

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, Hooghly during three consecutive *kharif* season to evaluate the effect of exogenous applied silicon by seed priming, seedling root dipping, foliar sprays and soil applications on the infestation of rice insect-pests and yield of rice. Rice is not important staple food of West Bengal as well as in India. But due to biotic stress, the crop hampers high yield production. When the farming community go ahead for chemical management practices to manage the biotic stress, not only the environment pollution, pesticide residue problem arises but also the chance of pest resurgence and pest resistance problems 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 dipping, foliar spray and soil application as rice is a silicon-loving crop and they accumulate silicon in their body. Additionally, silicon amendment has no detrimental impact on 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 basal treatment have significantly managed rice insects viz. whorl maggot, leaf folder and stem borer and high 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.

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

1. 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 food of more than half of

the world population and rice production and its 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 (Bajyaet *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* and rice leaf folder, *Cnaphalocrocismedinalis* 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). The status of YSB was predicted for future periods in India (Vennila *et al.*, 2019). One of the major insect of rice, yellow stem borer, *S. incertulasis* distributed widely, covering almost all the Asian countries. The YSB 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 the environment, ecosystem, human bodies as 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). Silicon acts 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 body. Our main objective was to increase silicon content in rice plant by applying Si exogenously to manage insect pests of rice.

2. MATERIALS AND METHODS

2.1 Experimental site

A field experiment was conducted on the rice cv *Swarna* (MTU 7029), a high yielding popular rice variety 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.

2.2 Experimental field details

The crop variety, *Swarna* was sown in the raised seed beds @ 50 g m⁻² seeds during 1st week of July without any seed treatment. The transplanting method was carried out by maintaining a distance of row to row and plant to plant as 20 cm and 15 cm respectively, in the plot size of 3m × 4m and around 25-30 days of old seedlings were transplanted in the main field. The recommended doses of fertilizer of N:P₂O₅:K₂O:: 80:40:40 were applied in the transplanted field where 1/4 N + full P₂O₅ + 3/4 K₂O were applied as basal, 1/2 N were applied at 15-20 DAT and the rest 1/4 N + 1/4 K₂O 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.

- T₁ : Seed priming with 3% silica gel [Sodium silicate (Na₂SiO₂)] before sowing (36 hours)
- T₂ : Foliar spray on seedlings with 0.6% silica gel [Sodium silicate (Na₂SiO₂)] on 7 days prior to transplanting
- T₃ : Seedling root dipping with 3% silica gel [Sodium silicate (Na₂SiO₂)] (12 hours)
- T₄ : Foliar spray with 0.6% silica gel [Sodium silicate (Na₂SiO₂)] at 30, 40 and 50 days after transplanting (DAT)
- T₅ : Foliar spray with 1.2% silica gel [Sodium silicate (Na₂SiO₂)] at 30, 40 and 50 DAT
- T₆ : Soil application of granular silica gel [Silicon dioxide (SiO₂) powder] at @ 40 kg ha⁻¹ as basal
- T₇ : Soil application of granular silica gel [Silicon dioxide (SiO₂) powder] at @ 80 kg ha⁻¹ as basal
- T₈ : Control (No application)

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

2.4 Observations and data collection

The insect-pest infestation was determined based on damaged leaves by rice whorl maggot (WM) (*Hydrelliaspp*), folded leaves by leaf folder (LF) (*C.medinalis*) and dead heart (DH) or white ear head (WE) due to attack of yellow stem borer (YSB) (*S.incertulas*) 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 selected randomly from each plot.

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

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

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

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

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

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

The morphological characters of rice such as plant height (in cm) and panicle sqm^{-1} (No.) from each treatment were also recorded in every season. From the standing crop 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 were 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 yield of paddy and straw were converted into kg ha⁻¹.

2.5. 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 $p=0.05$.

3. 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 indicate the 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 characters and comparison between existing per cent silicon on different plant parts and in soil with yield, respectively.

3.1 Effect of exogenous applied 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 sprays with 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 [Sodium silicate (Na_2SiO_2)] treatment (0.85% WM) was found to

lower down the whorl maggot attack maximum followed by foliar spray with 0.6% silica gel [Sodium silicate (Na_2SiO_2)] at 30, 40 and 50 DAT treatment (1.37% WM). The pooled data analysis also revealed the same trend with 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.

