EFFECT OF SILICON ON INSECT PESTS OF RICE, *Oryza sativa* LINNAEUS

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EFFECT OF SILICON ON INSECT PESTS OF RICE, *Oryza sativa* LINNAEUS

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ABSTRACT

Investigations on effect of silicon application on insect pest population / damage in rice, chemical and biochemical constituents of rice plants, natural enemies of rice insect pests and oviposition preference as well as antibiosis effect on yellow stem borer, *Scirpophaga incertulas* (Walker) were carried out at Agricultural Research Station, Anand Agricultural University, Derol, Dist. Panchmahal, Gujarat during the year 2011 to 2014.

Four doses of calcium silicate (500, 1000, 1500 and 2000 kg/ha) applied into soil at the time of transplanting and three concentrations (0.5, 1.0 and 2.0 %) of potassium silicate applied as foliar spray at 30, 45 and 60 days after transplanting were evaluated along with control for their efficacy against yellow stem borer, *S. incertulas,* leaffolder, *Cnaphalocrocis medinalis* (Guenee), whitebacked planthopper *Sogatella furcifera* (Horvath) and green leafhopper, *Nephotettix virescens* (Distant) under field conditions.

All the doses of soil application (SA) of calcium silicate were effective in reducing deadhearts and white earheads due to *S. incertulas* in rice. The most effective treatment was SA of calcium silicate @ 2000 kg/ha followed by calcium silicate @ 1500 kg/ha.

Calcium silicate (500 to 2000 kg/ha) and potassium silicate @ 2.0 per cent reduced leaf damage due to *C. medinalis* in rice. Calcium silicate @ 2000 kg/ha was found to be most effective followed by calcium silicate @ 1500 kg/ha.

All the four doses of calcium silicate reduced the population of *S. furcifera*. SA of calcium silicate @ 2000 kg/ha was the most effective treatment followed by calcium silicate @ 1500 kg/ha.

The most effective treatment for *N. virescens* in rice was calcium silicate @ 2000 kg/ha followed by calcium silicate @ 1500 and 1000 kg/ha.

The highest grain (5015 kg/ha) and straw (5690 kg/ha) yield of rice was obtained in the treatment of calcium silicate @ 2000 kg/ha followed by calcium silicate @ 1500 kg/ha and 1000 kg/ha. All three concentrations of potassium silicate could not increase grain yield when compared with control.

Nitrogen, sodium, iron and manganese content in rice plant decreased with increase in the doses of calcium silicate, whereas phosphorus, potassium and calcium content increased with increase in the dose of calcium silicate. Sulphur, zinc and copper content in plant was not affected by silicon application in the form either calcium silicate or potassium silicate.

Plant silica content was significantly negatively correlated with nitrogen, sodium, iron and manganese content, while it was significantly positively correlated with phosphorus, potassium and calcium content.

Silica, phosphorus, potassium and calcium content in plant was significantly negatively correlated with white earheads due to *S. incertulas,* leaf damage due to *C. medinalis* and population of *S. furcifera* in rice. Nitrogen content showed significantly positive relationship with white earheads due to *S. incertulas,* leaf damage due to *C. medinalis* and population of *S. furcifera* in rice.

Total phenol content in rice plant increased with increase in the dose of calcium silicate, whereas total sugar, crude protein and free amino acid content decreased with increase in the dose of calcium silicate.

The correlation coefficient between plant silica and phenol content was significantly positive, while the correlation coefficient between silica and total sugar, crude protein as well as free amino acid content was significantly negative. Plant phenol content was significantly negatively correlated with white earheads due to *S. incertulas,* leaf damage due to *C. medinalis* and population of *S. furcifera* in rice. On the other hand, total sugar, crude protein and free amino acid content were significantly positively correlated with incidence of all above insect pests.

Application of silicon in the form of either calcium silicate or potassium silicate did not adversely affect the population of spider and the parasitism of *S. incertulas* eggs by two egg hymenopteran parasitoids *viz., Tetrastichus schoenobii* Ferriere and *Telenomus dignus* (Gahan).

Scirpophaga incertulas females equally preferred silicon applied and control plant for egg laying in free-choice test.

Silicon application to rice plants @ 1 g/kg soil prolonged the larval period and duration of all five instars of *S. incertulas.* It also reduced body weight of all instars except first instar larva. Silicon application to rice plants did not affect the duration of pre-pupa, while it increased pupal period and reduced pupal weight. The pre-oviposition, oviposition and post-oviposition period of female was not affected by silicon application. In contrast to this, the longevity of females that received silicon applied (Si+) stem during larval stage as food was significantly shorter than the females that received stems without silicon (Si-) during larval stage as food. The male longevity was not affected by the type of food received during the larval stage. Number of egg masses laid by a female and hatching percentage was not affected by silicon, whereas Si+ females laid significantly lesser number of eggs than Si- females. The sex ratio (male : female) of adults developed from Si+ treatment was 1 : 1.60, whereas it was 1 : 1.80 for Si- treatment.

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C E R T I F I C A T E

This is to certify that the thesis entitled **"Effect of silicon on insect pests of rice, *Oryza sativa* Linnaeus"** submitted by **PATEL SHAILESH DALPATBHAI (Reg. No. 04-1501-2010)** in partial fulfillment of the requirements for the degree of ***Doctor of Philosophy*** in **Agricultural Entomology** of the Anand Agricultural University is a record of bonafide research work carried out by him under my guidance and supervision. The thesis has not previously formed the basis for the award of any degree, diploma or other title.

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DECLARATION

This is to declare that the whole of the research work reported herein for the partial fulfillment of the requirement for the degree of ***Doctor of Philosophy*** in ***Agricultural Entomology*** by the undersigned is the result of investigation done by me under the guidance and supervision of **Dr. P. K. Borad,** Professor and Head, Department of Agricultural Entomology, B. A. College of Agriculture, Anand Agricultural University, Anand and no part of work has been submitted for any other degree so far.

