Original Research Article

Critical Role of Exogenously Applied Silicon on Insect Pests and Yield in *Kharif* Rice

ABSTRACT

A field experiment was conducted at Rice Research Station, Department of Agriculture, Government of West Bengal, Chinsurah, Hooghlyduring three consecutive*Kharif* seasons to evaluate the effect of exogenouslyapplied siliconon the infestation of rice insect-pests and yield of rice. Rice is most important staple food in West Bengal and in India. However, due to biotic stress, the crop hampers high-yield production. When the farming community goes ahead for chemical management practices to manage the biotic stress, not only the environmental pollution, and pesticide residue problem arises but also the chance of pest resurgence and pest resistanceproblems arise. Therefore, an attempt was made in this present study to find out an alternate strategy to manage rice insects *viz.* whorl maggot, leaf folder and stem borer through the amendment of silicon by seed priming, seedling root dipping, foliar spray and soil application.As rice is a silicon-loving crop and they accumulate silicon in their system. Additionally, silicon amendment has no detrimental impact on the environment as well as no residual problem may arise. In this study, it was evident that in foliar spray with 1.2% silica gel [Sodium silicate (Na_2SiO_2)] at 30, 40 and 50 DAT or soil application of granular silica gel [80% silicon dioxide (SiO_2) powder] @ 80 kg ha^{-1} as basaltreatment have significantly managed rice insects *viz.* whorl maggot, leaf folder and stem borerandhigh grain and straw yield were obtained. Therefore, silica amendment exogenously by foliar spray and soil application in rice fields can be a viable option for rice IPM.

***Keywords*:** Silicon, whorl maggot, leaf folder, yellow stem borer, sodium silicate (Na_2SiO_2), silicon dioxide (SiO_2) powder

INTRODUCTION

In terms of the area under rice *(Oryza sativa* L.) cultivation and its production, India holds the second rank globally. Rice is one of the important staple foods of more than half of the world population and rice production and it's consumption are concentrated mainly in

Asian countries (Chatterjee and Mondal, 2014). However, due to the lack of inbuilt resistance to various biotic stresses, as discernible in about 1,000 rice cultivars across the country, the yield capacity is dented (Chatterjee *et al.*, 2020). Rice is considered as the dominant food crop in West Bengal and is grown in all the six agro-climatic zones of the state under diversified situations (Gangopadhyay and Chatterjee, 2020). The state is suffering from poor productivity due to different biotic stresses like, insect-pests, mites, nematodes, diseases etc. (Chatterjee *et al*., 2015). Yield losses due to pest attack of rice in tropical Asia range 25-43% and therefore, there is a need to explore management options for judicious use of chemicals (Chatterjee *et al.* 2020). A critical analysis of the difference between the nation's potential and actual rice yields will show that many variables act as constraints on yield. Among these factors, insect-pests significantly lead to the loss of rice production as well as rice productivity (Bajya*et al.*, 2010; Chatterjee *et al.*, 2016). Rice whorl maggot, *Hydrelliaphilippina*(Ferino) begins to infest the rice plant at transplanting and feeds on the central whorl leaf of the vegetative stage of the rice plant (Chatterjee *et al.*, 2019) which effects rice yield production. At present climatic situation, the whorl maggot is going to be an important insect of rice at vegetative stage of rice just after transplanting which interferes on photosynthesis of rice plants by damaging leaves. Therefore, the management of whorl maggot at early stages of the crop is essential for obtaining good yield. Rice yellow stem borer (YSB), *Scirpophagaincertulas*(Walker) and rice leaf folder, *Cnaphalocrocismedinalis*(Guenee) are the dominant and most destructive insect-pest occurring throughout the country causing yield loss ranging from 10 to 60% (Chatterjee and Mondal, 2014; Chatterjee *et al*., 2015, Chatterjee and Mondal, 2020). One of the major insectsof rice, yellow stem borer, *S.incertulas*is distributed widely, covering almost all the Asian countries. TheYSB usually comprised more than 90% of the borer populations and damage the rice crop from seedling to maturity causing "Dead heart" at vegetative stage and "White ear head" at the reproductive stage (Chatterjee *et al.*, 2017). Therefore, to obtain the good yield of rice the most destructive insects of rice, YSB and leaf folder should be managed properly.