3.2 Effect of exogenous applied 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 feeds on 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 [Sodium silicate (Na_2SiO_2)] before sowing for 36 hours treatment (0.26% LF) followed by foliar spray with 1.2% silica gel [Sodium silicate (Na_2SiO_2)] treatment (0.27% LF). Whereas at flowering stage, the lowest leaf folder attack was discernible in foliar spray with 1.2% silica gel [Sodium silicate (Na_2SiO_2)] treatment (0.28% LF) followed by foliar spray with 0.6% silica gel [Sodium silicate (Na_2SiO_2)] 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 [Sodium silicate (Na_2SiO_2)] 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 rates as 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.

3.3 Effect of exogenous applied 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.

3.3.1 Effect of exogenous applied silicon on dead heart

All the silicon applied treatments effectively reduced dead heart damage compared to control plots. Table 3 represented that on 40 DAT, the lowest dead heart (DH) symptoms were recorded in foliar spray with 1.2% silica gel [Sodium silicate (Na_2SiO_2)] treatment (1.01% DH) followed by soil application of granular silica gel [80% Silicon dioxide (SiO_2) powder] 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 [sodium silicate (Na_2SiO_2)] treatment (0.66% DH) was found highest reduction of dead heart followed by foliar spray with 0.6% silica gel [Sodium silicate (Na_2SiO_2)] treatment (0.91% DH). At par trends were calculated in pooled dead heart per cent data where foliar spray with 1.2% silica gel [Sodium silicate (Na_2SiO_2)] treatment (0.84% DH) was the best against dead heart followed by foliar spray with 0.6% silica gel [Sodium silicate (Na_2SiO_2)] treatment (1.24% DH). Figure 1 clearly shows the effect of applied silicon on insect infestation and yield where it proves that applied silicon contains lowers down the insect-pest infestation invariably as well as increase of 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.

3.3.2 Effect of exogenous applied 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 [Sodium silicate (Na_2SiO_2)] treatment (0.87%, 6.33% and 1.12% WE, respectively) followed by foliar spray with 0.6% silica gel [Sodium silicate (Na_2SiO_2)] treatment in 2018 (1.04% WE) and soil application of granular silica gel [80% silicon dioxide (SiO_2) powder] 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 [Sodium silicate (Na_2SiO_2)] treatment (2.77% WE) followed by soil application of granular silica gel [80% silicon dioxide (SiO_2) powder] 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 best performance in both the crop growth stages i.e. vegetative and reproductive stage of the crop amongst 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 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 boring success of rice stem borer larvae into rice stems decreased in plants supplied with silicon. Our present findings on impact of silicon amendments against yellow stem borer are in close conformity with reports of Han and Hou (2011) and Mishra et al. (2018) who reported 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.

3.4 Effect of exogenous applied silicon on grain and straw yield of rice

The yield of paddy and straw obtained from each treatment excluding two boarder rows were noted down and converted into kg ha^{-1} . The result revealed that the lowest paddy and straw yield were obtained from control plots in all the seasons. The highest grain yield as $5600, 5733, 5806 \text{ kg ha}^{-1}$ and straw yield as $6733, 6700, 6778 \text{ kg ha}^{-1}$ were recorded from foliar spray with 1.2% silica gel [Sodium silicate (Na_2SiO_2)] treatment in *kharif* 2018, 2019 and 2020, respectively. The next best yield was obtained from soil application of granular silica gel [80% silicon dioxide (SiO_2) powder] @ 80 kg ha^{-1} as basal treatment as $5278, 5578,$

5611 kg ha⁻¹ grain yield and 6333, 6541, 6444 kg ha⁻¹ straw yield in *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 SiO₂ 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 SiO₂ ha⁻¹ over the control plots was insignificant; this is due to the lack of a difference in number of effective panicles.

3.5 Effect of exogenous applied 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 [Sodium silicate (Na₂SiO₂)] 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 [Sodium silicate (Na₂SiO₂)] treatment (178) followed by soil application of granular silica gel [80% Silicon dioxide (SiO₂) powder] @ 80 kg ha⁻¹ as basal treatment (174). Fig. 3 shows the effect of applied silicon exogenously on morphological characters of rice.

