Silicon (2023) 15:3515–3523
https://doi.org/10.1007/s12633-022-02279-1

ORIGINAL PAPER

Effect of Silicon Fertilization on Eggplant Growth and Insect Population Dynamics

Hafiz Faiq Bakhat[1] · Najma Bibi[1] · Hafiz Mohkum Hammad[2] · Ghulam Mustafa Shah[1] · Sunaina Abbas[1] · Hafiz Muhammad Rafique[3] · Abdel Kareem Sayed Hussein Mohamed[4] · Muhammad Mudassar Maqbool[5]

Received: 14 July 2022 / Accepted: 16 December 2022 / Published online: 4 January 2023

Abstract

Silicon (Si) is the second most abundant element known for its beneficial effects on plants especially facing biotic and abiotic stresses. This study was conducted to determine the effects of Si on the growth, uptake of mineral nutrients and insect population dynamics on eggplant. Plants were treated with Si through various sources viz., sodium silicate in soil (56 mg kg soil^{-1}), sodium silicate sprayed on foliage (2 mM Si solution), rice husk and rice husks biochar in soil (equivalent to 56 mg kg soil^{-1}). The results showed that Si improved plant physical growth attributes i.e., rice husk and rice husk biochar treatments increased plant height 24.60% and 16.95%, respectively, compared to Control treatment. Silicon in the root medium improved the phosphorus uptake (2.86 vs 3.21 mg g^{-1} in control vs rice husk biochar treated plants) and Si concentration (1.33 vs 6.53 mg g^{-1} in control vs Soil Na_2SiO_3 treated plants) in leaves. Conversely, presence of Si in root medium decreased Ca concentration in plant leaves and the corresponding values were 1.43 vs 0.31 mg g^{-1} in control vs rice husk treated plants. Compared to control, Si-treated plants were less infested with insects i.e., jassid, whitefly and borer population was reduced in the range of 33.68–60.62%, 19.23–50.92% and 16.03–75.64%, respectively. Hence, it is concluded that rice husk and rice husk biocahr also could be used as a Si source to decreases the extent of insect infestation on eggplant and it could be a sustainable alternative strategy to reduce insecticide use.

Keywords Eggplant · Silicon sources · Insect infestation · Mineral nutrients

1 Introduction

Plant growth and development rely on several mineral nutrient elements available in the soil. These elements can be divided into three main categories; beneficial, essential and toxic [6]. Beneficial elements are necessary for some particular plant species which are grown under specific growing conditions. However, essential elements play a critical role in plant growth and are crucial for specific functions of plant development. While on the other hand toxic elements disrupt metabolic processes that badly effect the growth of plants.

Silicon (Si), a second most abundant element, is generally regarded as a non-essential beneficial element for the crops [47]. Even though the element is abundant in nature, however, the majority of the element is bound in alumino-silicates and silicates minerals. The silicate minerals undergo chemical, biological, and physical weathering to release Si into the soil solution and form silicic acid (H_4SiO_4) that can be readily taken up by the plant roots [16]. Due to its ubiquitous nature and abundance in soil, Si is available to every plant, hence, each soil grown plant contains appreciable amounts of Si [16]. However, the beneficial effects of Si are more prominent in plants having the inherent ability to accumulate higher Si contents and therefore these species are better to withstand against biotic and abiotic stresses

✉ Hafiz Faiq Bakhat
faiqsiddique@ciitvehari.edu.pk

1 Department of Environmental Sciences, COMSATS University Islamabad, Vehari-Campus, Vehari 61100, Pakistan

2 Department of Agronomy, Muhammad Nawaz Shareef University of Agriculture, Multan, Pakistan

3 Soil and Water Testing Laboratory Muzaffargarh, Muzaffargarh, Pakistan

4 Department of Botany and Microbiology, Faculty of Science, Al-Azhar University, Assiut BranchAssiut 71524, Egypt

5 Department of Agronomy, Faculty of Agricultural Sciences, Ghazi University, DG Khan, Pakistan

[30]. Previously, it's been revealed that plants fertilized with Si had better growth and higher Si contents compared to non-Si-fertilized plants [4, 5].