The indiscriminate use of chemical insecticides has a significant negative effect on theenvironment, ecosystem, human bodiesas well as on wildlife. Therefore, the pest management strategies by other than use of chemicals may be considered as environmentally safe feasible management practice and it also helps to overcome pest resurgence and pest resistant problems. External application of silicon (Si) in crops for pest management practice can confer enhanced crop resistance. Evidence at present situation has found that silicon plays an important role in plant defense against biotic stress (Reynolds*et al.* 2016). Rice is one of the typical silicon accumulating plant species, and silicon accumulation in rice is an active process (Ma and Yamaji, 2006). As reported for crops within the family Poaceae, increased resistance associated with Si addition may result from a cuticle-silica double layer, which is formed in the leaf blade and acts as a mechanical barrier to insect herbivores (Ma and Takahashi, 2002). Siliconacts as plant defenses through two primary modes of action. The first one is the mechanical defense derived from the deposition of inorganic amorphous silicon oxide (SiO_2) phytoliths in the epidermis of the plant tissues (Ma 2004; Hartley*et al.*, 2015), which renders the plant surface tougher for herbivores to feed on and digest (Massey and Hartley, 2009; Reynolds *et al.*, 2016). The second is enhancement of induced defenses through greater mobilization and activation of enzymes such as polyphenol oxidase and trypsin protease inhibitor (Ye *et al.*, 2013; Han *et al.*, 2016; Yang*et al.*, 2017), higher callose deposition (Yang *et al.*, 2018), or increased release of plant volatiles that attract the natural enemies of the attacking insect herbivores i.e. insect pests (Kvedaras*et al.*, 2010; Liu *et al.*, 2017). The phytohormone pathways are involved in the foregoing mechanisms of Si mediated plant resistance (Ye *et al.*, 2013). Rice is a silicon accumulator plant (Liang *et al.*, 2006; Ma and Yamaji, 2006) and harbors silicon concentrations above 10% of shoot dry weight (Yamamoto,*et al.* 2012). Silicon amendment is useful for better soil health and benefits rice production (Savant,*et al.*, 1997), especially in regions where soils are deficient in plant available silicon. Recently, Silicon amendment has been proven to impart substantial rice plant resistance to pests, including the major insect pests of rice,stem borer (Hou and Han, 2010), and leaf folder (Ye *et al.*, 2013; Han *et al.*, 2015, 2016, 2017). Increasing evidence shows that a high quantity of Si in plants confers resistance or tolerance to various biotic stresses (Ma, 2004). Silicon amendment in soils or hydroponic solutions has proved to enhance rice resistance to stem borer (Hou and Han, 2010; Sidhu *et al.*, 2013; Jeer *et al.*, 2017), leaf folder (Ye *et al.*, 2013; Han *et al.*, 2015, 2016, 2017).Therefore, a scientific attempt was made by the authors in this present study to find out an alternate strategy to manage rice insects viz. whorl maggot, leaf folder and stem borer with increase yield through external amendment of silicon by seed priming, seedling root dipping, foliar spray and soil application methods as rice is a silicon-loving crop and they accumulate silicon in their system. Our main objective was to increase silicon content in rice plant by applying Si exogenously to manage insect-pests of rice.

MATERIALS AND METHODS

Experimental site

A field experiment was conducted on the rice cv*Swarna*(MTU 7029),a high yielding popular ricevariety in West Bengal, in *kharif* season during 2018-20 (June-November) at Rice Research Station, Government of West Bengal, Chinsurah, Hooghly, located at 88°24′ E longitude and 22°52′ N latitude with an altitude of 8.62 m AMSL in the new alluvial zone of West Bengal.

Experimental field details

The crop variety, *Swarna* was sown in the raised seed beds @ 50 g m^{-2} seeds during 1^{st}week of July without any seed treatment.The transplanting method was carried out bymaintaining a distance of row to row and plant to plant as 20 cm and 15 cm respectively, in the plot size of 3m × 4mand around 25-30 days of old seedlings were transplanted in the main field. The recommended doses of fertilizer of $N:P_2O_5:K_2O$:: 80:40:40 were applied in the transplanted field where $^1/_4$ N + full P_2O_5 + $^3/_4$ K_2O were applied as basal, ½ N was applied at 15-20 DAT and the rest ¼ N +$^1/_4$ K_2O were applied at panicle initiation stage. No plant protection measure was undertaken in the transplanted field plots.

2.3 Treatment details

The silicon was applied externally by seed priming, seedling root dipping, foliar sprays and soil application methods and the eight treatments are as follows.

T_1 : Seed priming with 3% silica gel [Sodium silicate (Na_2SiO_2)] before sowing (36 hours)

T_2 : Foliar spray on seedlings with 0.6% silica gel [Sodium silicate (Na_2SiO_2)] on 7 days prior to transplanting

T_3 : Seedling root dipping with 3% silica gel [Sodium silicate (Na_2SiO_2)](12 hours)

T_4 : Foliar spray with 0.6% silica gel [Sodium silicate (Na_2SiO_2)] at 30, 40 and 50 days after transplanting (DAT)

T_5 : Foliar spray with 1.2% silica gel [Sodium silicate (Na_2SiO_2)] at 30, 40 and 50 DAT

T_6 : Soil application of granular silica gel [Silicon dioxide (SiO_2) powder] at @ 40 kg ha^{-1} as basal

T_7 : Soil application of granular silica gel [Silicon dioxide (SiO_2) powder] at @ 80 kg ha^{-1} as basal

T_8 : Control (No application)

The experiment was conducted with three replications in a Randomized Block Design (RBD). All the per cent data were calculated asangular transformed values.

Observations and data collection

The insect-pest infestation was determined based on damaged leaves by rice whorl maggot (WM), folded leaves by leaf folder (LF) and dead heart (DH) or white ear head (WE) due to attack of yellow stem borer (YSB)larvae, in all the experimental plots. The observations on damaged/folded leaves by rice WM (40 & 50 DAT) and LF (50 & 60 DAT) and DH (40 &50 DAT), WE (pre-harvest) by yellow stem borer were taken from ten hills selectedrandomly from each plot.

The percentage of whorl maggot and leaf folder damage were computed by using the following formula proposed by Chatterjee and Mondal (2020) and Singh and Chatterjee (2021).

$$\text{Per cent (\%) damaged leaves caused by whorl maggot or leaf folder} = \frac{\text{Number of damaged leaves per hill by WM or LF} \times 100}{\text{Total No. of leaves per hill}}$$

The percentage of the dead heart and white ear head infestation were computed by using the following formula proposed by Chatterjee and Mondal (2020) and Singh and Chatterjee (2021).

$$\text{Per cent (\%) dead heart} = \frac{\text{Number of DH damaged tillers per hill by YSB} \times 100}{\text{Total No. of tillers per hill}}$$

$$\text{Per cent (\%) white ear head} = \frac{\text{Number of WEdamaged tillersper hill by YSB} \times 100}{\text{Total No. of panicle bearing tillers per hill}}$$

All the per cent data were converted into angular transformed values before statistical analysis.

The morphological characteristics of rice such as plant height (in cm) and panicle sqm^{-1}(No.) from each treatment were also recorded in every season.From the standingcrop the leaves were collected, then the per cent silicon content in leaf was evaluated and the per cent silicon content in straw, paddy and soil was evaluated after crop harvest. This analysis was conducted at Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur by X-ray Fluorescence Spectrophotometer.