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LIST OF ABBREVIATIONS

Si	:	Silicon
Si+	:	With silicon
Si-	:	Without silicon
Anon.	:	Anonymous
@	:	At the rate of
Fig.	:	Figure
^{0}C	:	Degree Celsius
viz.,	:	Namely
%	:	Per cent
Ppm	:	Parts per million
et al.	:	*Et allii*; and others
etc.	:	Etcetera
=	:	Equal to
>	:	Greater than
<	:	Less than
Ha	:	Hectare
i. e.	:	That is
G	:	Gram
Mg	:	Milligram
µg	:	Microgram
kg/ha	:	Kilogram per hectare
M	:	Meter
Cm	:	Centimeter
Mm	:	Millimeter
Nm	:	Nanometer
L	:	Litre
Ml	:	Milliliter
NS	:	Non significant
S. D.	:	Standard Deviation
C. V.	:	Coefficient of Variance
C. D.	:	Critical Difference
S. Em. ±	:	Standard Error of mean
a. i.	:	Active Ingredient
M	:	Molar
mM	:	Millimolar
µm	:	Micron

I. INTRODUCTION

Rice, *Oryza sativa* Linnaeus is a staple food for more than half of the world's population. Rice, wheat and maize are leading food crops in the world; together they directly supply more than 50 per cent of all calories consumed by the entire human population. Wheat is the leader in area harvested each year with 222 million hectare followed by rice with 148 million hectare and maize with 133 million hectare (Maclean, 1997). Human consumption accounts for 85 per cent of total production for rice compared with 60 per cent for wheat and 25 per cent for maize. Rice is cultivated in 113 countries and on all the continents except Antarctica (FAO, 2003). Rice is the staple food for 17 countries in Asia and the Pacific, eight countries in Africa, seven countries in Latin America and the Caribbean and one in the Near East (FAO, 2003). When all developing countries are considered together, rice provides 27 per cent of dietary energy supply and 20 per cent of dietary protein intake (FAO, 2003). Considering its important position, the United Nations declared year 2004 as the international year of rice (FAO, 2003). Devoting a year to a commodity was unprecedented in United Nations history.

Asia is considered to be a "Rice Bowl" of world occupying 90 per cent of world's rice area. China and India are two largest rice producing countries. In India, during the year 2013-14, *kharif* and summer rice occupied the area of 44.14 million hectare with the production and productivity of 106.65 million tonne and 2416 kg/ha, respectively (Anon., 2015a). While, in the same year it covered the area of 7.88 lac hectare in Gujarat state with the total production and productivity of 16.36 lac tonne and 2076 kg/ha, respectively (Anon., 2015a). In Gujarat, the rice occupied about 5 per cent of the gross cropped area of the state and accounted for around 14 per cent of the total food grain production (Mehta, 2010). The major rice growing districts in Gujarat (in descending order) are Ahmedabad, Anand, Kheda, Panchmahal, Valsad, Surat, Navsari, Vadodara, Tapi and Dahod (Anon., 2015b).

The production constraints in rice cultivation are lack of high yielding, disease and pest resistant varieties, inadequate or excess use of fertilizers, poor water management and non-adaptability of recommended management strategies (Siddiq, 2000). In India, annual yield losses were estimated to the tune of Rs. 6000-7000 crore, maximum loss being attributed to diseases (26 %) followed by weeds (23 %), insects (20 %) and rest by birds and nematodes (Raju, 2000). Rice is attacked by more than 100 species of insects, of which about 20 are major pests (Pathak and Saxena, 1980). Some of these are localized in certain regions, while others are widespread. Sharma and Nayak (2005) listed the major insect pests attacking rice crop, which included stem borers [*Scirpophaga incertulas* (Walker), *Scirpophaga innotata* (Walker) and *Sesamia inferens* (Walker)], gall midge [*Orseolia oryzae* (Wood-Mason)], brown planthopper [*Nilaparvata lugens* (Stal)], whitebacked planthopper [*Sogatella furcifera* (Horvath)], rice leaf folder [*Cnaphalocrocis medinalis* (Guenee)], rice hispa [*Dicladispa armigera*

(Oliver)], green leafhopper [*Nephotettix virescens* (Distant) and *Nephotettix nigripictus* (Stal)], rice bugs [*Leptocorisa oratorius* (Fabricius) and *Leptocorisa acuta* (Thunberg)] and rice case worm [*Nymphula depunctalis* (Guenee)]. Major insect pests infesting rice under middle Gujarat conditions are *S. incertulas, C. medinalis, S. furcifera* and *N. virescens*. The losses caused by insect pest complex infesting rice crop in Gujarat have been estimated to be Rs. 15.6 crore annually (Pathak, 1996).

For many decades, insecticides have been widely used to control rice pests. However, continuous use of wide range of insecticides has caused many side effects including development of resistance against insecticide, residue of insecticides in foodstuffs, destruction of natural enemies, minor pest becoming major pest, environmental pollution, resurgence of sucking pests and loss of biodiversity. Of all insect control methods, the planting of pest resistant varieties is the most effective because, it leaves no insecticide residue in food or the environment and is constantly effective (Ukwungwu, 1990). However, pest damage may also be reduced through careful management of nutrient requirements of the crop or amendments with mineral nutrients, such as silicon (Si), that reduce crop susceptibility to pests (Meyer and Keeping, 2005).

Sasamoto (1961) found that an increase in the Si content of rice when grown in Si supplied soils and a parallel decrease in their susceptibility to the stem borer, *Chilo suppressalis* Walker. Similarly, Panda *et al.* (1975) reported that the larvae of yellow stem borer, *S. incertulas* were unable to attack resistant rice plants because of high silica content of their stems. Addition of silicate materials significantly reduced the incidence of *C. medinalis* and *O. oryzae* in rice at tillering stage (Subramanian and Gopalswamy, 1991). Salim and Saxena (1992) found that at high levels of Si, fewer planthopper nymphs became adults and there was decrease in adult longevity and female fecundity. Very few workers have studied the effect of silicon application on insect pests of rice in India and such studies have not been reported from Gujarat. Hence, it was thought worthwhile to conduct an investigation on impact of soil and foliar application of silicon on insect pests of rice and their natural enemies with following objectives.

OBJECTIVES

1. To study the effect of silicon application on insect pest population / damage in rice.
2. To study the effect of silicon application on chemical and biochemical constituents of rice plants.
3. To study the effect of silicon application on natural enemies of rice insect pests.
4. To study the effect of silicon application on oviposition preference and its antibiosis effects on *S. incertulas.*

II. REVIEW OF LITERATURE

Silicon (Si) is the second most abundant element in the soil (following oxygen) and comprises up to 28 per cent of the earth's crust (Epstein, 1999). Although silicon is not considered an essential element for the majority of plants, the beneficial effects of this element on growth, development, yield, stress resistance and defence have been well documented in many plant species. Silicon treatments have been shown to be beneficial for plants exposed to array of abiotic and biotic stresses (Ma, 2004). The literature available on various aspects of effects of silicon on insect pests of rice is vast and voluminous, but those have direct and indirect relevance to the present study have been reviewed in this chapter.