3.6 Effect of exogenous applied silicon on silicon percent over different plant parts and in soil

The silicon per cent over different plant parts and in soil were 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 [Sodium silicate (Na_2SiO_2)] treatment and the second highest silicon per cent was recorded in soil application of granular silica gel [80% Silicon dioxide (SiO_2) powder] @ 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% Silicon dioxide (SiO_2) powder] @ 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 application of silicon exogenously, the grain and straw yield were also increased simultaneously.

4. CONCLUSION

Our study demonstrates that in a field condition the crop damage by whorl maggot, leaf folder and stem borer were significantly lowered down as well as higher grain and straw yield were obtained in 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 as well as the yield 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.

5. ACKNOWLEDGEMENT

Authors are thankful to Dr. Somsubhra Chakraborty, Associate Professor, Department of Food Engineering, IIT, Kharagpur for testing the silicon content existing in different plant parts and in soil towards this research study.

Table 1. Effect of exogenous applied silicon on whorl maggot (*Hydrelliaspp*) infestation

Treatments	WM% 40 DAT			Mean WM%	WM% 50 DAT			Mean WM%	Pooled WM%
	2018	2019	2020		2018	2019	2020		
T1	2.53	2.19	3.16	2.63	2.40	2.13	4.69	3.07	2.85

	(9.15)	(8.51)	(10.24)	(9.32)	(8.91)	(8.39)	(12.50)	(10.09)	(9.72)
T2	2.79	2.45	2.79	2.68	2.80	2.62	3.77	3.06	2.87
	(9.61)	(9.00)	(9.61)	(9.41)	(9.63)	(9.31)	(11.19)	(10.07)	(9.75)
T3	1.75	1.41	3.25	2.14	2.87	1.60	2.72	2.40	2.27
	(7.60)	(6.82)	(10.38)	(8.40)	(9.75)	(7.26)	(9.49)	(8.91)	(8.66)
T4	1.72	2.81	1.75	2.09	1.42	1.06	1.62	1.37	1.73
	(7.53)	(9.65)	(7.60)	(8.32)	(6.84)	(5.91)	(7.31)	(6.72)	(7.55)
T5	1.06	0.94	1.46	1.15	0.87	0.45	1.23	0.85	1.00
	(5.91)	(5.56)	(6.94)	(6.16)	(5.35)	(3.84)	(6.36)	(5.29)	(5.74)
T6	1.93	1.60	1.95	1.83	1.45	1.54	2.18	1.72	1.78
	(7.98)	(7.26)	(8.02)	(7.76)	(6.91)	(7.13)	(8.49)	(7.53)	(7.66)
T7	2.06	2.06	2.00	2.04	1.34	1.47	1.97	1.59	1.82
	(8.25)	(8.25)	(8.13)	(8.21)	(6.64)	(6.96)	(8.07)	(7.24)	(7.75)
T8	4.52	5.42	3.95	4.63	5.35	4.40	8.85	6.20	5.42
	(12.27)	(13.46)	(11.46)	(12.42)	(13.37)	(11.46)	(17.30)	(14.41)	(13.46)
CD (0.05)	1.78	2.71	1.83	1.76	2.43	1.78	1.93	1.62	1.24
SEM (\pm)	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 exogenous applied silicon on leaf folder (*C. medinalis*) infestation

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

CD (0.05)	NS	1.02	NS	NS	NS	1.53	2.48	2.09	1.44
SEM (\pm)	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

Figures in the parentheses are angular transformed values.

Table 3. Effect of exogenous applied silicon on dead heart by yellow stem borer (*S. incertulas*) infestation

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

Treatments	WE%			Pooled WE%
	2018	2019	2020	
T1	1.79 (7.69)	13.37 (21.44)	2.66 (9.38)	5.94 (14.10)
T2	2.04 (8.21)	14.23 (22.15)	2.49 (9.08)	6.25 (14.47)

T3	1.88 (7.88)	14.35 (22.25)	2.59 (9.26)	6.27 (14.50)
T4	1.04 (5.85)	8.71 (17.16)	1.67 (7.42)	3.81 (11.25)
T5	0.87 (5.35)	6.33 (14.57)	1.12 (6.07)	2.77 (9.58)
T6	1.44 (6.89)	9.80 (18.24)	1.64 (7.35)	4.29 (11.95)
T7	1.37 (6.72)	8.04 (16.47)	1.48 (6.98)	3.63 (10.98)
T8	5.71 (13.82)	15.58 (23.24)	8.68 (17.13)	9.99 (18.42)
CD (0.05)	2.33	3.49	2.10	2.79
SEM (\pm)	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 exogenous applied silicon on grain and straw yield of rice

