): 1329. https://doi.org/10.3390/plants10071329

Gallegos-Cedillo, V.M., Diánez, F., Nájera, C. & Santos, M. 2021. Plant agronomic features can predict quality and field performance: A bibliometric analysis. Agronomy, 11(11): 2305. https://doi.org/10.3390/agronomy11112305

Helaly, M.N., El-Hoseiny, H., El-Sheery, N.I., Rastogi, A. & Kalaji, H.M. 2017. Regulation and physiological role of silicon in alleviating drought stress of mango. Plant Physiology and Biochemistry, 118: 31-44. https://doi.org/10.1016/j.plaphy.2017.05.021

Hosseini, S.Z., Jelodar, N.B. & Bagheri, N. 2012. Study of silicon effects on plant growth and resistance to stem borer in rice. Communications in Soil Science and Plant Analysis, 43(21): 2744-2751. https://doi.org/10.1080/00103624.2012.719972

Hu, J., Gettel, G., Fan, Z., Lv, H., Zhao, Y., Yu, Y., Wang, J., Butterbach-Bahl, K., Li, G. & Lin, S. 2021. Drip fertigation promotes water and nitrogen use efficiency and yield stability through improved root growth for tomatoes in plastic greenhouse production. Agriculture, Ecosystems & Environment, 313: 107379. https://doi.org/10.1016/j.agee.2021.107379

Hunt, R., Thomas, B., Murphy, D.J. & Murray, D. 2003. Growth analysis, individual plants. Encyclopedia of applied plant sciences, 2: 579-588. https://doi.org/10.1016/B0-12-227050-9/00028-4

Isbell, H. 2021. Why your plants need more Silica. Maximum Yield. URL http://www.maximumyield.com/simply-silica/2/1077 (accessed 12.04.2022)

Jayawardana, H.A.R.K., Weerahewa, H.L.D. & Saparamadu, M.D.J.S. 2014. Effect of root or foliar application of soluble silicon on plant growth, fruit quality and anthracnose development of capsicum. Tropical Agricultural Research, 26 (1): 74 - 81. https://doi.org/10.4038/tar.v26i1.8073

Kaluwa, K., Bertling, I., Bower, J.P. & Tesfay, S.Z. 2010. Silicon application effects on 'Hass' avocado fruit physiology. South African Avocado Growers' Association Yearbook, 33: 44-47.

Kapoor, R., Kumar, A., Sandal, S.K., Sharma, A., Raina, R. & Thakur, K.S. 2022. Water and nutrient economy in vegetable crops through drip fertigation and mulching techniques: a review. Journal of Plant Nutrition, 45(15): 2389-2403. https://doi.org/10.1080/01904167.2022.2063742

Laane, H.M. 2018. The effects of foliar sprays with different silicon compounds. Plants, 7(2): 45. https://doi.org/10.3390/plants7020045

Liang, Y., Hua, H., Zhu, Y.G., Zhang, J., Cheng, C. & Römheld, V. 2006. Importance of plant species and external silicon concentration to active silicon uptake and transport. New Phytologist, 172(1): 63-72. https://doi.org/10.1111/j.1469-8137.2006.01797.x

Liang, Y.C., Sun, W.C., Si, J. & Romheld, V. 2005. Effects of foliar- and root-applied silicon on the enhancement of induced resistance to powdery mildew in Cucumis sativus. Plant Pathology, 54: 678 - 85. https://doi.org/10.1111/j.1365-3059.2005.01246.x

Liu, J.M., Han, C., Sheng, X.B., Liu, S.K. & Qi, X. 2011. Potassium-containing silicate fertilizer: its manufacturing technology and agronomic effects. In: 5th International Conference on Si Agriculture. pp. 13-18.

Lucas, W.J., Groover, A., Lichtenberger, R., Furuta, K., Yadav, S.R., Helariutta, Y., He. X-Q., Fukuda, H., Kang, J., Brady, S.M., Patrick, J.W., Sperry, J., Yoshida, A., López-Millán, A-F., Grusak, M.A. & Kachroo, P. 2013. The plant vascular system: Evolution, development and functions f. Journal of Integrative Plant Biology, 55(4): 294-388. https://doi.org/10.1111/jipb.12041

Ma, J.F. & Takahashi, E. 2002. Soil, fertilizer, and plant silicon research in Japan. Elsevier Science, Amsterdam, The Netherlands. 294 pp. https://doi.org/10.1016/B978-044451166-9/50009-9

Ma, J.F. and Yamaji, N. 2008. Functions and transport of silicon in plants. Cellular and Molecular Life Science, 65: 3049-3057. https://doi.org/10.1007/s00018-008-7580-x

Ma, J.F. & Yamaji, N. 2006. Silicon uptake and accumulation in higher plants. Trends in Plant Science, 11(8): 392-397. https://doi.org/10.1016/j.tplants.2006.06.007