The normal harvesting of the was conducted during the month of November in *Kharif*season. The grain and straw yield of rice were recorded from each plot leaving two border rows from each side and the plot yieldsof paddy and straw wereconverted and calculated into kg ha^{-1}.

Data analysis

The experimental data were subjected to analysis of variance (ANOVA) with the requisite transformation whenever needed using SPSS statistical tools before comparison of treatment means at probability p=0.05.

RESULTS AND DISCUSSION

The insect-pest infestation, morphological characteristics of plant and yield of paddy and straw were recorded in three consecutive*Kharif* seasons (2018-2020). The observations on WM%, LF%, DH%, WE%, grain and straw yield, morphological characters and per cent silicon content in different plant parts as well as in soil have been depicted in Table 1, 2, 3, 4, 5, 6 and 7, respectively. Figure 1, 2, 3 and 4 indicatethe effect of applied silicon on insect infestation and yield; decreased insect infestation per cent over control and increased paddy and straw yield per cent over control;effect of silicon on morphological charactersand comparison between existing per cent silicon on different plant parts and in soil with yield, respectively.

Effect of exogenouslyapplied silicon on whorl maggot (*Hydrellia*spp)

The whorl maggot is a dipteran insect that attacks at the early stages of the crop and they are not a major insect. But now-a-days this insect is going to prove an important insect at the vegetative stage of the crop and their attack become severe just after transplanting to mid tillering stage of the crop. Rice leaves are affected by whorl maggot before opening of leaves and the photosynthesis of the plant hampers which may affect on good yield production. Application of silicon proved significant reduction of whorl maggot damage with compared to control treatment. Table 1 revealed that the lowest whorl maggot infestation at vegetative stage of crop at active tillering stage on 40 DAT,foliar sprayswith 1.2% silica gel i.e. Sodium silicate (Na_2SiO_2) on 30, 40 and 50 DAT treatment (1.15% WM) reduced whorl maggot damage significantly followed by soil application of granular silica gel [80% Silicon dioxide (SiO_2) powder] @ 40 kg ha^{-1} as basal (1.83% WM).At late tillering stage on 50 DAT,foliar sprays with 1.2% silica gel treatment (0.85% WM) was found to lower down the whorl maggot attack maximum followed byfoliar spray with 0.6% silica gel at 30, 40 and 50 DAT treatment (1.37% WM). The pooled data analysis also revealed the same trendwith 1.00%

WM damage followed by 1.73% WM damage, respectively. The whorl maggot infestation per cent and decreased WM% over control have been represented in Fig. 1 and Fig. 2 respectively.

Effect of exogenouslyapplied silicon on leaf folder (*C.medinalis*)

Rice leaf folder is one of the major insect-pests of rice. They fold the rice leaf.The caterpillar stays in between the folded leaf and feedson the chlorophyll tissues of the leaf which hampers photosynthesis. During flowering stage if the flag leaf is attacked, the significant yield loss occurs. Here leaf folder damage was significantly reduced in all the silicon applied plots with compared to control plots. At late tillering stage on 50 DAT, the lowest leaf folder attack was recorded in seed priming with 3% silica gel before sowing for 36 hours treatment (0.26% LF) followed by foliar spray with 1.2% silica gel treatment (0.27% LF). Whereas at flowering stage, the lowest leaf folder attack was discernible in foliar spray with 1.2% silica gel treatment (0.28% LF) followed by foliar spray with 0.6% silica gel treatment (0.57% LF). The pooled data analysis indicated that foliar spray with 1.2% silica gel [Sodium silicate (Na_2SiO_2)] treatment (0.27% LF) had resulted the best against leaf folder followed by foliar spray with 0.6% silica gel treatment (0.43% LF).The leaf folder infestation per cent and decreased LF% over control have been represented in Fig. 1 and Fig. 2 respectively.

Our results corroborate with the result of Mishra *et al.* (2018) who proved the significant difference in percent damage by leaf folder was marked among different silicon treatments applied basally in both vegetative and reproductive stage of the crop. Ye *et al.* (2013) and Han *et al.* (2015, 2017)observed that rice leaf folder larval settlement, larval survival, fecundity and population growth ratesas well as egg deposition on rice plants amended with silicon were significantly reduced.Rice varieties resistant to the rice leaf folder have closer silica chains, heavy deposition of silica, high epidermal silica deposition and a single or double row of silica, in contrast to susceptible rice varieties (Hao *et al.*, 2008). Similarly in case of leaf folder, our findings on impact of silicon amendments against leaf folder also supported by Chandramani *et al.* (2010) and Mishra *et al.* (2018) who found a negative correlation between increase in silica content and infestation by leaf folder. They also reported that reduced leaf folder incidence was attributed to wearing of mandibles and lack of feeding which was an antixenotic (non-preference) mechanism induced by silica.

Effect of exogenouslyapplied silicon on yellow stem borer (*S.incertulas*)

Yellow stem borer is one of the major insect-pests of rice which attack in vegetative stage causing ‘dead heart’, killing the tillers and at reproductive stage with ‘white ear head’ symptoms, drying up of complete ears without any grain formation which results a huge yield loss. Only the YSB larvae are the responsible to cause the damage symptoms. The data presented in Table 3 (dead heart) and 4(white ear head) revealed the effect of exogenous application of silicon from different sources and at different doses against yellow stem borer during *Kharif*, 2018-20.