2.1 SILICON ABSORPTION, TRANSLOCATION AND ACCUMULATION IN PLANTS

Since rice is a well-known silicon accumulator and an important scientific model organism, the silicon uptake mechanism has been most intensively studied in this plant species. Silicon is readily absorbed by plant roots in the form of uncharged monosilicic acid [$Si(OH)_4$] (Ma and Yamaji, 2006). After uptake by the roots, silicon is translocated to the shoot via the xylem. In the shoot, silicic acid is further concentrated through loss of water (transpiration) and is polymerized. The process of Si polymerization converts silicic acid to colloidal silicic acid and finally to silica gel with increasing silicic acid concentration (Ma and Takahashi, 2002). Chemically, silicic acid polymerizes to form silica gel ($SiO_2.nH_2O$) when the concentration of silicic acid exceeds 2 mM (Casey *et al.*, 2004 and Mitani *et al.*, 2005). In rice plants, >90 per cent of total Si in the shoot is present in the form of silica gel, whereas the concentration of colloidal plus monomeric Si is kept below 140–230 mg Si/litre. Soluble silicon and monosilicic acid are equivalent terms that commonly cause confusion in the scientific literature (Jones and Handreck, 1965).

Silicon can also be supplied to crops via foliar spraying as silicate compounds, which brings about the similar results to that of via roots. Basagli *et al.* (2003) showed that foliar spraying of sodium silicate in wheat resulted in plants that were more turgid than those in the unsprayed treatment.

Silicon is deposited as a 2.5 μm layer in the space immediately beneath the thin (0.1 μm) cuticle layer, forming a cuticle–Si double layer in leaf blades of rice. There are two types of silicified cells in rice leaf blades : silica cells and silica bodies or silica motor cells. Silica cells are located on vascular bundles and are dumbbell-like in shape, whereas silica bodies are in bulliform cells of rice leaves. The silicification of cells proceeds from silica cells to silica bodies. In addition to leaf blades, silicified cells are also observed in the epidermis and vascular tissues of the stem, leaf sheath and hull (Ma and Takahashi, 2002).

2.2 MECHANISMS OF SILICON ACTION

Plants are sessile organisms, unable to move away from attackers and have therefore evolved to use other means to protect themselves, both physically and chemically, from attack (Dicke, 2009). Plant defences are either constitutive, meaning they are always expressed or induced, meaning they are expressed following biotic or abiotic stress (Arimura *et al.,* 2005).

2.2.1 Silicon and constitutive defence

Physical defence

Among the various mechanisms of action of silicon, the most noticeable mechanism is the formation of cuticle-silicon double layer, which acts as a barrier against entry and feeding of various phytophagous insects. Ma and Takahashi (2002) reported that silicon was deposited as a 2.5 μm layer in the space immediately beneath the thin (0.1 μm) cuticle layer, forming a cuticle–Si double layer in leaf blades of rice. This cuticle–Si double layer acts as a mechanical barrier against probing and chewing by insects. Silicon also increases thickness of epidermic outer cell wall of leaf and leaf sheath (Zhou *et al.*, 1993). Silica deposition in the trichomes of leaf and awns of wheat plants increases their roughness and toughness, which impedes penetration of herbivores and pathogens through the cell walls (Rafi *et al.*, 1997). The silica treatment also increases the abrasiveness of leaves and silica addition acts as a feeding deterrent and reduces the growth performance of folivorous insects (Massey *et* *al.*, 2006). Silicon addition significantly prolongs the penetration duration of larvae of *Chilo suprressalis* and decreases larval development and weight gain (Han and Hou, 2011). This increase in penetration duration might indirectly help in suppression of pest by exposing young larvae to other control measures (like natural enemies and adverse weather conditions) for longer period.

Furthermore, high silica content in rice varieties caused wearing down of mandibles of *C. suppressalis* larvae, which interfered with the feeding (Djamin and Pathak, 1967). Similarly, Hanifa *et al.* (1974) demonstrated that high silica content caused wearing out of mandibles of rice leaffolder, *C. medinalis* caterpillars. Massey and Hartley (2009) also reported the wearing down of mandibles of larvae of *Spodoptera exempta* when feeding on grass species rich silicon. Mandibles of same insect species were not damaged when they fed on grasses low on silicon.

Chemical defence

Silicon in the form of solid silica or plant opal cannot influence plant biochemistry or molecular biology but only silicon in solution can have such effects (Samuels *et al.*, 1991). Foliar application of lignite fly ash dust @ 2 kg per plant at 90 and 120 days after transplanting of papaya plants increased phenol content of leaves (Eswaran and Manivannan, 2007). Lignite fly ash is a by-product from the combustion of pulverized coal / lignite in thermal power plants of India, which contains higher amount of silica. Similarly, Ranger *et al.* (2009) found that silicon application in the form of potassium silicate (K_2SiO_2) to *Zinnia elegans* Jacq. significantly increased 5-caffeoylquinic acid, *p*-coumaroylquinic acid and rutin in leaves, but none of seven other phenolics were significantly affected.

Exogenous application of silicon in the form of sodium metasilicate to sweet cherry significantly increased the activities of defensive enzymes such as phenylalanine ammonia-lyase (PAL), polyphenoloxidase (PPO) and peroxidise (POX) in sweet cherry fruit (Qin and Tian, 2005). Similar increase in the activities of PPO and POX was observed in wheat leaves treated with silicon (Gomes *et al.*, 2005). PAL is related to the synthesis of phenolic compounds with deterrent, toxic and antinutritional properties (Appel, 1993). POX is related to lignin and suberin synthesis, which increase the hardness of tissues and to the production of quinones (Stout *et al.*, 1994). PPO is involved in lignifications process and responsible for the oxidative catalysis of phenols to quinones, which become complexed with proteins thus decreasing nutritional quality of food, making protein digestion difficult (Mohammadi and Kazemi, 2002).

In addition to above, silicon application increased tannins in leaves of potato plants (Gomes *et al.*, 2008).

Anti-nutritional effect of silicon

Massey and Hartley (2009) concluded that high-silica diet reduced the efficiency with which African armyworm, *Spodoptera exempta* Walker converted ingested food into body mass and the amount of nitrogen absorbed from their food, leading to reduced insect growth rates. The approximate digestibility of food was reduced with increased exposure time to silica. The effect on feeding efficiency was non-reversible, persisted after the herbivore had switched diets. They suggested that there might be destructive effects of silica on the mid-gut of caterpillars, which may reduce food utilization efficiency.

