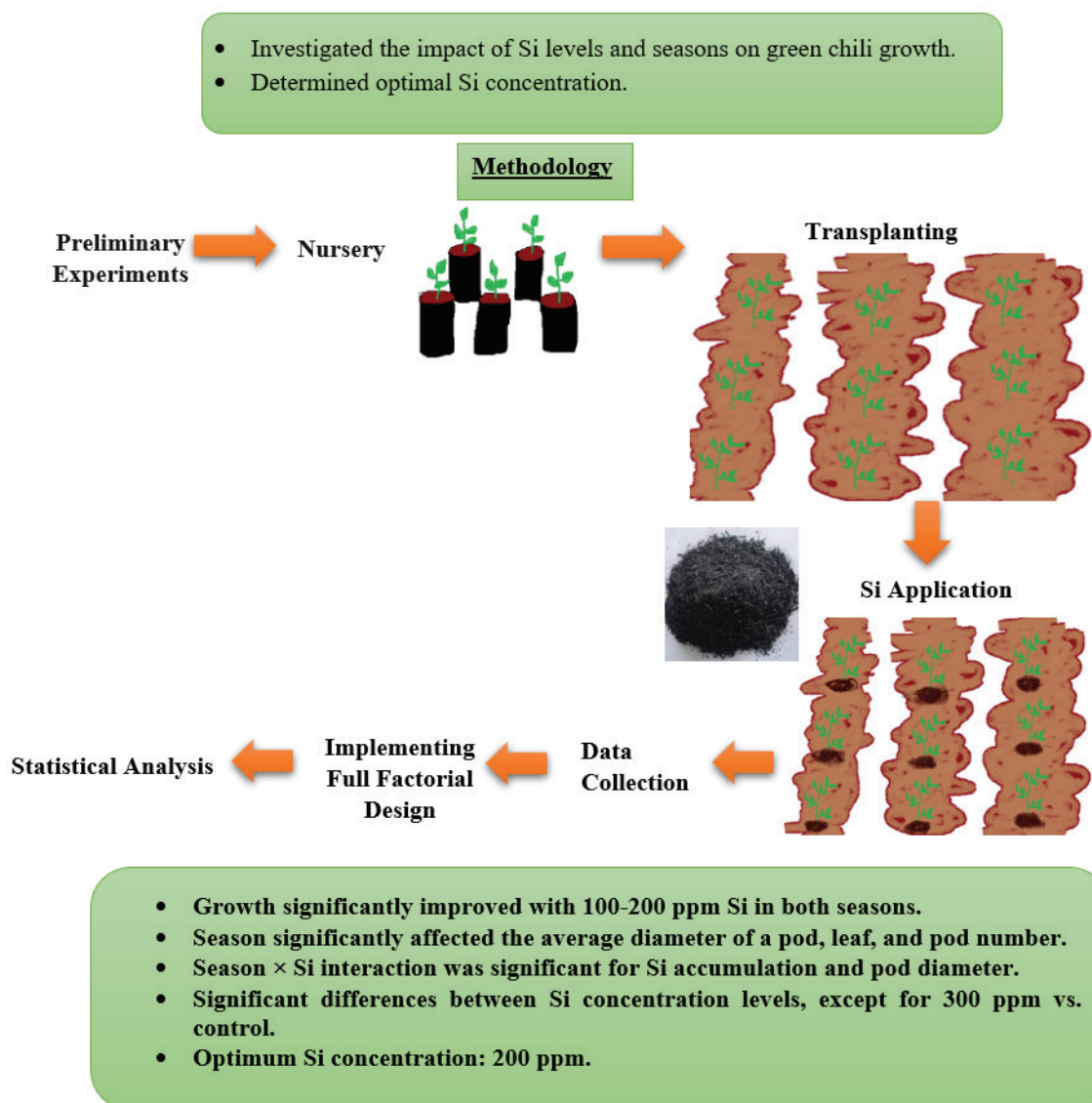


## RESEARCH ARTICLE

# Optimizing Soil-Applied Silicon Concentration for Enhanced Growth in Green Chili (*Capsicum annuum* L.): A Seasonal Analysis

S. P. Daundasekera, H. T. K. Abeyesundara\* and R. M. R. N. K. Ratnayake



## Highlights

- Silicon (Si) at 100–200 ppm significantly enhanced green chili growth in both seasons
- “Yala” season showed higher overall growth, while “Maha” season showed greater variability
- Significant season × Si interactions were observed for leaf Si content and pod diameter
- Optimal Si concentration (200 ppm) improved overall plant performance
- Higher Si concentration (300 ppm) resulted in reduced plant performance

RESEARCH ARTICLE

# Optimizing Soil-Applied Silicon Concentration for Enhanced Growth in Green Chili (*Capsicum annuum* L.): A Seasonal Analysis

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## Abstract

Green chili (*Capsicum annuum* L.) is a widely cultivated spice crop of high economic importance, playing a vital role in both global and Sri Lankan agriculture. Several factors influence the growth of green chili, and this study aimed to determine the optimal silicon (Si) concentration required to maximize its growth. The effects of two cultivation seasons (“Yala” and “Maha”) and different Si concentrations (0–300 ppm) were evaluated. Growth parameters assessed included leaf Si accumulation, plant height, number of leaves, number of pods per plant, average pod weight, pod diameter, and pod length. Univariate and multivariate statistical analyses were performed using a full factorial design with six replicates per treatment combination. The results revealed that both season and Si concentration had a significant impact on growth parameters. MANOVA results indicated that season, Si concentration, and their interaction had a significant overall effect on the combined set of growth traits. Univariate ANOVA further showed that Si concentration significantly affected all growth parameters, while season and the interaction effect influenced several traits. The optimal Si concentration was identified as 200 ppm, consistently producing the highest and most significant growth responses compared to other levels. The availability of Si in the soil solution, influenced by soil pH, was crucial for effective Si absorption. Therefore, considering soil pH is essential when determining the optimal Si content to promote plant growth. Overall, this study provides valuable insights into the interactions between seasonal variation, Si levels, and green chili growth, contributing to the development of improved cultivation strategies for enhanced yield and quality.