Treatments	Paddy yield (kg ha ⁻¹)			Pooled paddy 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 (\pm)	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 exogenous applied 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 (\pm)	-	-	-	1.07	-	-	-	5.24
CV	-	-	-	1.75	-	-	-	5.75

Table 7. Effect of exogenous applied 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

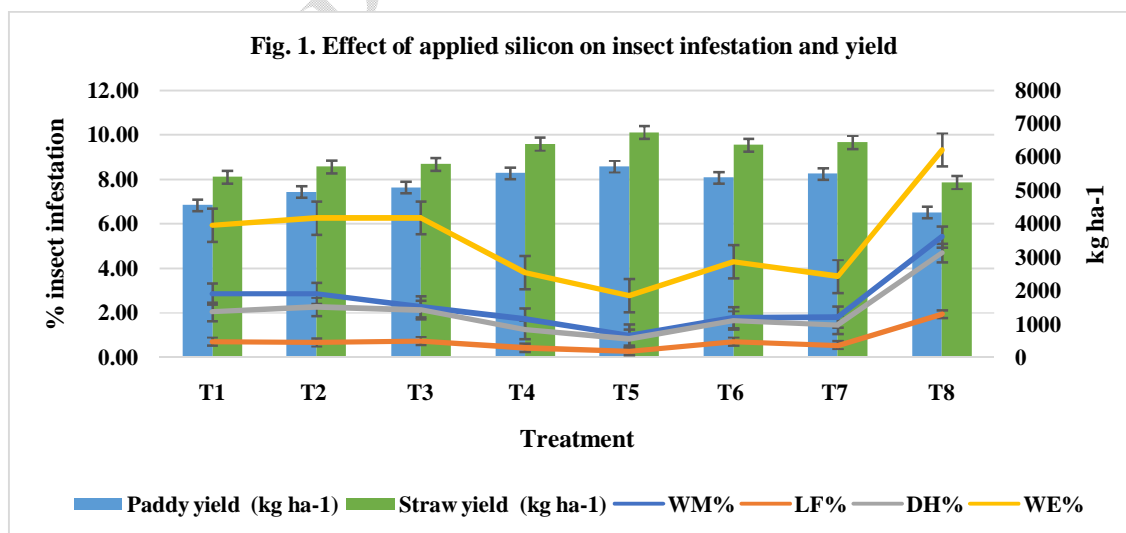


Fig. 2. Decreased insect infestation% over control and increased paddy & straw yield% over control