2.2.3 Silicon and induced resistance

Induced resistance has been defined as the "qualitative or quantitative enhancement of a plant's defense mechanisms against pests in response to extrinsic physical or chemical stimuli" (Kogan and Paxton, 1983). The induced resistance might function either as direct resistance (physical or chemical traits that act directly against further attack or reduce herbivore performance) or as indirect resistance. The latter was explained as the “attraction of enemies of the plant’s enemies” (Price *et al.*, 1980).

Direct induced resistance

Silicon application to wheat plants enhanced induced defense response by increasing activities of three enzymes (POX, PPO and PAL) involved in plant defense which reduced colonization of wheat plant by greenbug, *Schizaphis graminum* and lowered the rate of population increase of this pest (Gomes *et al.*, 2005). Three times silicon applications in the form of potassium silicate to avocado trees resulted in higher glucoside bound phenolic acid concentrations in root tissue as compared to the untreated control (Bekker *et al.*, 2007).

Massey *et al.* (2007) compared silica induction in two grass species in response to vertebrate and invertebrate damage and to mechanical defoliation. Induction was assessed at two levels of damage over 16 months. Foliar silica content did not increase in response to mechanical defoliation, but damage by either voles or locusts resulted in increases in silica content of over 400 per cent. This increase deterred feeding by both voles and locusts.

Ye *et al.* (2013) reported that silicon enhanced or primed jasmonic acid-inducible responses to herbivory, including the enhanced induction of defense-related enzymes and proteins, enhanced induction of transcripts encoding proteins involved in jasmonic acid signalling and increased accumulation of jasmonic acid itself following insect attack. Jasmonic acid promoted accumulation of silicon in rice plants. Defence priming is associated with enhanced or more rapid defence responses occurring subsequent to initial exposures to biotic or abiotic stresses (Conrath, 2011). In induced plant response to chewing insects, the jasmonic acid signalling pathway plays an essential role (Browse and Howe, 2008).

Indirect induced resistance

Recent studies conducted in Australia have shown that silicon increased the attraction of natural enemies and indirectly helped in control of pests. In a first study involving use of Y-tube olfactometer, silicon applied cucumber plants with subsequent damage by *Helicoverpa armigera* (Hubner) Hardwick attracted more adults of egg predator [*Dicranolaius bellulus* (Guerin-Meneville)] as compared to unapplied damaged plants (Kvedaras *et al.*, 2010). In a field experiment, predation rate of *H. armigera* eggs was greater for silicon applied infested plants than for other treatments.

Connick (2011) concluded that silicon fertilisation to grape vines altered the herbivore-induced plant volatiles (HIPV) profile emitted by the *Epiphyas postvittana* (Walker) infested plant, making the plant more attractive to *D. bellulus*. *Dicranolaius bellulus* is a common Australian native generalist predatory insect that preys on small lepidopteran larvae and insect eggs.

2.3 EFFECT OF SILICON ON INSECT PESTS OF RICE

2.3.1 Yellow stem borer, *S. incertulas*

Several workers have reported increase in resistance against stem borers in rice and other crops of Poaceae family with the application of silicon. Miller *et al.* (1960) found that wheat (*Triticum aestivum* L.) stem containing high levels of silicon were not injured severely by larvae of Hessian fly, *Phytophaga destructor* (Say). They also indicated that several susceptible varieties developed resistance when they were grown in a solution containing sodium silicate. Similarly, Sasamoto (1961) found an increase in the silicon content of rice plants when grown in silicon supplied soils and parallel decrease in the susceptibility to the stem borer, *Chilo suppressalis* (Walker).

Djamin and Pathak (1967) carried out a study to test reactions of several rice varieties to Asiatic rice borer, *C. suppressalis* infestation under natural field conditions and to examine the relationship between plant silica content and susceptibility to stem borer. They found highly significant negative correlation (r = -0.617) between silica content of stem and the percentage of dead hearts in the varieties. High silica content in plant interfered with feeding and boring of the larvae and caused defacing of their mandibles.

Rao (1967) reported that sugarcane varieties tolerant to shoot borer, *Chilo infuscatelus* Snellen showed the highest density of silicon per unit area of leaf sheath. Panda *et al.* (1975) reported that the larvae of the yellow rice borer, *S. incertulas* were unable to attack resistant rice plants because of the high silica content of their stems.

In Taiwan, Pan *et al.* (1979) applied different forms of silicon including bagasse furnace ash and silica slag to sugarcane. The results showed that the borer damage in silicon treated sugarcane was less than in untreated control.

Setamou *et al.* (1993) studied the effects of nitrogen and silica application to maize plants on various aspects of the bionomics of the maize stem borer, *Sesamia calamistis* Hampson in the laboratory. Increasing silica supply reduced ultimate larval survival from 26.0 per cent (control) to 4.0 per cent at 0.56 g Si/plant.

Rafi *et al.* (1997) studied the deposition of silicon in the cell wall of wheat leaves and awns. The joint use of scanning electron micrography and X-ray microanalysis of the same trichomes showed the localization of silica in the trichomes; none could be detected in the trichomes of plants grown in minus-silicon solutions. The silica in trichomes increased the roughness and the toughness of leaves and awns that impeded the penetration of herbivores through the cell walls. It acted as a physical barrier. That was one of the means by which silicon defend plants subjected to attack.

Application of silicon @ 200 kg/ha to sugarcane significantly reduced damage by stalk borer, *Eldana saccharina* Walker by an average of 47 per cent across all five varieties that were included in the study (Meyer and Keeping, 2005).

Balasubramaniam *et al.* (2005) conducted an experiment to study the influence of rice straw (RS), silicate solubilizing bacteria (SSB), RS + SSB and sodium meta silicate (SMS) with graded levels of soil test based potassium on the incidence of major rice pests. The application of different sources of silicon and potassium increased the content of these two elements in rice plant, which decreased pest incidence. The plot with SMS showed the lowest incidence of stem borer. The highest incidence was observed in the control. In addition to this, the incidence of stem borer was negatively correlated with silicon and potassium content.

Kvedaras *et al.* (2009) studied the effect of silicon and cultivar on mandibular wear of larvae of the sugarcane stalk borer, *Eldana saccharina* Walker. Four sugarcane cultivars were grown in pots in silicon deficient river sand, with (Si+) and without (Si-) calcium silicate. Mandibular wear was measured from the digital images using a quantitative method. Although there was a trend for increased wear in larvae that developed on Si+ cane, no significant effect of silicon, cultivar or site of feeding on mandibular wear of *E. saccharina* was observed.