Burning of crop residues is posing a serious threat to environmental quality. Rice crop residues burning after harvest has widely been associated with smog and poor air quality. In addition, rice processing yield rice husk (RH) which is rich in many essential and beneficial nutrients like Si. Utilization of the rice husk for crop production is testified and improved the chemical and physical properties of soil [31, 43, 54, 55]. Rice husk and its biochar inhibit the pathogens attack to plant roots and shoots [23, 48]. For instance, the processed rice crop residues into biochar amend soil chemical properties [52] thus has an advantage over inorganic Si fertilizers by improving soil fertility. Silicon fed plants have physical defense mechanisms such as toughness, spines and/or hairs on leaf which helps the plant against herbivory [22, 32]. Such plants have silica layer on leaf sheath that provide physical defense in deterring herbivory [19, 38]. These impacts are so pronounced that insect feeding behavior changes and changes in insects feeding preferences has been observed [37].

Kvedaras et al. [27] observed that insects fed on Si-rich diet had reduced digestive efficiency. Scientists have summarized Si-mediated inhibited herbivory mechanisms into two categories by which the element helps the plants to resist the insect attack. Silicon reduces the herbivore damages by physical mechanisms i.e. increased leaves abrasiveness results in deterioration of the insect's mandibles [32, 56] and Si also decrease the digestibility of the foods in the insect digestive tract [36]. Several reasons that could contribute to the feeding efficiency of herbivores include; i) silica as a physical barrier prevent access to nitrogen-containing metabolites within the leaves [56]; ii) mastication of leaf material could be reduced by the herbivore, thus enough nitrogen does not release from the plant tissues; iii) or the physical damages to the digestive tracts of herbivores due to silica. Therefore, digestive efficiency would be reduced as reported for the *Tuta absoluta* reared on the Si treated tomato plant has decreased larval and pupal survival. Similarly, morphological changes in the insect midgut due to higher Si concentration in plants have been observed [14]. Further, studies revealed that Si also inhibits the damages caused by insects pests such as brown plant hopper, stem borers, green leaf hopper and spider mites (non-insect pests) [34, 56]. The Si-mediated insects inhibition was due to the mechanical barrier due to its integration in the cell wall of leaves [26, 36]. The other mechanism by which Si deters the insect herbivory is linked with induced defenses due to production of some chemicals that affect the insect preference [4].

Eggplant (*Solanum melongena* L.), is considered among the top ten vegetables produced all over the world. It is a good source of nutrients, minerals, vitamins, bodybuilding factors, antioxidants, proteins, and dietary fibers [39]. Insect attack is a major limiting factor in the production and protection of vegetables. The predominant insects of brinjal plants are; jassid, whitefly, shoot borer, fruit fly, thrips, red spider mites, aphids, leafhopper, spotted beetles, blister beetle and leaf roller. These insects can cause huge crop losses by chewing the fruits and stems, sucking out plant juices and rolling the leaves. Due to the growing demand and need for food, the plants are heavily sprayed with various insecticides and chemicals to avoid the crop damages. It is estimated that during the whole growing season (180 days) eggplant is sprayed up to 72 times with different insecticides [42]. One of the potential solutions to reduce the intense use of insecticides in eggplant crop is to use some natural elements or compounds like Si as alternative to avoid their harmful effects on the human and environment [28]. Therefore, the present study was conducted to; 1) compare the various sources including agricultural waste and mode of Si treatment for their effectiveness to deter the insects and preventing the damages imposed by the insects. 2. In addition, the study was aimed to demonstrate the beneficial effects of Si on the growth and mineral nutrient composition of eggplant.