**Keywords:** Green chili; Growth parameters; Optimum Silicon concentration level; Seasonal impact

## INTRODUCTION

Green chili (*Capsicum annuum* L.) is a major commercial vegetable crop that is widely grown throughout the world’s tropical and subtropical regions (Brintha & Seran, 2012). This lucrative spice crop is cultivated throughout Sri Lanka and plays a vital role in the country’s agriculture. It is widely consumed and valued for its distinctive flavor and pungency, as well as its high content of vitamins A and C (Azlan et al., 2022) and the bioflavonoid rutin (Purseglove, 1968), which also makes it important to the pharmaceutical industry.

Sri Lanka’s tropical and subtropical climate supports extensive green chili cultivation, both in open fields and greenhouses. With an annual per capita consumption of 2.84 kg, the country produces only 7,500 metric tons of dried chili against a demand of 57,400 metric tons, relying

on substantial imports. Chili cultivation spans about 13,000 hectares, mainly during the “Maha” season, and significantly contributes to the economy and employment, particularly in the dry and intermediate zones (Lakpura™, n.d.). The availability of nutrients is crucial for optimal plant growth and productivity. Nutrient deficiencies, particularly during the early growth stages of chili (around one month after planting), can significantly reduce yield (Agustin et al., 2010). The application of silicon (Si) has shown numerous beneficial effects on plant growth and disease resistance (Siriwardhana et al., 2020). Although Si is not classified as an essential element for plant growth, it plays important roles in various physiological processes and enhances plant defense mechanisms (Fauteux et al., 2005; Ma & Yamaji, 2006). Increased Si uptake has been associated with improved plant growth, quality, yield, and resistance to certain bacterial and fungal pathogens (Ma

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& Yamaji, 2006). The use of Si derived from rice husk ash (RHA) as a biofertilizer in chili pepper (*Capsicum frutescens* Linn.) has been reported to enhance crop yield (Norhasanah, 2012). However, higher soil pH levels can reduce the availability of soluble Si for plant uptake, and excessive Si application may therefore have adverse effects (Yongchao et al., 2015; Haynes, 2019).

Siriwardhana et al. (2020) reported that pre-harvest soil application of silicon (Si) in the form of rice husk ash (RHA) improved the post-harvest quality of green chili by enhancing leaf Si accumulation, reducing weight loss, and increasing resistance to natural diseases. Lob et al. (2023) investigated the effects of different Si concentrations on chili growth using a fertigation system with root-applied Si solutions. Growth parameters measured included stem diameter, plant height, number of leaves, biomass, and Si accumulation in plant parts. The highest stem diameter, fresh and dry weights, and Si accumulation in stems and fruits were observed at 360 ppm, while 180 ppm resulted in the greatest plant height, number of leaves, and leaf Si accumulation, highlighting the positive effects of Si on chili growth. Nascimento et al. (2023) examined the impact of soil-applied silica-based fertilizer (ASF) on yield, mineral nutrition, chlorophyll fluorescence, and postharvest quality of two table grape cultivars. Treatments of 175 and 350 kg ha<sup>-1</sup> ASF improved fruit yield, bunch weight, berry number, berry firmness, total soluble solids, titratable acidity, nutrient accumulation, and photosynthetic efficiency compared to the control, demonstrating that soil-applied Si enhances grape yield and quality.

This study aimed to investigate the effects of two distinct cultivation seasons, “Yala” (May to August) and “Maha” (September to March), and varying silicon (Si) concentrations (0–300 ppm) on the growth of green chili. The growth parameters evaluated included leaf Si accumulation (% of dry weight), plant height (cm), number of leaves, number of pods per plant, average pod weight (g), pod diameter (cm), and pod length (cm). The study assessed the individual effects of season and Si concentration, as well as their interaction, on these parameters. The ultimate goal was to identify the optimal Si concentration that promotes the best growth conditions for green chili. These findings are expected to provide valuable insights for improving cultivation strategies and enhancing the yield and quality of this economically important crop.

## MATERIAL AND METHODS

### Experimental setup and Si application

Preliminary experiments were carried out in the research field to investigate the effects of applying different concentrations of Si on green chili plants. The concentrations of Si used were 100 ppm, 200 ppm, 300 ppm, and 0 ppm (the control). For these trials, Si was sourced in the form of potassium silicate (K<sub>2</sub>SiO<sub>3</sub>). Subsequently, the study took place in two separate districts in Sri Lanka: Anuradhapura and Matale. Data collection occurred during two distinct harvesting seasons known as “Yala” and “Maha.” The primary objective was to evaluate the growth parameters of the green chili cultivated in these specific farm fields.

Prior to planting them on the farm, the *C. annuum* cultivar MI-2 plants were first nurtured in the nursery for a duration of 20 days. Preliminary analysis of the Si level in RHA had shown that the soluble Si level ranges from 9-11%. In this research, it was assumed that the RHA had 10% soluble Si content. Consequently, the required amount of RHA in grams was calculated to achieve specific Si concentration levels (100 ppm, 200 ppm, and 300 ppm). The initial application of Si in the soil occurred 10 days after the plants were established on the farm, followed by weekly Si applications for 28 days.

### Data collection and variables recorded

The first set of data was collected seven days after the cessation of Si application. The dataset considered for analysis was obtained 70 days after the discontinuation of the Si application, which corresponded to the harvesting stage of the green chili. At the harvesting stage, various variables were recorded, including the accumulation of soluble Si in leaves (% dry weight), plant height (cm), number of leaves, number of pods per plant, average weight of a pod (g), average diameter of a pod (cm), and average length of a pod (cm). Each data point represented the average measurement of ten green chili plants. In total, 480 green chili plants were considered, resulting in 48 data points for inclusion in this study.