Chandramani *et al.* (2010) analysed the effect of application of neem cake, farm yard manure (FYM), *Azospirillum*, phosphobacterium, silicate solubilising bacteria and lignite fly ash on certain major pests of rice *viz.*, leaffolder, stem borer and gall midge. The results revealed that the combination of FYM, three biofertilizers, lignite fly ash and neem cake applied in splits significantly reduced the incidence of stem borer (58.66 %) as compared to NPK applied as inorganic form. As the age of the plant increased, silica content proportionately increased in the plants. The treatment *viz.*, application of three biofertilizers, lignite fly ash along with FYM and neem cake either as basal (7.80 %) or in splits (8.10 %) recorded high silica content as compared to other treatments. The occurrence of these major insects was negatively correlated with silica content. Correlation value between silica and stem borer damage was -0.930.

Hou and Han (2011) in China studied the potential of applied silicon in mediating rice plant resistance to the Asiatic rice borer, *C. suppressalis* in a susceptible and moderately resistant rice cultivar in pot trial. They found increase in penetration durations by *C. suppressalis* first-instar larvae by 112.9 and 35.1 per cent in susceptible and moderately resistant cultivar, respectively as compared to those on their respective controls. According to them prolonged penetration duration on silicon treated rice plants may increase exposure of early instars to adverse environmental factors (e.g. rain and high temperature) and / or predations and indirectly increase larval mortality. They also reported lower larval weight and shorter stem penetration in silicon treated plants.

Hosseini *et al.* (2011) investigated the effect of silica on feeding of striped rice stem borer, *C. suppressalis*, under greenhouse. They applied silica at four different levels of 0, 5, 10 and 20 g per pot (25 x 45 x 45 cm^3) to 3 different rice cultivars (Partow, line 34 and Neda) in Iran. White earhead percentage of cv. Partow was decreased by 24.95, 47.33 and 98.79 per cent at SiO_2 level of 5, 10 and 20 g compared to control, respectively and line 34 showed 7.32, 24.19 and 83.75 per cent decrease at the same SiO_2 levels, whereas cv. Neda showed 12.43, 31.19 and 82.66 per cent decrease. The highest decrease in damage was observed in cv. Partow at SiO_2 fertilization level of 20 g.

The dead hearts due to *S. incertulas* was negatively correlated with plant silica content in rice (Rajamani *et al.*, 2013). Plant silica content in different varieties was significantly negative correlated with per cent dead hearts (r = -0.756) as well as white earheads (r = -0.896) due to *S. incertulas* (Chavan, 2013).

2.3.2 Leaffolder, *C. medinalis*

Sudhakar *et al.* (1991) found significant negative correlation (r = -0.610) between leaffolder infestation and per cent silica content in leaves of different rice varieties.

Zhou *et al.* (1993) examined the structure of rice leaves and leaf sheathes collected from the plants treated with and without silicon by means of scanning electron microscopy. It was found that the silicon particles accumulated on the surface of epiderm and subepiderm of treated leaves which were thicker and bigger as compared to that of untreated leaves. Silicon increased the thickness of epidermic outer cell wall of leaf by 0.6-0.7 μm as compared to leaves of untreated rice plants. The changes of structure of leaf sheathes were similar to that of leaves. They also reported 50-60 per cent decrease in the population density of rice leaffolder, *C. medinalis* in treated areas in comparison to untreated areas. They concluded that the changes in anatomic structures of leaves and leaf sheathes after application of silicon were the main insect-resistance mechanism.

Balasubramaniam *et al.* (2005) conducted an experiment to study the influence of rice straw (RS), silicate solubilizing bacteria (SSB), RS + SSB and sodium meta silicate (SMS) with graded levels of soil test based potassium on the incidence of major rice pests. The application of different sources of silicon and potassium increased the content of these two elements in rice plant, which decreased pest incidence. The plot with SMS showed the lowest incidence of leaffolder. The highest incidence was observed in the control. In addition to above, the incidence of leaffolder was negatively correlated with silicon and potassium content.

Chandramani *et al.* (2010) carried out experiments in field conditions to analyse the effect of application of neem cake, farm yard manure (FYM), *Azospirillum*, phosphobacterium, silicate solubilising bacteria and lignite fly ash on certain major pests of rice *viz.*, leaffolder, stem borer and gall midge. The results revealed that the combination of FYM, three biofertilizers, lignite fly ash and neem cake applied in splits significantly reduced the incidence leaffolder (76.69 %) as compared to NPK applied as inorganic form. The occurrence of leaffolder was negatively correlated (r = -0.789) with silica content.

Ye *et al.* (2013) concluded that silicon treatment increased the resistance of rice plant against *C. medinalis.* Larvae fed on untreated wild type plants increased in mass by 168.3 per cent after 3 days, whereas larvae fed on silicon-treated plants increased in mass by only 84.2 per cent. The most important part of their conclusion was that silicon enhanced or primed jasmonic acid-inducible responses to herbivory, including the enhanced induction of defense-related enzymes and proteins, enhanced induction of transcripts encoding proteins involved in jasmonic acid signalling and increased accumulation of jasmonic acid itself following insect attack. Further, jasmonic acid promoted accumulation of silicon in rice plants. In induced plant response to chewing insects, the jasmonic acid signalling pathway plays an essential role (Browse and Howe, 2008). Defence priming often associated with enhanced or more rapid defence responses occurring subsequent to initial exposures to biotic or abiotic stresses (Conrath, 2011).

2.3.3 Brown planthopper, *N. lugens*

Sogawa (1982) reported that soluble silicic acid functioned as a feeding inhibitor against the brown planthopper at concentrations ≤ 0.01 mg Si/ml in rice. According to Sujatha *et al.* (1987), rice varieties containing higher silicon content (approximately 7.4 % silica) had lower population of brown planthopper and might be resistant to brown planthopper feeding. Additionally, rice varieties with low silicon content such as MTU-7029, which contained 4.56 per cent silica, had an average of 45.3 brown planthoppers, *N. lugens* per hill, which was 3.5 times greater than the mean of 12.9 per hill.

Silicon application to rice decreased the population of brown planthopper, *N. lugens* by 50-60 per cent as compared to control (Zhou *et al.*, 1993).

Balasubramaniam *et al.* (2005) conducted an experiment to study the influence of rice straw (RS), silicate solubilizing bacteria (SSB), RS + SSB and sodium meta silicate (SMS) with graded levels of soil test based potassium on the incidence of major insect pests of rice. The plot with SMS showed the lowest incidence of brown planthopper. The highest incidence was observed in the control. In addition to this, the incidence of brown planthopper was negatively correlated with silicon content.