2 Materials and Methods

An outdoor experiment was conducted at COMSATS University Islamabad, Pakistan, Vehari Campus (30.0318° N, 72.3145° E) during Rabi season of 2015–2016. The soil used in this experiment was taken from the experimental site of COMSATS University Islamabad Vehari Campus and sieved before filling the pots to remove the boulders and roots. The soil used in this experiment was non-saline (1.76 dS m^{-1}), alkaline in nature (pH 8.0) with low in phosphorus (5.7 mg kg^{-1}) and organic matter contents (0.4%). The rice husk biochar was prepared using rice straw following the method by Bakhat et al. [5]. Pots (filled with 9 kg soil) were arranged in a completely randomized order with the following treatments; Control (0 mM Si), 2 mM Na_2SiO_3 solution foliar application, 56 mg Si kg^{-1} Soil as Na_2SiO_3 (Na_2SiO_3 Assay 57% (SiO2); CAS Number 1344-09-8; DAEJUNG, Korea) in soil and rice husk containing 0.52% Si (56 mg Si kg^{-1} Soil) and rice husk biochar containing 0.8% Si (56 mg Si kg^{-1} Soil). The soil application of various treatment was done at the start of the experiment while foliar application was repeated fortnightly. At the start of experiment, basal dose of potassium (0.42 g kg^{-1}) and phosphorus (0.63 g kg^{-1}) was supplied to the plants while nitrogen (0.84 g $kg^{-1)}$ was given in three split doses. Plant growth attributes like number of branches, leaves, and flower per plant were documented before harvesting. The experimental plants were in open field condition and exposed to natural infestation. Plant after harvest were washed with deionized water and blotted with filter paper and proceeded for the biomass determination.

For chemical analysis, plant samples were washed with double distilled water to remove the adherent materials and blotted dry. The plants were oven dried (70 °C), crushed and dry ashed to examine the mineral nutrients in plant tissues for example phosphorus (P), calcium (Ca), sodium (Na) and potassium (K) [59]. For this purpose, the dried ground sample (0.5 g) of shoot was placed in porcelain crucible and in a conventional resistance muffle furnace samples were ashed for minimum 4 h. Hot distilled water (10 mL) and 2 mL of 20% HCl were added to dissolve the ash. The filtrate was used to calculate the value of P on spectrophotometer (Perkin Elmer Lambda 25 UV VIS Spectrometer) using Vanadate molybdate method while Na, K, and Ca values were determined on flame photometer (BWB XP 5) [9]. The eggplant shoot powder was filled in the Teflon tubes for Si measurement and then dissolved in 5 mL (3:2 ratio) of HNO_3 (65%) and H_2O_2 (30%) following the method mentioned by Zia et al. [61]. The acid digestate was heated with 20% NaOH (10 mL) on a hot plate for 1 h. The color method was used to determine the Si concentration in the filtrate while the color was established using 10% $(NH_4)_6Mo_7O_{24}$. The reductant used to establish the blue color contains Na_2SO_3, $NaHSO_3$, and 1-amino-2-naphthol-4-sulfonic acid [15] and absorbance was estimated at 600 nm at spectrophotometer (Perkin Elmer Lambda 25 UV VIS Spectrometer). Insect (cotton jassid (*Amrasca biguttula* Ishida 1912 (Hemiptera: Cicadellidae), brinjal shoot borer (*Leucinodes orbonalis* Guenée (Lepidoptera: Crambidae)), and whitefly (*Bemisia tabaci* (Hemiptera: Aleyrodidae) infestation was monitored on the shoots of eggplants. Jassid and whitefly (*Bemisia tabaci*) were observed during October to November. For whitefly and jassid data was collected on weekly basis while the attack of borer was monitored fortnightly. As insects become inactive in the early morning hours, therefore, scouting of insects was done during early hours on the bottom of three fully grown leaves.

2.1 Statistical Analysis

Statistical analysis of the mean values of chemical, physical and insect population dynamics was done by completely randomized ANOVA (Statistics 8.1). A two-way ANOVA for insect population was carried out for comparing the data of various treatments at various sampling dates. Standard errors of the means were calculated using MS-Office Excel 2013. Means were compared using Tukey test at $p < 0.05$.

3 Results

3.1 Effect of Si Fertilization on Plant Growth Attributes of Brinjal

Plants were supplied with Si showed significant differences in various plant growth parameters. Treatment without any Si amendment (Control) has the lowest biomass production (59.13 g/plant) as compared with the plants treated with different Si. Maximum biomass production was observed under rice husk treatment that was almost 50% higher than that of control treatment. There was no significant effect ($p < 0.05$) of different Si treatments on plant height. The plants treated with Si as foliar sprays produced the maximum number of leaves per plant (57 leaves per plant) and the number of branches per plant (10.75 branches per plant) i.e. almost 66% and 50% respectively, higher than the control treatment. On the other hand, at harvest maximum number of flower per plant were observed for rice husk treatment followed by $NaSiO_3$ as foliar application, $NaSiO_3$ soil and rice husk biochar. Minimum numbers of flowers were observed in the control (Table 1).