### Experimental design

The experiment followed a full factorial design. The experimental treatments included two factors. The first factor is the Season, labeled as Season 1 and Season 2 (formerly known as “Yala” and “Maha”), and the second factor is the Si concentration levels, labeled as A, B, C, and D (corresponding to 100 ppm, 200 ppm, 300 ppm, and 0 ppm, respectively). Each treatment combination was replicated six times, yielding 48 experimental units in total.

### Statistical data analysis

A detailed descriptive and inferential statistical analysis was conducted to assess the data. Graphical and numerical summaries were used to identify the behavior in the initial stage. Multivariate analysis of variance (MANOVA) was then performed in order to determine how the two independent variables, Seasons and Si concentration levels, and their interaction, have an impact on the seven dependent variables.

Subsequently, univariate statistical tests were employed to look at how each independent variable affected each dependent variable on its own. In order to achieve this, separate ANOVA tests were carried out for each dependent variable within the specified model. This allowed for a more in-depth examination of the effect of the independent variable on dependent variables.

To analyze the data further, pairwise comparisons of mean values for varying Si concentration levels were carried out using the Tukey HSD. This led to identifying important variations among particular treatment levels. Finally, interval plots were obtained for each growth parameter across Si concentration levels to determine the optimum Si concentration that would yield the best growth quality

parameters. This allowed for a visual comparison of each level to the others, revealing the most beneficial Si concentration for optimizing growth quality.

The R statistical software was used to examine the results with statistical significance at a 5% alpha.

## RESULTS AND DISCUSSION

### Descriptive analysis

Table 1 summarises the descriptive statistics of growth parameters for different Si levels in the “Yala” season, while the summary of the Descriptive Statistics of Growth Parameters for Different Si Levels in the “Maha” Season is tabulated in Table 2. During both “Yala” and “Maha” Seasons, the application of 200 ppm Si consistently demonstrated the highest values across multiple growth parameters, suggesting it may represent the optimal Si concentration for green chili growth (Tables 1 and 2). This shows that the optimum Si concentration for maximum green chili growth in both seasons may be 200 ppm. This supports the main objective of the study, confirming that

moderate Si application can effectively promote green chili growth. This finding also aligns with findings reported by Lob et al. (2023), who discovered that moderate Si concentrations (180 ppm) led to a greater plant height, a higher number of leaves, and increased Si accumulation in the leaves of green chili plants, compared with higher Si concentrations (360 ppm).

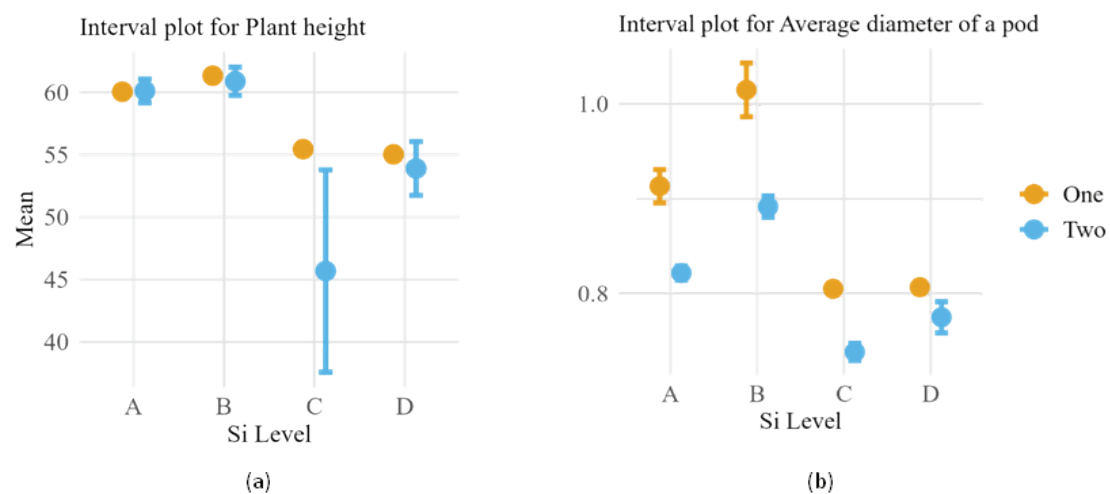
To provide a comprehensive comparison of the growth parameters for green chili plants under varying (Si) concentrations and across the two seasons, Figures 1 to 4 present interval plots. Each figure illustrates the impact of different Si levels on plant development in these seasonal conditions, highlighting the relationships between Si concentration and the specific growth parameters. The respective interval plot from Figure 1 to Figure 4 presents the interactions between Si levels and plant height, average pod length, average pod weight, number of leaves, number of pods, Si accumulation in leaves, and average pod diameter. The figures clearly show the effect of different Si levels and seasonal variations on the plant development.