Magaña-López, E., Palos-Barba, V., Zuverza-Mena, N., Vázquez-Hernández, M.C., White, J.C., Nava-Mendoza, R., Feregrino-Pérez, A.A., Torres-Pacheco, I. & Guevara-González, R.G. 2022. Nanostructured mesoporous silica materials induce hormesis on chili pepper (*Capsicum annuum* L.) under greenhouse conditions. Heliyon, 8(3): e09049. https://doi.org/10.1016/j.heliyon.2022.e09049

Marais, L.J. 2015. Efficacy of water-soluble silicon in managing Fusarium dry root rot of citrus. Acta Horticulturae, 1065: 993-1000. https://doi.org/10.17660/ActaHortic.2015.1065.124

Mohd, Y.S., Arshad, A.M., Muhammad, N.F. & Sidek, N.J. 2016. Potential and Viability of Chilli Cultivation using Fertigation Technology in Malaysia. International Journal of Innovation and Applied Studies, 17(4): 1114-1119.

Nikolic, M., Nikolic, N., Liang, Y., Kirkby, E.A. & Römheld, V. 2007. Germanium-68 as an adequate tracer for silicon transport in plants. Characterization of silicon uptake in different crop species. Plant Physiology, 143: 495-503. https://doi.org/10.1104/pp.106.090845

Norhasanah. 2012. Response growth and yield of chili (*Capsicum frutescens* Linn.) Cakra green variety to husk ash paddy on swampy marshland. Agroscientiea, 19(1): 1-5.

Rea, R.S., Islam, M.R., Rahman, M.M., Nath, B. & Mix, K. 2022. Growth, nutrient accumulation, and drought tolerance in crop plants with silicon application: A review. Sustainability, 14(8): 4525. https://doi.org/10.3390/su14084525

Sarto, M.V.M., do Carmo Lana, M., Rampim, L., Sérgio Rosset, J., Rocha Wobeto, J., Ecco, M., Bassegio, D. & Ferreira da Costa, P. 2014. Effect of silicate on nutrition and yield of wheat. African journal of Agricultural Research, 9(11): 956-962. https://doi.org/10.5897/AJAR2013.7617

Sudradjat, Afifah, F.J. & Eko, S. 2016. Studies on the effects of silicon and antitranspirant on chili pepper (Capsicum annuum L.) Growth And Yield. European Journal of Scientific Research, 137(1): 5-10.

Sukkaew, E., Amkha, S., Inboonchoy, T. & Mala, T. 2016. Utilization of silicon fertilizer application on pepper seedling production. Modern Applied Science, 10(11): 264-272. https://doi.org/10.5539/mas.v10n11p264

Tayade, R., Ghimire, A., Khan, W., Lay, L., Attipoe, J.Q. & Kim, Y. 2022. Silicon as a smart fertilizer for sustainability and crop improvement. Biomolecules, 12(8): 1027. https://doi.org/10.3390/biom12081027

Tominaga, J. & Kawamitsu, Y. 2015.Cuticle affects calculations of internal CO_2 in leaves closing their stomata. Plant and Cell Physiology, 56(10): 1900-1908. https://doi.org/10.1093/pcp/pcv109

Xu, J., Guo, L. & Liu, L. 2022. Exogenous silicon alleviates drought stress in maize by improving growth, photosynthetic and antioxidant metabolism. Environmental and Experimental Botany, 201: 104974. https://doi.org/10.1016/j.envexpbot.2022.104974

Yan, G.C., Nikolic, M., Ye, M.J., Xiao, Z.X. & Liang, Y.C. 2018. Silicon acquisition and accumulation in plant and its significance for agriculture. Journal of Integrative Agriculture, 17(10): 2138-2150. https://doi.org/10.1016/S2095-3119(18)62037-4

Yoshida, S., Ohnishi, Y. & Kitagishi, K. 1962. Chemical forms, mobility, and deposition in the rice plant. Soil Science and Plant Nutrition, 8: 107-113. https://doi.org/10.1080/00380768.1962.10430992

Zhang, K., Rossi, C., Tenailleau, C., Alphonse, P. & Chane-Ching, J. Y. 2007. Synthesis of large-area and aligned copper oxide nanowires from copper thin film on silicon substrate. Nanotechnology, 18(27): 275607. https://doi.org/10.1088/0957-4484/18/27/275607

Zhang, J., Zou, W., Li, Y., Feng, Y., Zhang, H., Wu, Z., Tu, Y., Wang, Y., Cai, X. & Peng, L. 2015. Silica distinctively affects cell wall features and lignocellulosic saccharification with large enhancement on biomass production in rice. Plant Science, 239: 84-91. https://doi.org/10.1016/j.plantsci.2015.07.014