3.2 Effect of Si Fertilization on Insect Population Dynamics on Brinjal

There were significant differences between treatments regarding the number of insects that infested the brinjal. Jassid population observed on a weekly basis showed that control plants have significantly ($p < 0.05$) higher no. of jassid per leaf in comparison with other treatments (Table 2).

Table 1 Effect of various sources of silicon on plant physical growth attributes. Values are the means of four replicates ± (SE)

Treatments	Fresh weight (g/plant)	Plant height (cm)	Leaves/plant	Branches/plant	Flowers/plant
Control	59.13 ± 15.07 a	41.13 ± 0.97 b	34.63 ± 3.61 b	5.00 ± 0.68 b	1.63 ± 0.13 c
Na_2SiO_3 foliar	67.75 ± 11.81 a	45.38 ± 5.95 ab	57.75 ± 3.10 a	10.75 ± 0.88 a	5.88 ± 0.52 ab
Na_2SiO_3 soil	85.00 ± 23.54 a	39.25 ± 4.03 b	36.38 ± 3.24 b	5.75 ± 0.83 b	3.63 ± 0.85 abc
Rice husk	89.38 ± 18.69 a	51.25 ± 8.95 a	42.00 ± 2.86 b	7.50 ± 0.41 ab	6.50 ± 1.02 a
Rice husk biochar	80.63 ± 11.91 a	47.75 ± 5.95 a	34.38 ± 3.48 b	5.63 ± 1.03 b	3.25 ± 0.43 bc

Means with the same letter in a column are not significantly different from each other (p < 0.05, Tukey test)

Table 2 Effect of various sources of silicon on no. of jassid on *Solanum melongina* L. in rabi season of 2015–2016. Values are the means of four replicates ± (SE)

Treatment	Sampling Date					Mean
	21/10/2015	28/10/2015	4/11/2015	11/11/2015	18/11/2015	
Control	6.75 ± 0.48 a	10.00 ± 1.41 a	14.75 ± 1.25 a	10.50 ± 0.65 a	6.25 ± 0.48 a	9.65 ± 1.53 a
Na_2SiO_3 foliar	4.25 ± 0.25 b	5.50 ± 0.65 b	7.75 ± 0.48 b	7.75 ± 1.11 b	4.50 ± 0.65 b	5.95 ± 0.77 b
Na_2SiO_3 soil	3.75 ± 0.25 b	7.75 ± 0.63 ab	8.25 ± 0.48 b	8.25 ± 0.48 b	4.00 ± 0.41 bc	6.40 ± 1.04 b
Rice husk	3.00 ± 0.41 b	5.50 ± 0.65 b	4.25 ± 0.63 c	4.25 ± 0.63 c	2.00 ± 0.41 d	3.80 ± 0.60 b
Rice husk biochar	2.75 ± 0.63 b	7.25 ± 0.48 b	6.50 ± 0.29 b	6.50 ± 0.29 b	3.00 ± 0.41 cd	5.20 ± 0.96 b

Means with the same letter in a column are not significantly different from each other ($p < 0.05$, Tukey test)

The highest population of the jassids was observed on 4th November for the control treatment. In contrast, the lowest number of jassids was observed in plants treated with rice husk on 11th November. Overall, the control treatment had the maximum number of jassid population among all the treatments, while there was a significant decrease ($p < 0.05$) in mean seasonal population of jassid for all Si treatments as compared to control (Table 2). Rice husk treated plant has the lowest numbers of jassid among all the Si treatments. Throughout the season (21st Oct 2015 to 18th Nov 2015), the control treatment showed the significantly higher population of jassid as compared to other treatments. Among Si treatments, significant decrease ($p < 0.05$) was observed in number of jassid for rice husk as compared to other Si treatments (Table 2).