Effect of exogenouslyapplied silicon on dead heart

All the silicon-applied treatments effectively reduced dead heart damage compared to control plots. Table 3 shows that on 40 DAT, the lowest dead heart (DH) symptoms were recorded in foliar spray with 1.2% silica gel treatment (1.01% DH) followed by soil application of granular silica gel at @ 80 kg ha^{-1} as basal treatment (1.55% DH). At late tillering stage on 50 DAT, foliar spray with 1.2% silica gel treatment (0.66% DH) was found highest reduction of dead heart followed by foliar spray with 0.6% silica gel treatment (0.91% DH). At par trends were calculated in pooled dead heart per cent data where foliar spray with 1.2% silica gel treatment (0.84% DH) was the best against dead heart followed by foliar spray with 0.6% silica gel treatment (1.24% DH).Figure 1 clearly shows the effect of applied silicon on insect infestation and yield which proves that applied silicon contains lowers down the insect-pest infestation invariably as well as increases grain and straw yield. The dead heart infestation per cent by stem borer and decreased dead heart per cent over control have been represented in Fig. 1 and Fig. 2 respectively.

Effect of exogenouslyapplied silicon on white ear head

It has been recorded that white ear damage at pre-harvest stage was reduced after silicon application in all the plots and the ranges of white ear per cent were 0.87-5.71% WE (2018), 6.33-15.58% WE (2019) and 1.12-8.68% WE (2020) where in all the season, the control plots were found maximum white ear damage. During 2018-20, the lowest white ear damage was noticed in foliar spray with 1.2% silica gel treatment (0.87%, 6.33% and 1.12% WE, respectively) followed by foliar spray with 0.6% silica gel treatment in 2018 (1.04% WE) and soil application of granular silica gel as basal treatment in 2019 and 2020 (8.04% and 1.48% WE, respectively). The pooled data analysis indicated that the lowest WE% was calculated in foliar spray with 1.2% silica gel treatment (2.77% WE) followed by soil application of granular silica gel as basal treatment (3.63% WE). The white ear head infestation per cent by stem borer and decreased white ear per cent over control have been represented in Fig. 1 and Fig. 2 respectively.

Our experimental results followed the results presented by Hou and Han (2010) who proved that silicon amendment has been observed to decrease stem borer larval weight gain and stem damage, and to prolong penetration duration and larval development. Our results also comply with Voleti *et al.* (2008) and Jeer *et al*. (2017) that silicon amendment also reduced damage (percent dead heart and white ear) by the yellow stem borer, *S. incertulas* as compared with the control. According to Hao *et al*. (2008), the rice varietal resistance to rice stem borer has been linked with silicon content and indicates silicon-mediated antibiosis. Calcium silicate ($CaSiO_3$), an inorganic source of silicon at 2.0 t ha^{-1} exhibited the best performance in both the crop growth stages i.e. vegetative and reproductive stage of the crop amongst the incidence of DH and WE, respectively as well as, according to grain yield, the lowest dose of $CaSiO_3$ yielded highest with a record of 50.50 q ha^{-1} as against 36.0 q ha^{-1} in the untreated control.(Mishra *et al.*, 2018). In addition to the biochemical mechanisms, the reduced pest severity in silicon-amended plots in field tests can also result from the behavioral changes of insect herbivores. Hou and Han (2010) and Sidhu *et al.* (2013) revealed that the boring success of rice stem borer larvae in rice stems decreased in plants supplied with silicon.Our present findings on the impact of silicon amendments against yellow stem borer are in close conformity with the reports of Han and Hou (2011) and Mishra *et al.* (2018) who reported a similar impact of silicon on rice with fairly high level of efficacy against stem borer. The present results are also in agreement with Fallah *et al.* (2011) who found 10-20% less stem borer infestation in silicate fertilizer-treated plants as compared to control plants and less incidence was attributed to silica deposition in shoot, leaf and panicle.

Effect of exogenouslyapplied silicon on grain and straw yield of rice

The result revealed that the lowest paddy and straw yield were obtained from control plots in all the seasons. The highest grain yield as 5600, 5733, 5806 kg ha^{-1}and straw yield as 6733, 6700, 6778 kg ha^{-1}were recorded from foliar spray with1.2% silica gel treatment in *Kharif*2018, 2019 and 2020, respectively. The next best yield was obtained from soil application of granular silica gel @ 80 kg ha^{-1} as basal treatment as 5278, 5578, 5611 kg ha^{-1} grain yield and 6333, 6541, 6444 kg ha^{-1} straw yieldin *kharif*2018, 2019 and 2020, respectively. The pooled data analysis revealed that the same trend was followed with 5713 and 6737 kg ha^{-1} grain and straw yield, respectively from best treatment and with 5489 and 6439 kg ha^{-1} grain and straw yield, respectively from the second best treatment. Figure 2 denotes the paddy & straw yield per cent over control increased as well as insect infestation per cent over control decreased when silicon applied exogenously.

Our observations have close conformity with the observations of Tamai and Ma (2008) who observed that in addition to enhancing plant resistance to pests, silicon has been recognized as a beneficial element to improve rice grain yields. Pati *et al.* (2016) observed a significant increase in rice yield in field plots amended with >480 kg SiO_2 ha^{-1}, Alvarez and Datno (2001) assumed a yield increase of 500 kg ha^{-1} from silicon amendment. The current research findings generally confirm previous reports that exogenous silicon supply enhances straw biomass (Tamai and Ma, 2008; Detmann*et al.*, 2012) due to its beneficial effects on water use efficiency and cell elongation (Hossain *et al.*, 2002; Isa *et al.*, 2010). Although the mechanisms for the silicon-mediated rice yield increase are complex and largely unclear (Detmann*et al.*, 2012), it was certain that the reduced pest occurrence had played a significant role. Han*et al.* (2018) observed significant increases in the number of grains per panicle, grain-filling percentage, and thousand-grain weight in silicon amended plots compared to the control plots, however, the increase of rice yield of 16.4% (604.5 kg ha^{-1}) in the plots with 300 kg SiO_2 ha^{-1} over the control plots was insignificant; this is due to the lack of a difference in number of effective panicles.