**Table 1:** Summary of the Descriptive Statistics of Growth Parameters for Different Si Levels in “Yala” Season

| Si Level (ppm) | Growth Parameter                         | Mean $\pm$ Standard Deviation | Minimum | Maximum | Median |
|----------------|------------------------------------------|-------------------------------|---------|---------|--------|
| 100            | Si accumulation in leaves (% dry weight) | 1.79 $\pm$ 0.01               | 1.79    | 1.80    | 1.79   |
| 200            |                                          | 1.84 $\pm$ 0.03               | 1.81    | 1.87    | 1.85   |
| 300            |                                          | 1.71 $\pm$ 0.04               | 1.67    | 1.79    | 1.71   |
| 0              |                                          | 1.73 $\pm$ 0.03               | 1.70    | 1.76    | 1.73   |
| 100            | Plant height (cm)                        | 60.05 $\pm$ 0.79              | 58.8    | 61.1    | 60.15  |
| 200            |                                          | 61.33 $\pm$ 0.58              | 60.9    | 62.4    | 61.15  |
| 300            |                                          | 55.45 $\pm$ 1.04              | 54.1    | 57.1    | 55.30  |
| 0              |                                          | 55.03 $\pm$ 0.76              | 54.1    | 56.3    | 55.00  |
| 100            | Number of leaves per plant               | 122.50 $\pm$ 6.09             | 117     | 134     | 120.5  |
| 200            |                                          | 131.16 $\pm$ 4.79             | 126     | 139     | 130.5  |
| 300            |                                          | 96.66 $\pm$ 3.83              | 90      | 101     | 97.5   |
| 0              |                                          | 93.83 $\pm$ 3.82              | 89      | 98      | 94.0   |
| 100            | Number of pods per plant                 | 22.83 $\pm$ 3.60              | 19      | 27      | 23.0   |
| 200            |                                          | 26.33 $\pm$ 3.44              | 22      | 30      | 27.0   |
| 300            |                                          | 18.50 $\pm$ 2.07              | 15      | 20      | 19.5   |
| 0              |                                          | 17.00 $\pm$ 2.53              | 13      | 20      | 17.0   |
| 100            | Average weight of a pod (g)              | 5.067 $\pm$ 0.29              | 4.7     | 5.5     | 5.10   |
| 200            |                                          | 5.62 $\pm$ 0.64               | 4.9     | 6.5     | 5.65   |
| 300            |                                          | 4.62 $\pm$ 0.19               | 4.3     | 4.8     | 4.65   |
| 0              |                                          | 4.52 $\pm$ 0.38               | 4.0     | 5.0     | 4.50   |
| 100            | Average diameter of a pod (cm)           | 0.91 $\pm$ 0.04               | 0.88    | 1.00    | 0.90   |
| 200            |                                          | 1.02 $\pm$ 0.07               | 0.93    | 1.10    | 0.99   |
| 300            |                                          | 0.81 $\pm$ 0.02               | 0.79    | 0.83    | 0.81   |
| 0              |                                          | 0.81 $\pm$ 0.02               | 0.79    | 0.83    | 0.81   |
| 100            | Average length of a pod (cm)             | 4.67 $\pm$ 0.2                | 4.5     | 5.0     | 4.60   |
| 200            |                                          | 4.98 $\pm$ 0.19               | 4.8     | 5.3     | 4.95   |
| 300            |                                          | 4.40 $\pm$ 0.13               | 4.3     | 4.6     | 4.35   |
| 0              |                                          | 4.47 $\pm$ 0.14               | 4.3     | 4.6     | 4.50   |

**Table 2:** Summary of the Descriptive Statistics of Growth Parameters for Different Si Levels in “Maha” Season

| Si Level (ppm) | Growth Parameter                         | Mean $\pm$ Standard Deviation | Minimum | Maximum | Median |
|----------------|------------------------------------------|-------------------------------|---------|---------|--------|
| 100            | Si accumulation in leaves (% dry weight) | $1.85 \pm 0.05$               | 1.81    | 1.91    | 1.83   |
| 200            |                                          | $1.85 \pm 0.05$               | 1.79    | 1.89    | 1.88   |
| 300            |                                          | $1.71 \pm 0.04$               | 1.66    | 1.74    | 1.72   |
| 0              |                                          | $1.7 \pm 0.01$                | 1.69    | 1.70    | 1.70   |
| 100            | Plant height (cm)                        | $60.12 \pm 2.31$              | 57.9    | 62.8    | 60.00  |
| 200            |                                          | $60.88 \pm 2.77$              | 58.0    | 64.1    | 61.00  |
| 300            |                                          | $45.68 \pm 19.85$             | 6.2     | 59.1    | 50.05  |
| 0              |                                          | $53.9 \pm 5.28$               | 48.9    | 59.2    | 53.70  |
| 100            | Number of leaves per plant               | $131.33 \pm 7.12$             | 120     | 141     | 131.5  |
| 200            |                                          | $140.33 \pm 5.20$             | 134     | 149     | 139.5  |
| 300            |                                          | $114.17 \pm 4.67$             | 108     | 121     | 113.0  |
| 0              |                                          | $109.33 \pm 9.27$             | 101     | 123     | 105.0  |
| 100            | Number of pods per plant                 | $17.5 \pm 2.43$               | 14      | 21      | 17.5   |
| 200            |                                          | $20.17 \pm 0.98$              | 19      | 21      | 20.5   |
| 300            |                                          | $14.83 \pm 1.94$              | 12      | 17      | 14.5   |
| 0              |                                          | $14.33 \pm 2.34$              | 11      | 18      | 14.5   |
| 100            | Average weight of a pod (g)              | $5.03 \pm 0.18$               | 4.9     | 5.3     | 4.95   |
| 200            |                                          | $5.52 \pm 0.19$               | 5.3     | 5.8     | 5.45   |
| 300            |                                          | $4.48 \pm 0.15$               | 4.3     | 4.6     | 4.55   |
| 0              |                                          | $4.62 \pm 0.15$               | 4.4     | 4.8     | 4.65   |
| 100            | Average diameter of a pod (cm)           | $0.82 \pm 0.02$               | 0.80    | 0.85    | 0.82   |
| 200            |                                          | $0.89 \pm 0.03$               | 0.86    | 0.93    | 0.9    |
| 300            |                                          | $0.74 \pm 0.02$               | 0.70    | 0.76    | 0.74   |
| 0              |                                          | $0.78 \pm 0.04$               | 0.70    | 0.81    | 0.79   |
| 100            | Average length of a pod (cm)             | $4.58 \pm 0.08$               | 4.5     | 4.7     | 4.60   |
| 200            |                                          | $5.18 \pm 0.26$               | 4.9     | 5.5     | 5.20   |
| 300            |                                          | $4.43 \pm 0.12$               | 4.2     | 4.5     | 4.50   |
| 0              |                                          | $4.38 \pm 0.13$               | 4.2     | 4.5     | 4.40   |

**Figure 1:** Interval plot showing the mean and standard deviation of **a)** plant height across different Si concentrations, **b)** pod diameter across different treatments (A = 100 ppm, B = 200 ppm, C = 300 ppm, D = 0 ppm) for two seasons (One = Season 1, Two = Season 2).