Among treatments, rice husk treated plants have the lowest infestation of jassid throughout the season followed by Rice husk biochar treatment. Application of Na_2SiO_3 foliar, Na_2SiO_3 soil, and rice husk biochar were statistically non-significant.

The observed data showed that whiteflies (CWF) population was significantly decreased ($p > 0.05$) in treated plants compared to Control plants (Table 3). Control has the highest population of CWF during all sampling dates as compared to other treatments. Comparison among Si treatments shows that Na_2SiO_3 soil applications have the highest number of CWF as compared to other Si treatments. In contrast, the the lowest number of CWF was observed on rice husk application, so it was most effective treatment for controlling CWF population. The lowest population was observed on November 11 (sampling date) on rice husk treated plants. Mean seasonal variation in CWF population in response to various treatments showed a significant effect of various Si sources on CWF population as compared to control.

Throughout the season, rice husk treated plants have the lowest infestation of CWF, followed by Rice husk biochar and Na_2SiO_3 foliar application treatments. The results show that there were no significant differences in recorded CWF population among three Si treatments (Na_2SiO_3 soil, Na_2SiO_3 foliar, rice husk biochar), however rice husk has a significantly lower population than other treatments. On average, relatively greater number of CWF population was observed on plants receiving Na_2SiO_3 as soil application compared to others Si treatments throughout the sampling season (Table 3).

Brinjal Shoot Borer (BSB) was observed on a fortnightly basis. During the growing season, marked differences were recorded in the BSB population on control and treated plants at sampling dates. Control plants have the highest BSB population during all sampling dates as compared to other treatments (Table 4). When rice husk was applied to plants, the lowest number of BSB was observed. Maximum infestation was recorded on October 21 and November 4 on all treatments because sampling began at the end of October, when BSB infestation was at its peak. In contrast to this situation, the lowest numbers of BSB populations were observed on sampling date December 2 on all treatments.

Table 3 Effect of various sources of silicon on number of cotton whitefly on *Solanum melongina* L. in the period of October-December. Values are the means of four replicates ± SE

Treatments	Sampling Date				Mean
	21/10/2015	28/10/2015	4/11/2015	11/11/2015	
Control	7.75 ± 0.85 a	8.50 ± 0.65 a	6.25 ± 1.93 a	3.50 ± 0.65 a	6.50 ± 1.10 a
Na_2SiO_3 foliar	5.50 ± 0.29 ab	5.50 ± 0.65 b	4.00 ± 0.41 ab	3.00 ± 0.71 ab	4.50 ± 0.61 bc
Na_2SiO_3 soil	7.50 ± 0.65 a	7.25 ± 0.48 ab	3.50 ± 0.29 bc	2.75 ± 0.48 ab	5.25 ± 1.24 ab
Rice husk	3.75 ± 0.75 b	6.00 ± 0.71 b	1.25 ± 0.25 c	1.75 ± 0.48 b	3.19 ± 1.08 c
Rice husk biochar	5.25 ± 0.85 ab	6.75 ± 0.48 ab	2.50 ± 0.29 bc	2.75 ± 0.48 ab	4.31 ± 1.02 bc

Means with the same letter in a column are not significantly different from each other ($p < 0.05$, Tukey test)

Table 4 Effect of various sources of silicon on number of shoot borer *L. orbonalis* on *Solanum melongina* L. in the period of 2015–2016. Values are the means of four replicates ± (SE)

Treatments	Sampling Date				Mean
	21/10/2015	4/11/2015	18/11/2015	2/12/2015	
Control	2.25 ± 0.25 a	2.25 ± 0.25 a	1.25 ± 0.48 a	0.50 ± 0.29 a	1.56 ± 0.43 a
Na_2SiO_3 foliar	2.00 ± 0.41 a	2.25 ± 0.63 a	0.75 ± 0.25 ab	0.25 ± 0.25 a	1.31 ± 0.48 a
Na_2SiO_3 soil	1.75 ± 0.63 a	2.00 ± 0.41 ab	0.75 ± 0.25 ab	0.50 ± 0.50 a	1.25 ± 0.37 a
Rice husk	0.50 ± 0.50 a	1.00 ± 0.41 b	0.00 ± 0.00 b	0.00 ± 0.00 a	0.38 ± 0.24 b
Rice husk biochar	1.25 ± 0.75 a	1.75 ± 0.25 ab	0.50 ± 0.29 ab	0.25 ± 0.25 a	0.94 ± 0.34 ab