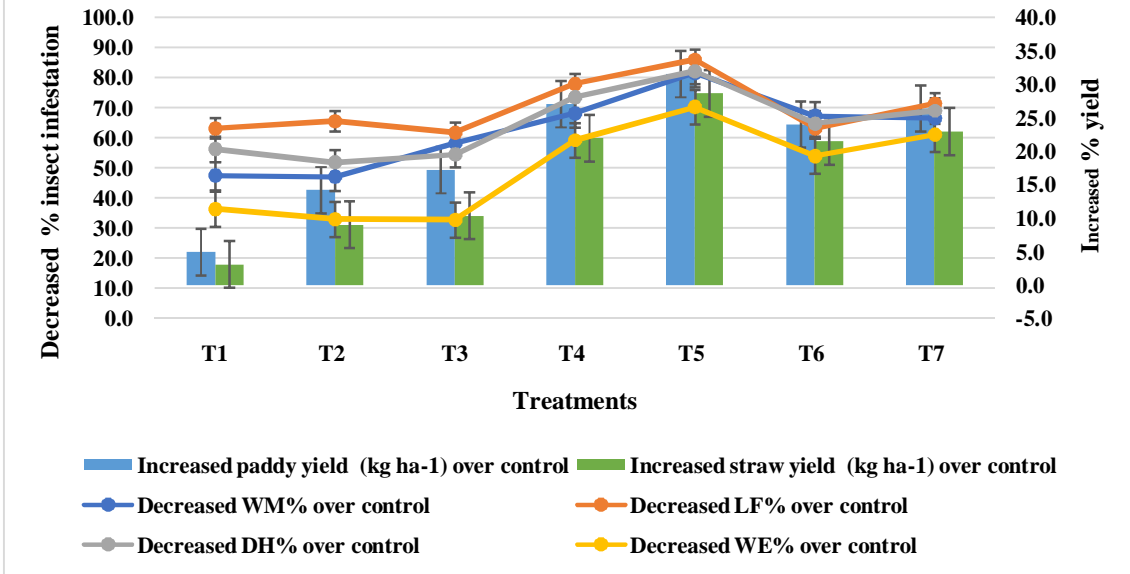
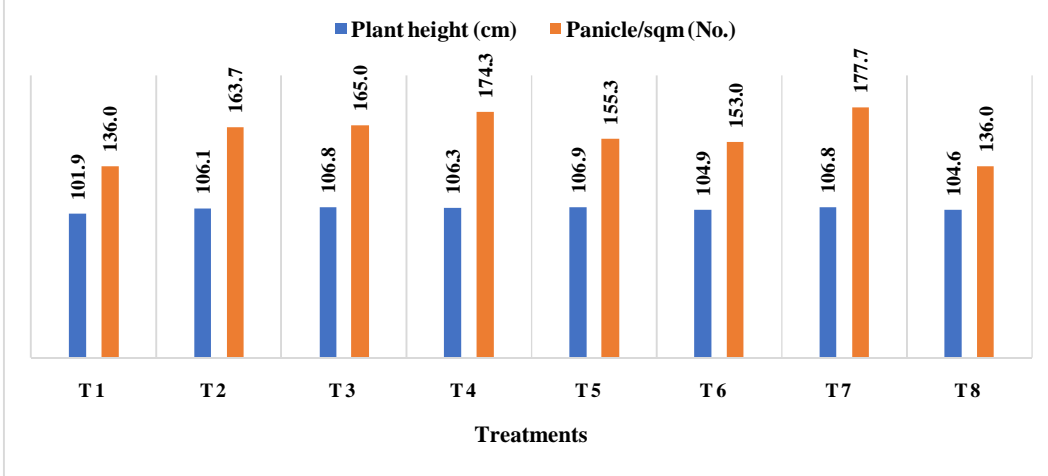
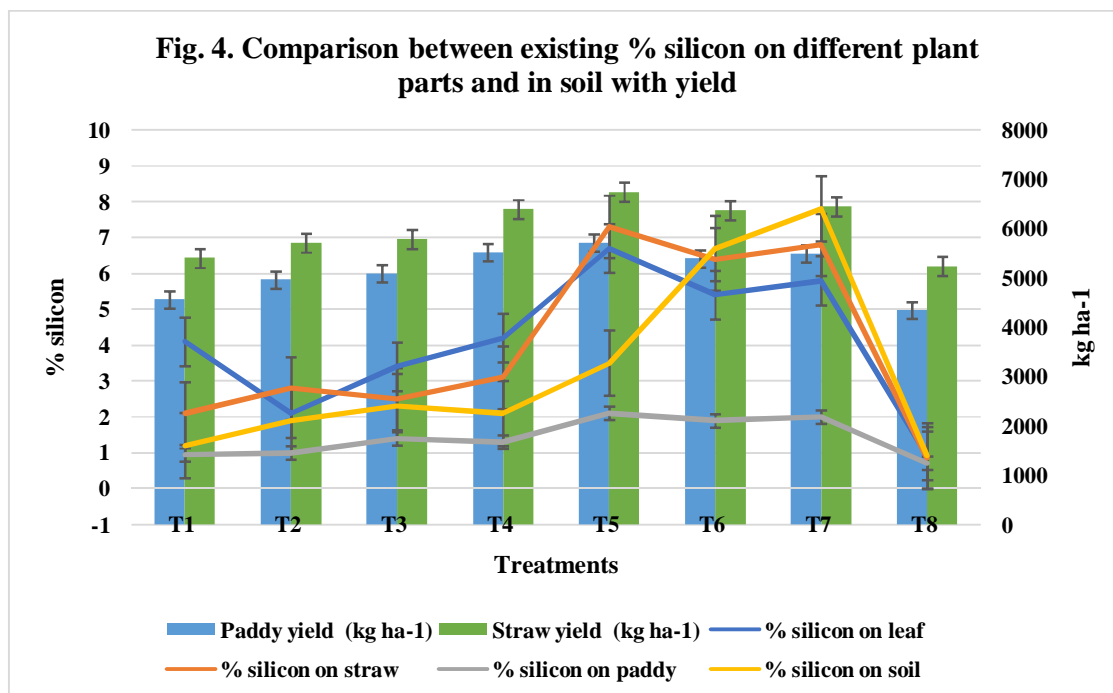