Effect of exogenouslyapplied silicon on morphological characters of rice plant

The average plant height (cm) of the rice plant varied from 96.2-99.8 cm, 102.8-110.9 cm, 106.8- 114.3 cm during *Kharif* 2018, 2019 and 2020, respectively. Pooled data analysis revealed that the highest plant height was recorded from foliar spray with 1.2% silica gel treatment (106.9 cm). The average panicle sqm^{-1}(No.) ranged from 135-171, 138-190 and 135-185 during *Kharif* 2018, 2019 and 2020, respectively. It was calculated from pooled data that the maximum panicle sqm^{-1}(No.) was found in foliar spray with 1.2% silica gel treatment (178) followed by soil application of granular silica gel @ 80 kg ha^{-1} as basal treatment (174).Fig. 3 shows the effect of applied silicon exogenously on the morphological characters of rice.

Effect of exogenouslyapplied silicon on silicon percent over different plant parts and in soil

The silicon per cent over different plant parts and in soil was evaluated and the result revealed that the highest silicon per cent was found in leaf (6.7%), straw (7.3%), paddy (2.1%) in foliar spray with 1.2% silica gel treatment and the second highest silicon per cent was recorded in soil application of granular silica gel @ 80 kg ha^{-1} as basal treatment as 5.8% in leaf, 6.8% in straw, 2.0% in paddy and the highest per cent silicon in soil (7.8%) was recorded in same treatment. The next highest per cent of silicon in soil (6.7%) was noticed in soil application of granular silica gel @ 80 kg ha^{-1} as basal treatment. The control treatment always showed the lowest silicon percent in leaf (0.92%), straw (0.86%), paddy (0.71%) and soil (0.93%). It is clear from Fig.4 that with the increase of silicon content in leaf, straw, paddy and soil after the application of silicon exogenously, the grain and straw yield wasalso increased simultaneously.

CONCLUSION

Our study demonstrates that in a field condition the crop damage by whorl maggot, leaf folder and stem borer was significantly lowered down as well as higher grain and straw yields were obtainedin exogenously silicon-amended treatments with compared to the control plots. Therefore, the silicon content in rice plant were increased by applying Si exogenously and insect-pests of rice were managed significantly and the yields of paddy and straw were increased significantly. Thus, considering all the facts, tables and figures discussed in our present study, it is evident that in foliar spray with 1.2% silica gel [Sodium silicate (Na_2SiO_2)] at 30, 40 and 50 DAT or soil application of granular silica gel [80% Silicon dioxide (SiO_2) powder] @ 80 kg ha^{-1} as basal may be recommended for integration into the IPM system in rice for good management practice of rice insects as well as higher yield.

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Table 1. Effect of exogenouslyapplied silicon on whorl maggot (*Hydrellia*spp) infestation in rice

Treatments	%WM 40 DAT			Mean WM (%)	%WM 50 DAT			Mean WM (%)	Pooled WM (%)
	2018	2019	2020		2018	2019	2020		
T1	2.53 (9.15)	2.19 (8.51)	3.16 (10.24)	2.63 (9.32)	2.40 (8.91)	2.13 (8.39)	4.69 (12.50)	3.07 (10.09)	2.85 (9.72)
T2	2.79 (9.61)	2.45 (9.00)	2.79 (9.61)	2.68 (9.41)	2.80 (9.63)	2.62 (9.31)	3.77 (11.19)	3.06 (10.07)	2.87 (9.75)
T3	1.75 (7.60)	1.41 (6.82)	3.25 (10.38)	2.14 (8.40)	2.87 (9.75)	1.60 (7.26)	2.72 (9.49)	2.40 (8.91)	2.27 (8.66)
T4	1.72 (7.53)	2.81 (9.65)	1.75 (7.60)	2.09 (8.32)	1.42 (6.84)	1.06 (5.91)	1.62 (7.31)	1.37 (6.72)	1.73 (7.55)
T5	1.06 (5.91)	0.94 (5.56)	1.46 (6.94)	1.15 (6.16)	0.87 (5.35)	0.45 (3.84)	1.23 (6.36)	0.85 (5.29)	1.00 (5.74)

T6	1.93 (7.98)	1.60 (7.26)	1.95 (8.02)	1.83 (7.76)	1.45 (6.91)	1.54 (7.13)	2.18 (8.49)	1.72 (7.53)	1.78 (7.66)
T7	2.06 (8.25)	2.06 (8.25)	2.00 (8.13)	2.04 (8.21)	1.34 (6.64)	1.47 (6.96)	1.97 (8.07)	1.59 (7.24)	1.82 (7.75)
T8	4.52 (12.27)	5.42 (13.46)	3.95 (11.46)	4.63 (12.42)	5.35 (13.37)	4.40 (11.46)	8.85 (17.30)	6.20 (14.41)	5.42 (13.46)
CD (0.05)	1.78	2.71	1.83	1.76	2.43	1.78	1.93	1.62	1.24
SEM (±)	0.58	0.89	0.60	0.57	0.79	0.58	0.63	0.53	0.43
CV	11.83	18.08	11.47	11.39	16.44	13.26	10.67	10.55	12.13

Figures in the parentheses are angular transformed values.