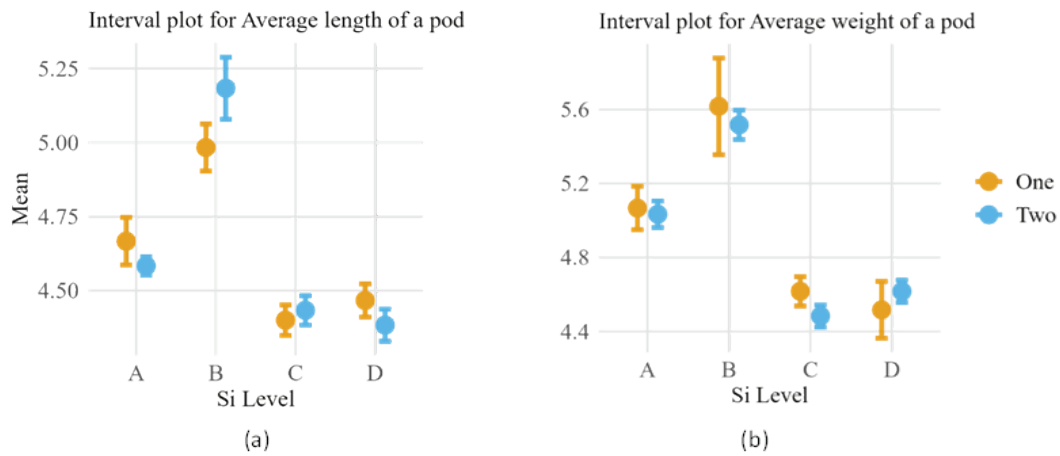


**Figure 2:** Interval plot showing the mean and standard deviation of **a)** average pod length across different treatments, **b)** average pod weight across different treatments (A = 100 ppm, B = 200 ppm, C = 300 ppm, D = 0 ppm) for two seasons (One = Season 1, Two = Season 2).

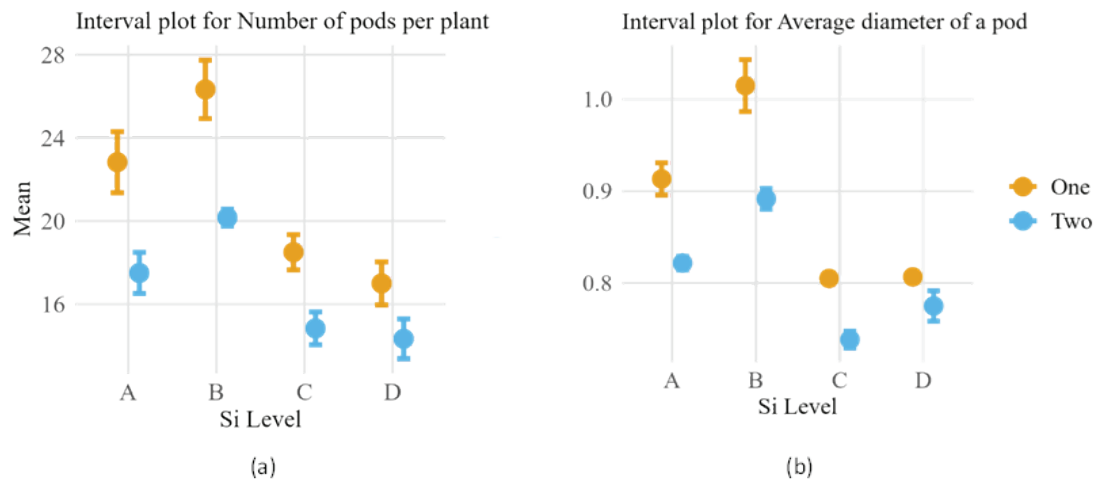


**Figure 3:** Interval plot showing the mean and standard deviation of **a)** number of pods per plant across different treatments, **b)** diameter of pods across different treatments (A = 100 ppm, B = 200 ppm, C = 300 ppm, D = 0 ppm) for two seasons (One = Season 1, Two = Season 2).

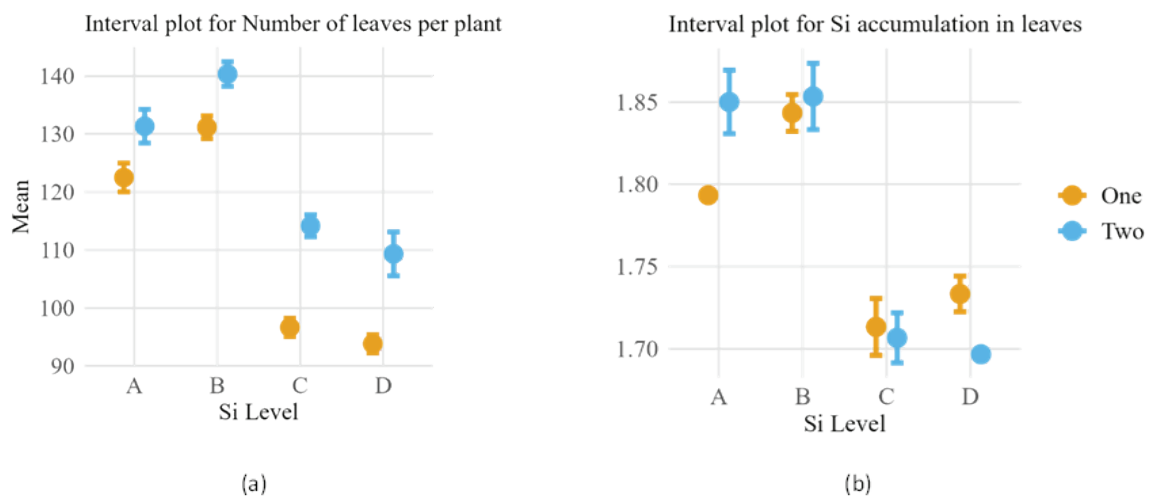


**Figure 4:** Interval plot showing the mean and standard deviation of **a)** number of leaves per plant, **b)** Si accumulation in leaves across different treatments (A = 100 ppm, B = 200 ppm, C = 300 ppm, D = 0 ppm) for two seasons (One = Season 1, Two = Season 2)