Fig. 3. Effect of silicon on morphological characters





6. REFERENCE

Alvarez, J and Datno, L E. 2001. The economic potential of silicon for integrated management and sustainable rice production. *Crop Protection*. **20**:43–48.

Bajya, D.R., Monga, D., Meena, B.L. and Tyagi, M.P. 2010. Insecticide Resistance Management strategies for managing cotton pest complex. *Annals of Plant Protection Sciences*.**18**(1):1-5.

Chandramani, P; Rajendran, R; Muthiah, C; Chinniah, C. 2010. Organic source induced silica on leaf folder, stem borer and gall midge population and rice yield. *Journal of Biopesticides*.**3**(2):423-427.

Chatterjee, S. and Mondal, P. 2014. Management of rice yellow stem borer, *Scirpophagaintertulas*Walker using some biorational insecticides. *Journal of Biopesticides*. **7**:143-47.

Chatterjee, S and Mondal, P. 2020. Impact of nitrogen and potash on the incidence of *Scirpophagaintertulas* and *Cnaphalocrocismedinalis* and yield of rice. *International Journal of Bio-resource and Stress Management*.**11**(5):482-487.

Chatterjee, S; Dana, I; Gangopadhyay, C and Mondal, P. 2017. Monitoring of yellow stem borer, *Scirpophagaintertulas* (Walker) using pheromone trap and light trap along with determination of field incidence in *kharif* rice. *Journal of Crop and Weed*. **13**: 156-159.

Chatterjee, S; Gangopadhyay, C and Roy, S K. 2015. Management of rice insects by granular formulation of chlorantraniliprole along with foliar sprays of some new molecules. *The Journal of Plant Protection Sciences*. **7**(1-2):6-13.

Chatterjee, S; Gangopadhyay, C; Bandyopadhyay, P; Bhowmick, MK; Roy, SK; Majumder, A; Gathala, MK; Tanwar, RK; Singh, SP, Birah, A and Chattopadhyay, C. 2020. Input-based assessment on integrated pest management for transplanted rice (*Oryza sativa*) in India. *Crop Protection*., 10-27. <https://doi.org/10.1016/j.cropro.2020.105444>.

Chatterjee, S; Halder, P; Gangopadhyay, C; Dana, I and Halder, A. 2019. Field screening of few popularly grown and some newly developed rice varieties against different insect-pests in wet season. *International Journal of Research Culture Society*. **3**(7): 45-50.

Chatterjee, S; Ghose, M and Gangopadhyay, C. 2016. Field screening of different rice entries against different insect-pests of rice during *kharif* season. *International Journal of Agriculture Environment and Biotechnology*.**9**(4): 667-671.

Detmann, K C; Araújo, W L; Martins, S C; Sanglard, L M V P; Reis, J V; Detmann, E; Rodrigues, F Á; Nunes-Nesi, A; Fernie, A R and DaMatta, F M. 2012. Silicon nutrition increases grain yield, which, in turn, exerts a feed-forward stimulation of photosynthetic rates via enhanced mesophyll conductance and alters primary metabolism in rice. *New Phytologist*. **196**:752–762.

Fallah, A; Osko, T; Khosravi, V; Mohammadian, M and Rosttami, M. 2011. Reduction of chemical pesticides by using silicate fertilizer in paddy fields. In: *Proceedings of 5th International Conference on Silicon in Agriculture*, Beijing, China, 46.

Gangopadhyay, C and Chatterjee, S. 2020. Pesticidal compatibility against yellow stem borer and sheath blight in *kharif* and *rabi* Rice. *International Journal of Current Microbiology and Applied Sciences*.**9**(11):261-268.