Table 2. Effect of exogenouslyapplied silicon on leaf folder (*C. medinalis*) infestation in rice

Treatments	%LF 50 DAT			Mean	%LF 60 DAT			Mean	Pooled
	2018	2019	2020	LF (%)	2018	2019	2020	LF (%)	LF (%)
T1	0.07 (1.52)	0.20 (2.56)	0.52 (4.13)	0.26 (2.92)	0.24 (2.81)	1.02 (5.79)	2.24 (8.60)	1.17 (6.21)	0.72 (4.87)
T2	0.09 (1.72)	0.30 (3.14)	0.47 (3.93)	0.29 (3.09)	0.27 (2.98)	0.86 (5.32)	2.03 (8.19)	1.05 (5.88)	0.67 (4.69)
T3	0.24 (2.81)	0.27 (2.98)	0.42 (3.71)	0.31 (3.19)	0.25 (2.86)	0.93 (5.53)	2.35 (8.81)	1.18 (6.23)	0.74 (4.93)
T4	0.23 (2.75)	0.47 (3.93)	0.16 (2.29)	0.29 (3.09)	0.43 (3.76)	0.39 (3.58)	0.90 (5.44)	0.57 (4.33)	0.43 (3.76)
T5	0.17 (2.36)	0.32 (3.24)	0.32 (3.24)	0.27 (2.98)	0.18 (2.43)	0.20 (2.56)	0.45 (3.84)	0.28 (3.03)	0.27 (2.98)
T6	0.25 (2.86)	0.40 (3.62)	0.50 (4.05)	0.38 (3.53)	0.60 (4.44)	0.90 (5.44)	1.64 (7.35)	1.05 (5.88)	0.72 (4.87)
T7	0.17 (2.36)	0.35 (3.39)	0.36 (3.44)	0.29 (3.09)	0.37 (3.49)	0.87 (5.35)	1.21 (6.31)	0.82 (5.19)	0.56 (4.29)
T8	0.19 (2.50)	0.62 (4.51)	1.14 (6.13)	0.65 (4.62)	1.23 (6.36)	2.54 (9.17)	5.93 (14.09)	3.23 (10.35)	1.94 (8.00)
CD (0.05)	NS	1.02	NS	NS	NS	1.53	2.48	2.09	1.44
SEM (±)	1.04	0.33	1.44	0.41	0.96	0.50	0.81	0.97	0.50
CV	99.17	16.98	77.97	21.80	50.79	16.33	18.11	21.09	27.72

NS: Non-Significant

Figures in the parentheses are angular transformed values.

Table 3. Effect of exogenouslyapplied silicon on dead heart by yellow stem borer (*S. incertulas*) infestation in rice

Treatments	%DH 40 DAT			Mean DH (%)	%DH 50 DAT			Mean DH (%)	Pooled DH (%)
	2018	2019	2020		2018	2019	2020		
T1	0.15	1.73	5.43	2.44	0.28	1.48	3.39	1.67	2.06
	(2.22)	(7.55)	(13.47)	(8.98)	(3.03)	(6.98)	(10.61)	(7.42)	(8.25)
T2	0.16	1.57	6.95	2.89	0.33	1.41	3.32	1.63	2.26
	(2.29)	(7.20)	(15.28)	(9.78)	(3.29)	(6.82)	(10.49)	(7.33)	(8.64)
T3	0.18	1.71	5.45	2.45	0.37	1.52	3.80	1.83	2.14
	(2.43)	(7.51)	(13.49)	(9.00)	(3.49)	(7.08)	(11.24)	(7.77)	(8.41)
T4	0.24	1.01	3.46	1.57	0.47	1.19	1.31	0.91	1.24
	(2.81)	(5.77)	(10.72)	(7.20)	(3.93)	(6.26)	(6.57)	(5.47)	(6.39)
T5	0.16	0.66	2.22	1.01	0.32	0.74	1.09	0.66	0.84
	(2.29)	(4.66)	(8.57)	(5.77)	(3.24)	(4.93)	(5.99)	(4.66)	(5.26)
T6	0.99	1.49	3.00	1.83	1.28	1.32	2.15	1.49	1.66
	(5.71)	(7.01)	(9.97)	(7.77)	(6.49)	(6.59)	(8.43)	(7.01)	(7.40)
T7	0.85	1.16	2.64	1.55	1.05	1.22	2.01	1.36	1.46
	(5.29)	(6.18)	(9.35)	(7.15)	(5.88)	(6.34)	(8.15)	(6.69)	(6.94)
T8	1.93	4.88	10.44	5.75	2.87	3.54	5.43	3.63	4.69
	(7.98)	(12.76)	(18.84)	(13.87)	(9.75)	(10.84)	(13.47)	(10.98)	(12.50)
CD (0.05)	3.34	2.96	3.28	3.07	1.19	1.45	2.66	2.40	1.70
SEM (±)	1.09	0.97	1.07	1.00	0.39	0.47	0.87	0.78	0.59
CV	13.37	23.41	14.99	22.00	16.53	11.84	16.20	20.13	19.68

Figures in the parentheses are angular transformed values.

Table 4. Effect of exogenouslyapplied silicon on white ear head by yellow stem borer (*S. incertulas*) infestation in rice

Treatments	%WE			Pooled WE (%)
	2018	2019	2020	
T1	1.79	13.37	2.66	5.94
	(7.69)	(21.44)	(9.38)	(14.10)
T2	2.04	14.23	2.49	6.25
	(8.21)	(22.15)	(9.08)	(14.47)
T3	1.88	14.35	2.59	6.27
	(7.88)	(22.25)	(9.26)	(14.50)
T4	1.04	8.71	1.67	3.81
	(5.85)	(17.16)	(7.42)	(11.25)
T5	0.87	6.33	1.12	2.77
	(5.35)	(14.57)	(6.07)	(9.58)
T6	1.44	9.80	1.64	4.29

	(6.89)	(18.24)	(7.35)	(11.95)
T7	1.37	8.04	1.48	3.63
	(6.72)	(16.47)	(6.98)	(10.98)
T8	5.71	15.58	8.68	9.99
	(13.82)	(23.24)	(17.13)	(18.42)
CD (0.05)	2.33	3.49	2.10	2.79
SEM (±)	0.76	1.14	0.68	0.91
CV	17.02	10.29	13.11	13.08

Figures in the parentheses are angular transformed values.