According to the above figures, generally, Season 1 has a higher mean for the majority of dependent variables, indicating greater growth performance. Season 2, on the other hand, has a larger standard deviation, indicating greater fluctuation in growth during this season. For each dependent variable, different Si levels exhibit diverse growth patterns. Season 1 generally shows stronger development circumstances, whilst Season 2 has more unpredictability in growth. Since Chili plants are highly sensitive to environmental factors, seasonal/temporal variations can significantly influence the overall productivity of this crop (Nugroho et al., 2025). Understanding these patterns can aid in the optimization of agricultural methods and the improvement of crop development and yields under various Si concentrations and seasonal conditions.

### Interpreting MANOVA using Wilks' lambda

A two-way MANOVA was conducted to evaluate the effects of Season, Si Level (SiL), and their interaction on the combined set of growth parameters. The Wilks' Lambda test statistic revealed highly significant multivariate effects of Season (Wilks' lambda = 0.14589,  $p$ -value < 0.001) and SiL (Wilks' lambda = 0.01817,  $p$ -value < 0.001). This indicates that the combined growth parameters differ significantly between the two seasons and the four Si levels. A significant Season  $\times$  SiL interaction was also observed (Wilks' lambda = 0.39908,  $p$ -value = 0.034), indicating that the combined effect of Si concentration levels on the growth parameters is not consistent across the two seasons. These results indicate that both main effects and their interaction significantly affect the multivariate profile of growth parameters.

### Executing univariate test statistics

The significance of the independent variables (Season and Si Concentration level) on the individual response variables was then examined by performing separate two-way ANOVA tests. The  $p$ -values shown in Table 3 are used to determine if each independent variable and the interaction of independent variables have a significant impact on the specific response variable.

The results demonstrate that the main effect of season was significant for some of the growth parameters but not for others. Season had no significant effect on Si accumulation in leaves, plant height, the average weight, and the average length of a pod ( $p$ -value > 0.05 for each), whereas it had a significant effect on the number of leaves per plant, the number of pods per plant, and the average diameter of a

pod ( $p$ -value < 0.001). In contrast, the main effect of SiL was highly significant for all growth parameters ( $p$ -value < 0.001). The Season  $\times$  SiL interaction effect was significant for only two growth parameters: Si accumulation in leaves and the average diameter of a pod ( $p$ -value < 0.05 for each). This suggests that the effect of SiL for these two growth parameters depends on the season. That is, the magnitude or direction of SiL's effect on these growth parameters was not consistent between the two seasons. For all the other growth parameters, the interaction effect was not significant, meaning that SiL had a consistent influence on them across the two seasons. To further explore these differences, post hoc pairwise comparisons were conducted to identify which Si concentration levels had significantly different effects on the growth parameters.

### Post hoc pairwise comparisons

Pairwise comparisons of treatment means were carried out using Tukey's HSD method. The corresponding mean differences in Table 5 confirm these observations. Compared to the 0 ppm control, plants treated with 200 ppm Si showed an increase of 0.13% (of dry weight) in Si accumulation in leaves, increased plant height by 6.64 cm, produced 34.17 more leaves per plant, 7.58 more pods per plant, pods that were 1.00 grams heavier, a 0.66 cm greater pod length, and a 0.16 cm greater pod diameter. Similarly, a Si level of 100 ppm increased 25.33 leaves per plant, 0.11% (of dry weight) more Si accumulation in leaves, 4.50 additional pods per plant, pods that were 0.48 grams heavier, and increases of 0.08 cm in pod diameter, 5.62 cm in plant height, and 0.20 cm in pod length. This confirms that the Si application enhances green chili growth as compared to the control, consistent with Sudradjat et al. (2016). These increments reflect the effect of applying moderate SiLs on growth parameters, which are consistent with a previous study conducted by Trejo-Téllez et al. (2020), which indicated that the pepper plants that are subjected to moderate Si levels (60 - 125 mg/L) revealed increased stem diameter, leaf area, biomass, soluble sugar, and chlorophyll content than those exposed to higher doses (250 mg/L).

Tables 4 and 5 indicate that a silicon level (SiL) of 300 ppm did not improve growth parameters compared to moderate levels (100 ppm and 200 ppm). None of the growth parameters at 300 ppm showed significant differences from the 0 ppm control. Both 100 ppm and 200 ppm outperformed 300 ppm across all traits. Moreover, the differences between 200 ppm and 300 ppm were greater

**Table 3:** P-values associated with separate ANOVA tests

| Growth Parameters          | Season (p-value) | SiL (p-value) | Season: SiL (p-value) |
|----------------------------|------------------|---------------|-----------------------|
| Si accumulation in leaves  | 0.558            | < 0.001       | 0.015                 |
| Plant height               | 0.194            | 0.003         | 0.326                 |
| Number of leaves per plant | < 0.001          | < 0.001       | 0.183                 |
| Number of pods per plant   | < 0.001          | < 0.001       | 0.335                 |
| Average weight of a pod    | 0.647            | < 0.001       | 0.806                 |
| Average diameter of a pod  | < 0.001          | < 0.001       | 0.025                 |
| Average length of a pod    | 0.726            | < 0.001       | 0.128                 |

than those between 100 ppm and 300 ppm, suggesting that 200 ppm was more effective than 100 ppm. These findings imply that a high Si level of 300 ppm may hinder plant growth rather than improve it.