Han, Y Q; Gong, S L; Wen, L Z and Hou, M L. 2017. Effect of silicon addition to rice plants on *Cnaphalocrocismedinalis* feeding and oviposition preference. *Acta Ecologica Sinica*. **37**: 1623–1629. (in Chinese)

Han, Y; Lei, W; Wen, L and Hou, M. 2015. Silicon-mediated resistance in a susceptible rice variety to the rice leaf folder, *Cnaphalocrocismedinalis* Guenée (Lepidoptera: Pyralidae). *PLoS ONE*. **10**:e0120557.

Han, Y; Li P; Gong, S; Yang, L; Wen, L and Hou, M. 2016. Defense responses in rice induced by silicon amendment against infestation by the leaf folder *Cnaphalocrocismedinalis*. *PLoS ONE*. **11**:e0153918.

Han, Yong-qiang; Wen, Ji-hui; Peng, Zhao-pu; Zhang, De-yong; Hou, Mao-lin; 2018. Effects of silicon amendment on the occurrence of rice insect pests and diseases in a field test; *Journal of Integrative Agriculture*. **17**(10): 2172–2181.

Han, YQ and Hou M. 2011. Silicon mediated rice plant resistance to the rice stem borer *Chilo suppressalis*: Effects of silicon treatment, rice varietal resistance and larval stage. In: *Proceedings of the 5th International Conference on Silicon in Agriculture*. 62-63.

Hao, L X; Han, Y Q; Hou, M L and Liao, X L. 2008. Resistance of japonica rice varieties in Liaoh Valley to *Chilo suppressalis* and its underlying mechanisms. *Acta Ecologica Sinica*. **28**, 5987–5993. (in Chinese).

Hartley, S E; Fitt, R N; McLarnon, E L and Wade, R N. 2015. Defending the leaf surface: Intra- and inter-specific differences in silicon deposition in grasses in response to damage and silicon supply. *Frontiers in Plant Science*. **6**:35.

Hossain, M T; Mori, R; Soga, K; Wakabayashi, K; Kamisaka, S; Fujii, S; Yamamoto, R and Hoson, T. 2002. Growth promotion and an increase in cell wall extensibility by silicon in rice and some other Poaceae seedlings. *Journal of Plant Research*. **115**:23–27.

Hou, M and Han, Y. 2010. Silicon-mediated rice plant resistance to the Asiatic rice borer (Lepidoptera: Crambidae): Effects of silicon amendment and rice varietal resistance. *Journal of Economic Entomology*. **103**:1412–1419.

Isa, M; Bai, S; Yokoyama, T; Ma, J F; Ishibashi, Y; Yuasa, T and Iwayanoue, M. 2010. Silicon enhances growth independent of silica deposition in a low-silica rice mutant. *lsi1*. *Plant and Soil*, **331**:361–375.

Jeer, M; Telugu U M; Voleti S R and Padmakumari, A P. 2017. Soil application of silicon reduces yellow stem borer, *Scirpophagaintertulas* (Walker) damage in rice. *Journal of Applied Entomology*. **141**:189–201.

Kvedaras, O L; An, M; Choi, Y S and Gurr, G M. 2010. Silicon enhances natural enemy attraction and biological control through induced plant defences. *Bulletin of Entomological Research*. **100**:367–371.

Liang, Y; Hua, H; Zhu, Y; Zhang, J; Cheng, C and Römheld, V. 2006. Importance of plant species and external silicon concentration to active silicon uptake and transport. *New Phytologist*. **172**:63–72.

Liu, J; Zhu, J; Zhang, P; Reynolds, O L; Han, L; Wu, J; Shao, Y; You, M and Gurr, G M. 2017. Silicon supplementation alters the composition of herbivore induced plant volatiles and enhances attraction of parasitoids to infested rice plants. *Frontiers in Plant Science*. **8**:1265.

Ma, J. 2004. Role of silicon in enhancing the resistance of plants to biotic and abiotic stresses. *Soil Science & Plant Nutrition*. **50**:11–18.

Ma, J and Yamaji, N. 2006. Silicon uptake and accumulation in higher plants. *Trends in Plant Science*. **11**:392–397.