Table 5. Effect of exogenouslyapplied silicon on grain and straw yield of rice

Treatments	Grain yield (kg ha^{-1})			Pooled grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})			Pooled straw yield (kg ha^{-1})
	2018	2019	2020		2018	2019	2020	
T1	4733	4300	4639	4557	5436	5196	5561	5398
T2	4967	5133	4778	4959	5533	5927	5667	5709
T3	5163	5190	4917	5090	5667	5892	5778	5779
T4	5483	5542	5528	5518	6235	6367	6556	6386
T5	5600	5733	5806	5713	6733	6700	6778	6737
T6	5223	5436	5500	5386	6133	6343	6611	6362
T7	5278	5578	5611	5489	6333	6541	6444	6439
T8	4640	4083	4306	4343	5500	4820	5389	5236
CD (0.05)	314.49	527.81	294.06	334.72	635.04	139.94	392.39	343.16
SEM (±)	102.69	172.34	96.02	109.30	207.36	45.69	128.13	112.05
CV	3.46	5.83	3.24	3.69	5.99	1.33	3.64	3.23

Table 6. Effect of exogenouslyapplied silicon on morphological characters of rice

Treatments	Plant height (cm)			Pooled plant height (cm)	Panicle sqm^{-1} (No.)			Pooled panicle sqm^{-1} (No.)
	2018	2019	2020		2018	2019	2020	
T1	96.2	102.8	106.8	101.9	139	140	135	138
T2	99.8	108.1	110.3	106.1	150	159	150	153
T3	96.8	109.4	114.3	106.8	171	148	147	155
T4	96.6	110.9	111.5	106.3	152	169	174	165
T5	99.0	109.8	111.8	106.9	169	179	185	178
T6	97.3	109.7	107.7	104.9	155	173	163	164
T7	99.3	110.9	110.3	106.8	163	190	170	174

T8	98.5	103.6	106.8	102.9	135	138	135	136
CD (0.05)	-	-	-	NS	-	-	-	16.04
SEM (±)	-	-	-	1.07	-	-	-	5.24
CV	-	-	-	1.75	-	-	-	5.75

NS: Non-Significant

Table 7. Effect of exogenouslyapplied silicon on silicon per cent (%) over different plant parts and in soil

Treatments	% silicon in leaf	% silicon in straw	% silicon in paddy	% silicon in soil
T1	4.1	2.1	0.94	1.2
T2	2.1	2.8	1.0	1.9
T3	3.4	2.5	1.4	2.3
T4	4.2	3.1	1.3	2.1
T5	6.7	7.3	2.1	3.5
T6	5.4	6.4	1.9	6.7
T7	5.8	6.8	2.0	7.8
T8	0.92	0.86	0.71	0.93