2.3.4 Whitebacked planthopper, *S. furcifera*

Salim and Saxena (1992) studied the effect of silicon application to susceptible and resistant rice variety on the establishment of *S. furcifera* under glasshouse conditions. Addition of silicon @ 400 mg Si/litre of culture solution of rice plants reduced intake and assimilation of food, adult longevity, fecundity and population increase by *S. furcifera* on susceptible rice variety.

Mishra and Misra (1992) studied the effects of silica levels (0, 50, 100 and 200 ppm SiO_2) on the growth and development of whitebacked planthopper, *S. furcifera*, under pot culture. Silica levels were prepared from sodium metasilicate, while variety was TN-1. Compared to control, adult emergence was significantly reduced at silica level of 100 ppm and above. There was increase in male/female ratio with the increase in silica levels, but the difference was non-significant.

Application of silicon in the form sodium meta silicate (SMS) to rice fields reduced the incidence of whitebacked planthopper. Further, the incidence of pest was negatively correlated with plant silicon content (Balasubramaniam *et al.*, 2005).

2.3.5 Green leafhopper, *N. virescens*

Maxwell *et al.* (1972) reported that silicon suppressed green leafhopper in rice.

2.4 EFFECT OF SILICON APPLICATION ON CHEMICAL AND BIOCHEMICAL CONSTITUENTS OF RICE PLANTS

2.4.1 Effect on chemical constituents of rice plants

2.4.1.1 Effect on silica content of rice plants

Islam and Saha (1969) reported that application of silicon to rice plants grown on nutrient culture solution resulted in increase in silicon content of rice plants. An experiment to study the influence of different sources of silicon namely rice straw (RS), silicate solubilizing bacteria (SSB), RS + SSB and sodium meta silicate (SMS) with graded levels of soil test based potassium on the incidence of major rice pests was conducted by Balasubramaniam *et al.* (2005). The application of different sources of silicon to rice plants increased the content of this element in rice plants that decreased pest incidence.

Chandramani *et al.* (2010) carried out experiments under field conditions to analyse the effect of application of neem cake, farm yard manure (FYM), *Azospirillum*, phosphobacterium, silicate solubilising bacteria and lignite fly ash on certain major pests of rice *viz.*, leaffolder, stem borer and gall midge. The results revealed that as the age of the plant increased, silica content proportionately increased in the plants. There was significant difference among treatments in silica content on 45 and 60 days after transplanting. The treatments *viz.*, application of three biofertilizers, lignite fly ash along with FYM and neem cake either as basal (7.80 %) or in splits (8.10 %) recorded higher silica content as compared to other treatments.

2.4.1.2 Effect on macronutrient content of rice plants

Nitrogen

Mitsui and Takatoh (1963) observed decrease in nitrogen content in rice plant with increase in silicon application rate. Application of silicon to rice plants grown on nutrient culture solution decreased nitrogen content (Islam and Saha, 1969). Lysimeter study by Deren (1997) showed that soil application of silicon in the form calcium silicate decreased nitrogen concentration in all parts of rice plant. Wright *et al.* (2013) studied the effects of application of silicate slag to St. Augustine grass, which was used for lawns throughout the southern USA. They used three grass varieties *viz.*, Captiva, Floratam and Raleigh. Tissue nitrogen concentrations were not affected by adding silicate slag. Chavan (2013) reported significantly positive correlation (r = 0.884) between white earhead damage and plant nitrogen content.

Phosphorus

Islam and Saha (1969) reported that application of silicon to rice plants grown on nutrient culture solution increased phosphorus content. In contrast to this, Ma and Takahashi (1990) reported that silicon application to rice plant decreased uptake of phosphorus. They conducted a pot experiment to measure the effect of silicon on phosphorus uptake and on the growth of rice at different phosphorus levels. Rice was cultured in Kimura B nutrient solution without and with silicon (1.66 mM Si) and three phosphorus levels (0.014 mM P, low; 0.21 mM, medium and 0.70 mM, high). Silicon did not significantly decrease P uptake by rice at 0.014 mM P, however, uptake at 0.21 and 0.70 mM was 27 and 30 per cent less than without silicon, respectively.

Lysimeter study by Deren (1997) showed that soil application of silicon in the form calcium silicate increased phosphorus concentration in rice plant. Phosphorus contents in grain and straw significantly increased due to Si application up to 180 kg Si/ha (Singh *et al.*, 2006). Silicon addition decreased phosphorus content in two of the three varieties of St. Augustine grass studied, whereas in the third variety phosphorus content was not affected (Wright *et al.*, 2013).

Ma (2004) explained the mechanism behind the beneficial effect of silicon on phosphorus uptake. The uptake of Fe and Mn significantly decreased in the Si-treated plants. Phosphorus is translocated and redistributed in plants in an inorganic form. Since P shows high affinity with metals such as Fe and Mn, internal availability of P could be controlled by the level of Mn, Fe and other metals when the P concentration is low. Therefore, the larger beneficial effect of Si on plant growth under P deficiency stress may be attributed to the enhanced availability of internal P through the decrease of excess Fe and Mn uptake. This is supported by the fact that Si supply increased the rate of P translocation to the panicles in rice (Nagaoka, 1998).

Shatrughna (1996) reported that the rice varieties having higher content of phosphorus exhibited resistant reaction against *S. incertulas.* Whereas, Chavan (2013) reported that phosphorous content showed significant and positive correlation with per cent dead hearts (r = 0.570) and white earheads (r = 0.758) due to *S. incertulas.*

Potassium

Islam and Saha (1969) reported that application of silicon to rice plants grown in nutrient culture solution decreased potassium content of rice plants. Singh *et al.* (2006) showed increase in potassium concentration when silicon was applied to rice grown under field conditions. Wright *et al.* (2013) observed increase in potassium content in one of the three varieties of St. Augustine grass with the application of silicate slag and in rest of two varieties no effect was seen.

Chavan (2013) significantly negatively correlated (r = -0.922) potassium content in rice plant with white earheads.

Calcium

Islam and Saha (1969) reported that application of silicon to rice plants grown on nutrient culture solution increased calcium content of rice plants. Tissue calcium content was not influenced by silicon addition in any of the varieties of St. Augustine grass studied (Wright *et al.,* 2013).

Magnesium

Application of silicon to rice plants resulted in increase of magnesium content (Islam and Saha, 1969). Silicon addition decreased magnesium content in St. Augustine grass. Magnesium content in treatments not receiving silicon was 23 per cent higher as compared to treatments receiving silicon (Wright *et al.,* 2013). Application of electric furnace slag, which contained silicon in the form of calcium silicate, to sugarcane crop did not increase leaf magnesium content (McCray and Ji, 2013). Lalithya *et al.* (2014) reported that application of calcium silicate @ ≥ 1.0 kg/tree increased concentration of magnesium in sapota leaves.