Means with the same letter in a column are not significantly different from each other ($p < 0.05$, Tukey test)

During the observation period, (21/10/2015 to 2/12/2015) Control plants showed higher number of bores as compared to other treatments, although its number was not significantly high. Among the treatments, significant ($P < 0.05$) less number of bores by BSB were observed on rice husk treated plants compared other treatments (Table 4).

Mean seasonal population of BSB showed that higher infestation was observed under control treatment throughout the season. While rice husk treated plants have the lowest infestation of BSB during the season followed by rice husk biochar treatment. Comparatively, Na_2SiO_3 soil and Na_2SiO_3 foliar application has less number of BSB infestation than control, however, the difference was statistically at par with control (Table 4).

3.3 Concentration of Various Mineral Nutrients in Eggplant through Different Si Treatment Sources

Various sources of Si significantly changed the phosphorus concentration in brinjal plants in comparison to control treatment. While no significant differences were found between different Si sources.

The results indicated that the mean values for potassium concentration in plant leaves were almost similar for all treatments. Similarly, no significant difference ($p < 0.05$) was observed on plant sodium, potassium, (Table 5). The highest Na level was found in Na_2SiO_3 soil and the lowest level was found in Na_2SiO_3 foliar applications. The highest K level was found in Na_2SiO_3 soil and the lowest level was found in control applications. Calcium concentrations lower in the order Control > Rice husk biochar > Na_2SiO_3 foliar ≈ Na_2SiO_3 soil > Rice husk. There were significant differences ($p < 0.05$) of P concentration in the different Si sources. Phosphorus concentration was almost similar in all treatments of Si sources except control. Additional Si supply through various sources and means of application resulted in higher Si accumulation in shoot tissues. Among the treatments, plants fertilized with sodium silicate in soil showed maximum Si concentration that was significantly higher from other sources as well.

4 Discussions

4.1 Effect of Silicon on the Growth Attributes of Brinjal

In this study, Si had positive effects on the physical growth parameters of plants such as plant height, number of leaves, branches and flowers per plant and the shoot biomass production. As the Si is ubiquitous in soil–plant continuum and all terrestrial plants uptake and accumulate it in their bodies that may reach up to 0.1% to 10% on dry weight basis depending on plant species [34]. However, Si does not play any direct role in plant metabolism, therefore considered as non-essential element for plant growth. Although, fact of the matter is, Si deficiency causes many abnormalities in higher plants [16]. Silicon is taken up by the plants roots and translocated to aerial parts depending on the expression level of the Si-transporters [10, 35]). Several monocots such as *Triticum aestivum* and *Oryza sativa* are considered Si accumulators, in which plant absorption is active by root

Table 5 Effect of different silicon sources on plant mineral nutrients. Values represent the means of four replicates ± (SE)

Treatments	Sodium mg/g leaf DW	Potassium	Calcium	Phosphorus	Silicon
Control	2.03 ± 0.20 a	23.90 ± 3.26 a	1.43 ± 0.37 a	2.86 ± 0.03 b	1.33 ± 0.14 d
Na_2SiO_3 foliar	1.55 ± 0.15 a	25.05 ± 1.70 a	0.55 ± 0.11 b	3.03 ± 0.02 ab	2.88 ± 0.28 c
Na_2SiO_3 soil	3.50 ± 0.86 a	28.85 ± 2.52 a	0.55 ± 0.30 b	3.16 ± 0.06 a	6.53 ± 0.25 a
Rice husk	3.23 ± 0.54 a	27.78 ± 0.50 a	0.31 ± 0.08 b	3.06 ± 0.10 ab	5.73 ± 0.28 ab
Rice husk biochar	2.38 ± 0.43 a	28.18 ± 2.16 a	0.65 ± 0.20 b	3.21 ± 0.03 a	4.70 ± 0.26 b

Means with the same letter in a column are not significantly different from each other ($p < 0.05$, Tukey test) system. In plants, Si treatment improves the leaf structure and other major metabolic processes e.g. gas exchanges [46], photosynthetic pigments [50] by improving leaf area, and antioxidant system [2, 60].