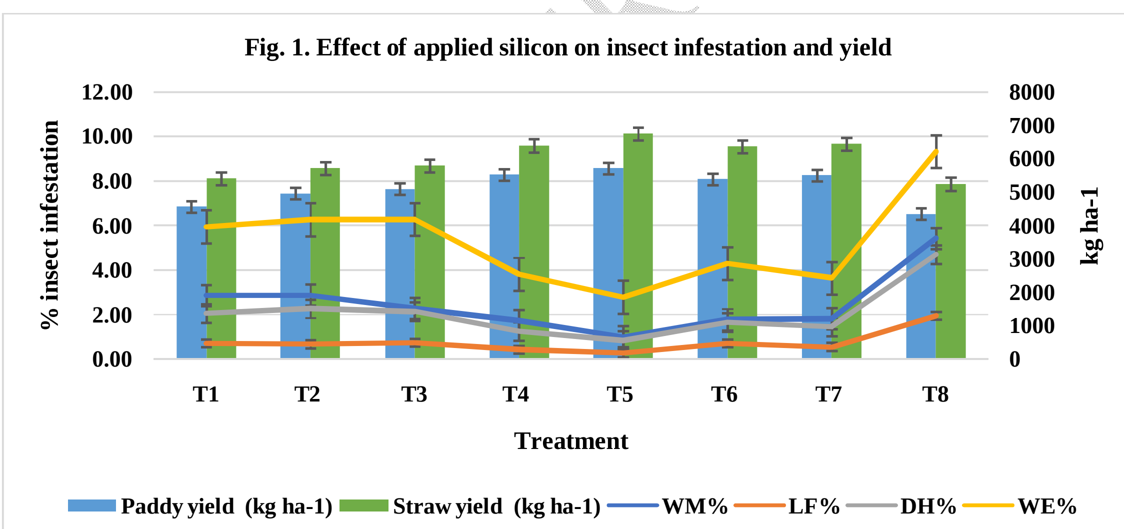

Figure 1. Effect of applied silicon on insect infestation and yield

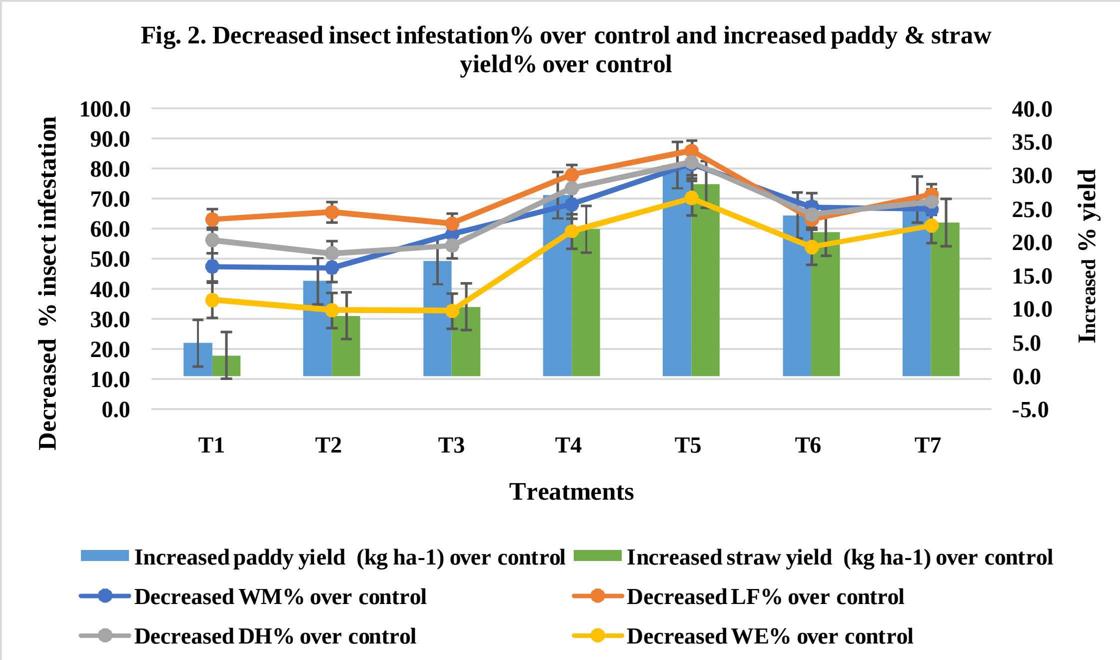

Figure 2. Decreased insect infestation% over control and increased paddy & straw yield% over control

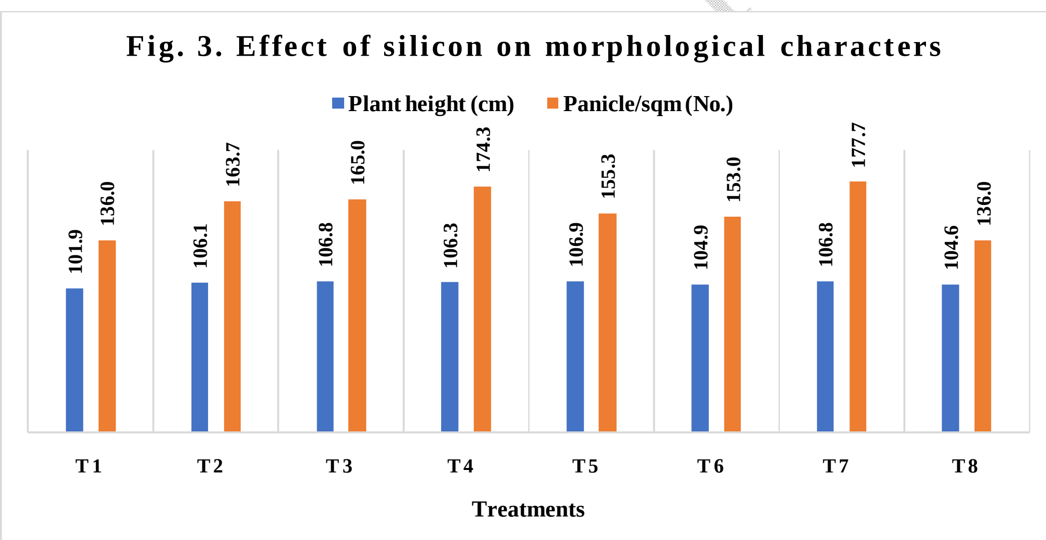

Figure 3. Effect of silicon on morphological characters

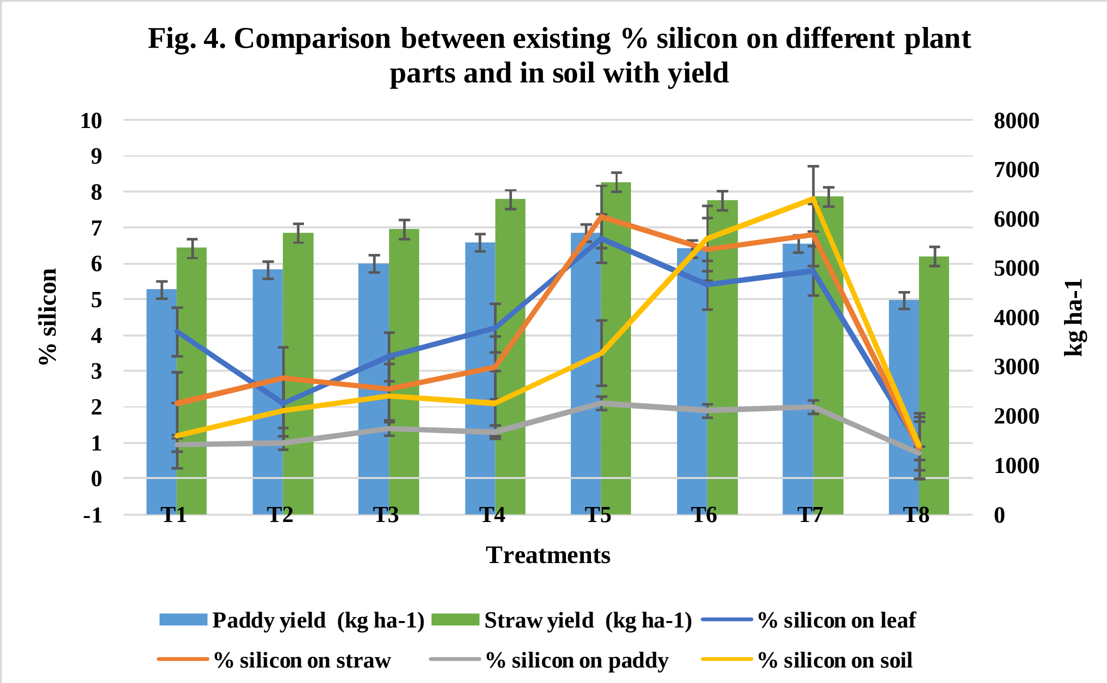

Figure 4. Comparison between existing % silicon on different plant parts and in soil with yield

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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