Ma, JF and Takahashi, E. 2002. Soil, Fertilizer, and Plant Silicon Research in Japan. *Elsevier Science*, Amsterdam.

Massey, F P and Hartley, S E. 2009. Physical defences wear you down: Progressive and irreversible impacts of silica on insect herbivores. *Journal of Animal Ecology*. **78**:281–291.

Mishra, Ipsita OP; Panda, SK and Dash, AB. 2018. Effect of organic and inorganic silicon amendments against yellow stem borer (*Scirpophagaincertulas* Walker) and leaf folder (*Cnaphalocrocismedinalis* Guenee) of rice in Costal Odisha. *Journal of Entomology and Zoology Studies*. **6**(3):1495-1499.

Pati, S; Pal, B; Badole, S; Hazra, G G and Mandal, B. 2016. Effect of silicon fertilization on growth, yield, and nutrient uptake of rice. *Communications in Soil Science and Plant Analysis*. **47**:284–290.

Reynolds, O L; Padula, M P; Zeng, R and Gurr, G M. 2016. Silicon: Potential to promote direct and indirect effects on plant defense against arthropod pests in agriculture. *Frontiers in Plant Science*. **7**:744.

Savant, N K; Snyder, G H and Datnoff, L E. 1997. Silicon management and sustainable rice production. *Advances in Agronomy*. **58**:151–199.

Sidhu, J K; Stout, M J; Blouin, D C and Datnoff, L E. 2013. Effect of silicon soil amendment on performance of sugarcane borer, *Diatraea saccharalis* (Lepidoptera: Crambidae) on rice. *Bulletin of Entomological Research*. **103**:656–664.

Singh, Banhishikha and Chatterjee, Suresh. 2021. Relative efficacy of some biorational and microbial insecticides against yellow stem borer and whorl maggot of *boro* paddy. *Journal of Biopesticides*. **14**(2):90-96.

Tamai, K and Ma, J. 2008. Reexamination of silicon effects on rice growth and production under field conditions using a low silicon mutant. *Plant and Soil*. **307**:21–27.

Vennila, S; Bagri, M; Tomar, A; Rao, MS; Sarao, PS; Sharma, S; Jalgaonkar, V; Kumar, MKP; Suresh, S; Mathirajan, VG; Chatterjee, S; Tanwar, RK; Kumari, A and Prabhakar, M. 2019. Future of rice yellow stem borer *Scirpophagaincertulas* (Walker) under changing climate. *National Academy Science Letters*. [https:// doi.org/10.1007/s40009-018-0751-x](https://doi.org/10.1007/s40009-018-0751-x)

Voleti, S R; Padmakumari, A P; Raju, V S; Babu, S M and Ranganathan, S. 2008. Effect of silicon solubilizers on silica transportation, induced pest and disease resistance in rice (*Oryza sativa* L.). *Crop Protection*. **27**:1398–1402.

Yamamoto, T; Nakamura, A; Iwai, H; Ishii, T; Ma, J F; Yokoyama, R; Nishitani, K; Satoh, S and Furukawa, J. 2012. Effect of silicon deficiency on secondary cell wall synthesis in rice leaf. *Journal of Plant Research*. **125**:771–779.

Yang, L; Han, Y; Li, P; Li, F; Ali, S and Hou, M. 2017a. Silicon amendment is involved in the induction of plant defense responses to a phloem feeder. *Scientific Reports*. **7**:4232.

Yang, L; Han, Y; Li, P; Wen, L and Hou, M. 2017b. Silicon amendment to rice plants impairs sucking behaviors and population growth in the phloem feeder *Nilaparvatalugens* (Hemiptera: Delphacidae). *Scientific Reports*. **7**:1101.

Yang, L; Li, P; Li, F; Ali, S; Sun, X and Hou, M. 2018. Silicon amendment to rice plants contributes to reduced feeding in a phloem sucking insect through modulation of callose deposition. *Ecology and Evolution*. **8**:631–637.

Ye, M; Song, Y; Long, J; Wang, R; Baerson, S R; Pan, Z; Zhu Salzman, K; Xie, J; Cai, K; Luo, S and Zeng, R. 2013. Priming of jasmonate-mediated antiherbivore defense responses in rice by silicon. *Proceedings of the National Academy of Sciences of the United States of America*. **110**:E3631-E3639.