Overall, our results imply that moderate Si levels ( 100 ppm, 200 ppm ) maximise the growth and yield, and high Si levels ( 300 ppm ) were suboptimal, and had no advantage over the control 0 ppm level.

### Interval Plots of Growth Parameters Under Varying Silicon Levels

Interval plots of growth parameters under varying Si levels are depicted in Figures 5 and 6. Figure 5 displays plant growth and development parameters (plant height, number of leaves per plant, number of pods per plant), whereas Figure 6 displays reproductive and yield parameters (number of pods per plant, average weight of a pod, average diameter of a pod, average length of a pod)

**Table 4:** Tukey-Adjusted p-values for Pairwise Comparisons of Silicon Concentration Levels Across Growth Parameters

| Si Levels (ppm) | Si in leaves | Plant height | # leaves per plant | # pods per plant | Average weight of a pod | Average diameter of a pod | Average length of a pod |
|-----------------|--------------|--------------|--------------------|------------------|-------------------------|---------------------------|-------------------------|
| 100 vs 0        | 0.000        | 0.261        | 0.000              | 0.001            | 0.003                   | 0.000                     | 0.024                   |
| 200 vs 0        | 0.000        | 0.141        | 0.000              | 0.000            | 0.000                   | 0.000                     | 0.000                   |
| 300 vs 0        | 0.984        | 0.573        | 0.389              | 0.770            | 0.999                   | 0.567                     | 0.999                   |
| 200 vs 100      | 0.240        | 0.986        | 0.004              | 0.025            | 0.001                   | 0.000                     | 0.000                   |
| 300 vs 100      | 0.000        | 0.016        | 0.000              | 0.009            | 0.002                   | 0.000                     | 0.017                   |
| 300 vs 200      | 0.000        | 0.006        | 0.000              | 0.000            | 0.000                   | 0.000                     | 0.000                   |

**Table 5:** Tukey HSD Mean Differences Between Silicon Levels for Growth Parameters

| Si Levels (ppm) | Si in leaves | Plant height | # leaves per plant | # pods per plant | Average weight of a pod | Average diameter of a pod | Average length of a pod |
|-----------------|--------------|--------------|--------------------|------------------|-------------------------|---------------------------|-------------------------|
| 100 vs 0        | 0.11         | 5.62         | 25.33              | 4.50             | 0.48                    | 0.08                      | 0.20                    |
| 200 vs 0        | 0.13         | 6.64         | 34.17              | 7.58             | 1.00                    | 0.16                      | 0.66                    |
| 300 vs 0        | -0.01        | -3.90        | 3.83               | 1.00             | -0.02                   | -0.02                     | -0.01                   |
| 200 vs 100      | 0.03         | 1.03         | 8.83               | 3.08             | 0.52                    | 0.09                      | 0.46                    |
| 300 vs 100      | -0.11        | -9.52        | -21.50             | -3.50            | -0.50                   | -0.10                     | -0.21                   |
| 300 vs 200      | -0.14        | -10.54       | -30.33             | -6.58            | -1.02                   | -0.18                     | -0.67                   |

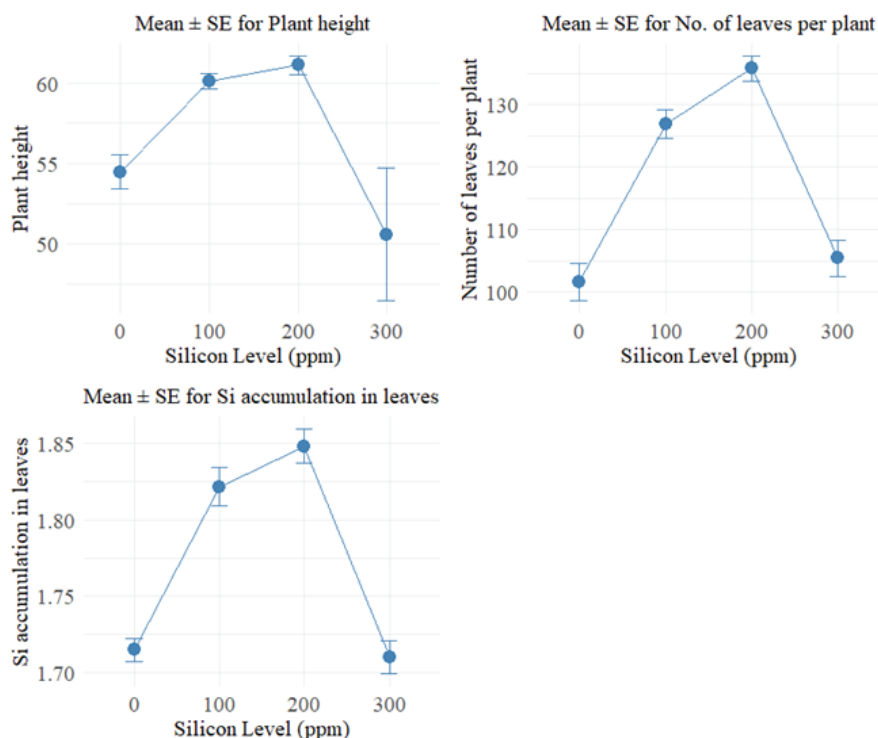


**Figure 5:** Interval plots of the mean and standard error for silicon accumulation in plant growth and development parameters for different silicon treatments