Sulphur

Jawahar and Vaiyapuri (2010) found that silicon application in rice enhanced sulphur uptake. Sarto *et al.* (2014) conducted pot experiments to study the effect of application of calcium silicate on the nutrition and yield of wheat. They found that application of calcium silicate did not affect the concentration of sulphur in flag leaves.

Sodium

Silicon application to culture solution of rice plants, grown hyroponically under salt stress, reduced the sodium concentration in shoots by 54 per cent of that recorded in the plants that did not receive silicon (Matoh *et al.*, 1986). This function of Si may be ascribed to the Si-induced decrease of transpiration (Matoh *et al.*, 1986) and to the partial blockage of the transpirational bypass flow, the pathway by which a large proportion of the uptake of Na in rice occurs (Yeo *et al.*, 1999). Gong *et al.* (2006) also suggested that silicon application to rice grown under sodium chloride (NaCl) stress reduced sodium uptake in rice seedlings through a reduction in transpirational bypass flow.

2.4.1.3 Effect on micronutrient content of rice plants

Iron

Okuda and Takahashi (1961) concluded that addition of silicon to nutrient solution increased the oxidation power of rice roots leading to an oxidation of Fe^{2+} and subsequent precipitation on the root surface and hence to a reduced Fe uptake of the rice plant.

Islam and Saha (1969) reported that application of silicon to rice plants grown in nutrient culture solution decreased iron content of rice plants. Ma and Takahashi (1990) showed 20 per cent reduction in plant uptake of iron by rice plants grown in pots with the addition of silicon to culture solution.

Manganese

Addition of silicon to nutrient solution increased the oxidation power of rice roots leading to an oxidation of Mn^{2+} and subsequent precipitation on the root surface and hence to a reduced Mn uptake of the rice plant (Okuda and Takahashi, 1961).

Application of silicon to rice plants grown in nutrient culture solution decreased manganese content in rice plants (Islam and Saha (1969). As per the reports of Ma and Takahashi (1990), silicon addition in nutrient solution of rice reduced uptake of manganese by 50 per cent. They added silicon @ 1.66 mM to nutrient solution of rice plants grown in pots.

Zinc

Significant improvement in zinc concentrations was recorded with silicon application up to 120 kg Si /ha to rice (Singh *et al.*, 2006). In contrast to this, Souza *et al.* (2011) reported that calcium silicate decreased zinc concentration in palisade grass. Silicon treatment did not significantly influence zinc accumulation in sorghum roots and shoots (Masarovic *et al.*, 2012). Ghasemi *et al.* (2013) reported that silicon application decreased zinc content in rice plant. In St. Augustine grass zinc content was not influenced by the addition of silicon in the form of silicate slag (Wright *et al.*, 2013). Lalithya *et al.* (2014) reported that application of calcium silicate @ 1.0 kg/tree and higher increased concentration of zinc in sapota leaves. Kim *et al.* (2014) found that silicon application to culture solution of rice, grown hydroponically, increased zinc content in rice plants.

Copper

Toxicity of Cu in arabidopsis (*Arabidopsis thaliana*) was shown to be alleviated by Si through active metal transporter regulation (Li *et al.*, 2008). Wright *et al.* (2013) found increase in copper content in all the three varieties of St. Augustine grass with addition of silicate slag. Sarto *et al.* (2014) conducted pot experiment to study the effect of application of calcium silicate on the nutrition and yield of wheat plants. They found that application of calcium silicate did not affect the concentration of copper in wheat flag leaves.

2.4.2 Effect on biochemical constituents of rice plants

Total phenol

Three times silicon applications in the form of potassium silicate to avocado trees resulted in higher glucoside bound phenolic acid concentrations in root tissue as compared to the untreated control. Data analysis by HPLC separation revealed that all treatments samples contained 3,4-hydroxibenzoic and vanillic acid. The presence of syringic acid could be related to the application of silicon (Bekker *et al.*, 2007).

Lignite fly ash is a by-product from the combustion of pulverized coal / lignite in thermal power plants of India containing higher amount of silica. Foliar application of lignite fly ash dust @ 2 kg per plant to papaya plants at 90 and 120 days after transplanting increased phenol content of leaves (Eswaran and Manivannan, 2007).

Ranger *et al.* (2009) conducted studies to examine the effect of treating *Zinnia elegans* Jacq. with soluble silicon. *Zinnia elegans* plants were irrigated every 2 days throughout the duration of the experiment with a nutrient solution amended with potassium silicate (K_2SiO_2) or a nutrient solution without K_2SiO_2. High performance liquid chromatography-mass spectrometry (HPLC-MS) analysis was used to identify and quantify phenolic acids in leaf tissue of *Z. elegans*. Compared with untreated control plants, significant elevations in 5-caffeoylquinic acid, *p*-coumaroylquinic acid and rutin were detected in leaves of *Z. elegans* plants treated with K_2SiO_2, but none of seven other phenolics were significantly affected. Dallagnol *et al.* (2011) observed that total soluble phenolics in silicon supplied rice plants was greater compared with plants not supplied with silicon. Chavan (2013) reported significantly negative correlation (r = -0.905) between white earheads due to *S. incertulas* and total phenol content in rice.

Total sugar

Silicon increased carbohydrate content of rice plants (Islam and Saha, 1969). Eswaran and Manivannan (2007) reported that foliar application of lignite fly ash dust @ 2 kg per papaya plant at 90 and 120 days after transplanting reduced sugar content of leaves. Chandramani *et al.* (2009) observed significantly positive correlation between total sugar content and population of WBPH (r = 0.604) as well as population of BPH (r = 0.493) in rice.

Crude protein

The application of silicon decreased protein content of rice plants (Islam and Saha, 1969). In contrast to this, Eswaran and Manivannan (2007) reported that foliar application of lignite fly ash dust @ 2 kg per to papaya plant at 90 and 120 days after transplanting increased crude protein content in leaves. Application of calcium silicate to palisade grass decreased concentration and accumulation of crude protein (Souza *et al.*, 2011). Chavan (2013) found significantly positive correlation (r = 0.884) between white earheads due to *S. incertulas* and protein content. Punithavalli *et al.* (2013) noticed positive correlation between leaf protein content and damage by rice leaffolder.

Free amino acids

Eswaran and Manivannan (2007) showed that foliar application of lignite fly ash dust @ 2 kg per papaya plant at 90 and 120 days after transplanting reduced amino nitrogen content of papaya leaves. Chandramani *et al.* (2009) reported that plots treated with FYM, biofertilizers, neem cake and lignite fly ash showed lower free amino acids content than plots treated with recommended dose of fertilizer.