In the present study, plant growth was improved due to Si treatments. Plants with supplemental Si, had higher fresh weight, plant height, and number of flowers, branches and leaves compared to the Control treatments. Overall maximum biomass production was witnessed in plants treated with rice husk. The possible reason behind the Si-mediated improved plant growth may due to increased surface area for better light interception with increased photosynthetic activity [25]. Similarly, another study reported that Si-supplementation increased the growth and yield of cucumber by increasing the rigidity of mature leaves which have a rough and tough texture and were held horizontally to intercept more light [1]. This deposition of Si in the cell walls in epidermal cell has been confirmed under electron microscopy and X-ray microanalysis [25]. Plants treated with Na_2SiO_3 foliar and Rice Husk also have higher lateral growth rate (higher number of branches) compared with the Control treatments. Similar observations have been reported by Brecht et al. [7] and Wang and Galletta [57], who observed that plant supplemented with potassium silicate and calcium silicate through foliar means had improved growth. Silicon produced beneficial effects on Cucumber plants when plants were grown with an additional 100 mg L^{-1} of SiO_2. The mature leaves having high Si levels had characteristics of leaves grown in high light intensity, i.e. shorter petioles, higher chlorophyll contents with higher RuBP carboxylase activity, increased soluble protein and fresh and dry weight per unit area. In addition root fresh and dry weight were also improved [1].

The highest rate of flowering was also observed on rice husk treated plants as compared with other treatments. The same phenomena was observed in the previous studies when Si was supplied to plants (even non accumulating), it has increased the flowering rate and the total number of fruit production of plants as compared with no Si supplied plants [41].

4.2 Effect of Si on the Insect Pests of Brinjal

Induction of defenses in plants through chemical or physical means against herbivore damage is always an effective strategy. The strategies are most crucial to the environments where other means of controlling insects are costly and level of infestation is intermittent [24]. Silicon deposition in the epidermal cells of plants played a protective role against insect herbivores and plant diseases [33]. It has been suggested that the histological accumulation of Si may inhibit herbivore attack in three ways. Firstly, silica bodies may protect the underlying vascular tissue by restricting chewing, sucking and rasping herbivores to intercostal zones. Secondly, the silicification of epidermal cell walls may provide resistance to entry in these areas. Thirdly, chewing herbivores may be inhibited from penetration into tissues by silicification of the leaf margins.

On the eggplant, different Si treatments were found effective in controlling jassid and whitefly. The higher accumulation Si could have reduced the insect infection in plants by improving molecular defense signaling responses in plants. A strong interaction of jasmonate and Si signaling pathway has been reported in rice in which Si pre-treatment led to higher levels of jasmonate production with the increased expression of a range of defense related genes in the rice [58]. Another study demonstrates the important role of Si against biotic stress, where an increased resistance against rice leaf folder, *Cnaphalocrocis medinalis Guenee,* in rice plants with higher shoot-Si was attributed to reduced quality/digestibility of the leaf, due to higher Si content of the leaf [21, 53].

Rice husk application was most effective in controlling the jassid population. The rice straw and rice husks have also been used in the field for some time [54, 55]. Rice husks contain almost 20% of Si [8] owing to rice ability for Si accumulation [34]. In rice Si is deposited as opaline silica in the epidermis of leaves leading abrasiveness of cell walls which act as deterrent to insect herbivory. De Almeida et al. [13] also observed this effect when eggplant was treated with calcium silicate and this has reduced the population of *Thrips palmi* Karny (Thysanoptera: Thripidae). Our results are in line with Goussain et al. [20] who stated that applied Si to wheat either as foliar or soil had a deterring effects on green stink bug *Schizaphis graminum* Rond (Hemiptera: Aphididae). The foliar application of rice husk and other Si sources used in our study showed similar results as these treatments reduced the population of sucking insects. Our results are also in consistent with Costa and Moraes [12] who reported that Na_2SiO_3 induced resistance by in sorghum against green aphid *Schizaphis graminum*. But there was no other study found in which rice husk has been used to control insect population.