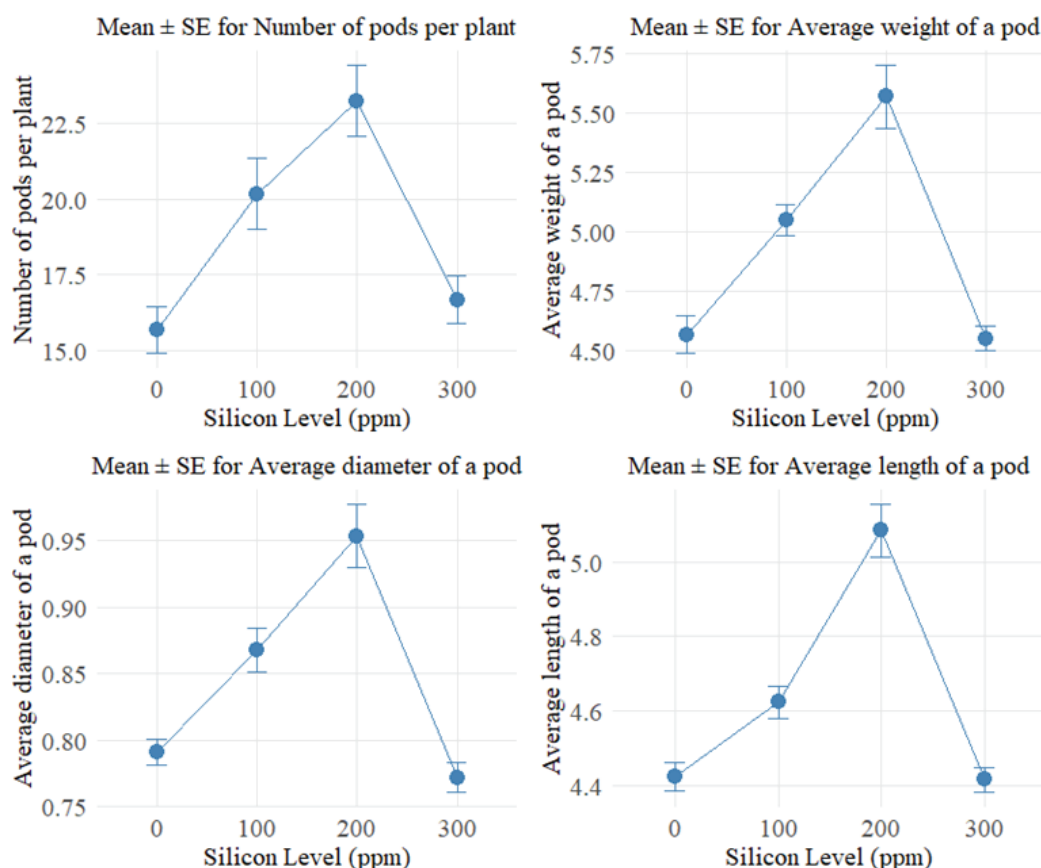


**Figure 6:** Interval plots of the mean and standard error for reproductive and yield parameters across different silicon treatments

To determine the optimal SiL for green chili plant growth, we obtained interval plots illustrating the means and standard errors ( $\pm$ SE) for each growth parameter across each SiL: 0 ppm (control), 100 ppm, 200 ppm, and 300 ppm. These plots show how each growth parameter responds to increasing Si Levels and allow us to compare the impacts of treatments alongside the variability.

According to the figures 5 and 6, all parameters showcased a consistent trend. A SiL of 200 ppm resulted in the highest mean values for all the growth parameters, suggesting that a SiL of 200 ppm would be the optimal concentration for promoting growth.

In contrast, a concentration of 300 ppm resulted in reduced performance equivalent to or even lower than 0 ppm (control) in some growth parameters: silicon accumulation in leaves, plant height, average weight of a pod, average diameter of a pod, and average length of a pod. This reduction is likely due to decreased bioavailability at the increased soil pH resulting from excessive Si application, since at elevated pH levels, Si becomes increasingly adsorbed to soil minerals, decreasing plant-available Si (Haynes, 2014). This suggests that extremely high Si concentrations may hinder the growth rather than improve it. These results are consistent with a previous study conducted by Trejo-Téllez et al. (2020), which indicated that the pepper plants that are subjected to higher Si levels (250 mg/L) have decreased root length and stem diameter.

Overall, the growth responses of chili plants to varying Si levels also appear to differ slightly depending on the cultivar evaluated. This study presents clear evidence that silicon treatment, specifically at 200 ppm, significantly improves the growth and yield of green chili plants (*Capsicum annuum* cultivar MI-2) under field conditions, and this concentration level should be prioritized in cultivation strategies.

## CONCLUSIONS

This study demonstrates that moderate levels of soil-applied Si concentrations, particularly 200 ppm, significantly enhanced all growth parameters measured in green chili across both seasons under field conditions. MANOVA results indicate that both SiL and season, as well as their interaction, significantly affected the overall set of growth parameters. This suggests that both individual factors and their interaction influence the combined growth parameters. The ANOVA results indicated that SiL had a significant effect on all individual growth parameters, while the seasonal fluctuation significantly affected only certain growth parameters, including number of leaves, number of pods, and average pod diameter, with the “Yala” season often producing higher averages, whereas the “Maha” season exhibited greater variability. 300 ppm SiL showed no benefit over the 0 ppm (control) level, and sometimes even reduced growth. This could be attributed to the increase in soil pH level, which reduces the availability of

soluble Si for absorption. Therefore, excessive application of Si can be counterproductive. Overall, 200 ppm SiL is identified as the optimal SiL for enhancing the growth parameters of green chili. These findings offer practical guidance for future farming methods aimed at getting the maximum yield and quality.

## DECLARATION OF CONFLICT OF INTEREST

The authors confirm that they have no conflicts of interest to declare.

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## AUTHOR CONTRIBUTION

Conceptualization, Methodology, Supervision: **H.T.K.A.**; Data collection, Experimental work: **R.M.R.N.K.R.**; Statistical analysis, Data interpretation: **S.P.D.**; Writing the first draft: **S.P.D.**; Manuscript editing and reviewing: **S.P.D., H.T.K.A., R.M.R.N.K.R.**; Project administration: **H.T.K.A.**

## DATA AVAILABILITY STATEMENT

The datasets generated during the current study are not publicly available due to regulations of the National Institute of Post-Harvest Management, Anuradhapura, Sri Lanka; however, they are available from the corresponding author upon reasonable request.

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