Similarly, in case of whitefly, Miller et al. [40] indicated that wheat plants are resilient to hessian fly attack because they have silica bodies. Since rice husks contain a greater concentration of Si and it increases the concentration of Si in plant bodies improving their tolerance that resulted in reduced CWF attack. Correa et al. [11] also reported that foliar application of calcium silicate ($CaSiO_3$) on cucumber leaves induced resistance against whitefly *Bemisia tabaci* (Gennadius) biotype B. In another study by Ferreira and Moraes [18], it was reported that when soybean plants were treated with silicic acid it decreases the population of *B. tabaci*. Our results were in line with all these studies because fewer number of CWF was found on different Si treatments compared with control and significant differences were found on CWF population among different treatments especially rice husk on different sampling dates.

In the current study, brinjal fruit and shoot borer damage and intensity were reduced among different Si treatments especially plant treated with rice husk. In case of shoot borers, it has been found in many studies that different Si sources were effective in controlling it on different crops. According to Anderson and Sosa [3], calcium silicate slag used as a Si source on sugarcane plants reduced sugarcane borer (*Diatraea saccharalis*) populations. Similar results were found in a study by Kvedaras and Keeping [26] when calcium silicate was applied to sugarcane, Si-treated plants were less damaged by *Eldana saccharina* Walker (Lepidoptera: Pyralidae). As already discussed that Si uptake by plants minimize the susceptibility to chewing insects such as stem borer; it might be due to decreased preference and digestibility of plant material and/or due to deterioration of mandibles of the feeding insects [36].

4.3 Effect of Silicon on the Mineral Nutrient Status of Brinjal

In various studies it has been indicated that Si-treatment may change the nutrient acquisition in plants and may have balancing effect on other mineral nutrient consecrations in plants [49, 62] especially phosphorus (P), calcium (Ca) nitrogen (N) and some other micronutrients [17]. Liang [29] reported that Si not only increased the P concentration but also total P content in barley plants. The possible causes may have been Si-stimulated root enzymes activity including root dehydrogenase activity [29] as well as due to improved P bioavailability in soils. Competition between $H_2PO_4^-$ and silicate ($H_3SiO_4^-$) anions at the sorption sites in soil may have increased P concentration in soil solution and subsequently its contents in plants as well [44, 51]. Our study also indicated the that Ca concentration was decreased with Si supplementation. The decline in plant Ca accumulation with increasing Si supply has been reported in common reed and rice that has been associated with decreased transpiration rate due to Si deposition at leaf surface, biosilicification of casparian band in root and Si-Ca interaction in the growing media or apoplast [45].

5 Conclusion

The study has shown that Si improved the eggplant height, number of leaves per plant, number of branches per plant and total biomass production. Various sources of silicon especially rice husk was effective in controlling the insect infestation in plants. The incidence and abundance of the pests was reduced in all Si treated plants, hence agricultural waste product (rice husk) could be used as cheap source of Si for plants.

6 Recommendation

It is recommended that further work should be done to evaluate the potential of rice husk on insect feeding preference and the possible pathways by which Si affects insect pest population. Furthermore, the role of silicon in plant induced resistance against insect population also require due attention.

Funding & Acknowledgement Generous funding by COMSATS University Islamabad-Office of Research Innovation and Commercialization under the grant No.16-47/CRGP/CIIT/VEH/14/659 to author H.F. Bakhat is highly acknowledged.

Authors' Contributions H. F. B. Conceived the idea, arrange the funding, planned the experimentation, NB and SA gathered the data and prepare the initial draft of the manuscript, HMH, GMS, HMR and AK S H M did the statistical analysis, critically reviewed and improved the initial draft while MMM contributed to the interpretation of the results. All authors read and approved the final draft of the manuscript.

Data Availability All data generated or analyzed during this study are included in this article.

Declarations

Ethics Approval Not applicable.

Consent to Participate Not applicable.

Consent for Publication Not applicable.

Competing Interests The authors declare that they have no competing interests.

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