2.5 EFFECT OF SILICON APPLICATION ON NATURAL ENEMIES OF RICE INSECT PESTS

Moraes *et al.* (2004) studied the tritrophic interaction : wheat, greenbug, *Schizaphis graminum* and its key natural enemies, [*Chrysoperla externa* (Hagen) and *Aphidius colemani* Viereck], in plants with or without silicon fertilization. No significant effect of silicon was observed on the development of the predator *C. externa* fed with aphids from plants treated with sodium silicate or from control plants (without silicon application) for duration and survival of instars. They also reported that the duration of the larval and pupal stages, as well as the sex ratio of *C. externa* were not influenced by the type of food received by the prey. Similarly, duration of immature stage, adult longevity and total life cycle as well as sex ratio and per cent parasitism by *A. colemani* was not affected when the insect developed on aphids reared on plants treated with silicon or without silicon.

Recent studies conducted in Australia, which was methodologically and conceptually more advanced showed increased attraction of natural enemies to silicon treated plants. In first study, Kvedaras *et al.* (2010) maintained cucumber plants treated with potassium silicate (Si+) and untreated control plants (Si−) in separately vented glasshouse compartments. Y-tube olfactometer studies showed that adult of *Dicranolaius bellulus* were significantly more attracted to Si+ plants upon which *Helicoverpa armigera* larvae had fed compared with Si− pest-infested plants. Predators were not significantly more attracted to Si+ plants when comparing uninfested cucumbers. In a field experiment, they placed *H. armigera*-infested and uninfested Si+ and Si− cucumber plants in a lucerne stand. Removal rates of *H. armigera* egg baits showed predation was greater for Si+ infested plants than for other treatments. Results suggested that Si applied to plants with subsequent pest infestation increased the plants' attractiveness to natural enemies; an effect that was reflected in elevated biological control in the field.

Similarly, Connick (2011) in Australia investigated the tri-trophic effects of Si-treatment of grapevines on important native

Australian insects; two insect pest species, *Epiphyas postvittana* (Walker) and *Phalaenoides glycinae* (Lewin) and two beneficial insect species, *Dicranolaius bellulus* (Guerin-Meneville) and green lace wing, *Mallada signata* (Schneider) under laboratory conditions. *Dicranolaius bellulus* is a common Australian native generalist predatory insect that preys on small lepidopteran larvae and insect eggs. The response of *D. bellulus* to silicon applied (Si+) and control (Si-) grapevines infested with *E. postvittana* third-fourth instar larvae was measured using a Y-tube olfactometer. Analysis of grapevine leaf tissue samples found the mean total Si content of Si+ plants (0.315 %) was greater than for Si- plants (0.177 %). *Dicranolaius bellulus* exhibited a significant positive response to pest-infested grapevines with the highest leaf-tissue Si-content. The increased attraction was suggested to be due to Si fertilisation altering the herbivore-induced plant volatiles (HIPV) profile emitted by the pest-infested plant, making the plant more attractive to *D. bellulus.* In contrast to this, Y-tube olfactometer bioassays found that *M. signata* was equally attracted to pest-infested grapevines from both Si+ and Si- treatments.

2.6 EFFECT OF SILICON APPLICATION ON OVIPOSITION PREFERENCE AND ITS ANTIBIOSIS EFFECTS ON *S. incertulas*

2.6.1 Effect of silicon application on oviposition preference of *S. incertulas*

Varietal differences in silica content and susceptibility to Asiatic rice borer, *C. suppressalis* in 20 varieties were investigated by Djamin and Pathak (1967). The silica (SiO_2) content of the varieties ranged from 9.7 per cent in Sapan Kwai, which was susceptible to borers, to 13.9 per cent in Yabami Montakhab 55, which was resistant. The silica contents showed a highly significant negative correlation with the percentage of dead hearts in the varieties (r = –0.617). The percentage of dead hearts and the number of living larvae per hill were positively correlated (r = 0.60). Thus, varieties with high silica content had fewer rice borers. However, the silica content of the plants and the number of egg masses laid on them were not correlated. Therefore, higher amounts of silica present in the host plants appeared to affect larval survival adversely and to reduce the incidence of dead hearts on the plants, but it did not affect the oviposition preference of Asiatic rice borer.

Correa *et al.* (2005) evaluated the effect of calcium silicate and the activator, acibenzolar-S-methyl on resistance induction in cucumber against the whitefly, *Bemisia tabaci* (Gennadius) biotype B. They conducted free-choice and no-choice preference tests in greenhouse and laboratory. In a free-choice test, application of silicon in the form of calcium silicate to cucumber plants significantly affected the oviposition preference of *B. tabaci*. The mean numbers of eggs laid by a female on cucumber plant were 487.0 ± 28.11, 317.2 ± 33.92 and 223.1 ± 16.47 in control, soil application of calcium silicate and foliar application of calcium silicate, respectively. However, no significant effect of silicon on egg laying preference was observed in no-choice test. In contrast to this, silicon application to soybean, in the form of silicic acid, decreased the number of eggs laid by the female of silverleaf whitefly *B. tabaci* Biotype B in free-choice as well as no-choice test, but the differences between them were not significant. (Ferreira *et al.*, 2011).

2.6.2 Antibiosis effects of silicon on *S. incertulas*

Effect on larvae

Djamin and Pathak (1967) tested reactions of several rice varieties to Asiatic rice borer, *C. suppressalis* infestation under natural field conditions to examine the relationship between plant silica content and susceptibility to stem borer. High silica content in plant interfered with feeding and boring of the larvae and caused defacing of their mandibles. Setamou *et al.* (1993) studied the effects of nitrogen and silica application to maize plants on various aspects of the bionomics of the maize stem borer, *Sesamia calamistis* Hampson in the laboratory. Increasing silica supply reduced ultimate larval survival from 26.0 per cent (control) to 4.0 per cent at 0.56 g Si/plant.

Silica addition reduced larval growth rate on each of the four grass species studied and resulted in increased developmental time of African army worm *Spodoptera exempta* Walker (Massey *et al.*, 2006).

Massey and Hartley (2009) carried out experiments to understand the mechanisms by which silica affected herbivore performance. They exposed herbivorous insect African armyworm, *S. exempta* to high-silica diet. Silica reduced the efficiency with which *S. exempta* converted ingested food into body mass and the amount of nitrogen absorbed from their food, leading to reduced insect growth rates. The approximate digestibility of food was reduced with increased exposure time to silica. Exposure to silica-rich diets caused increased mandible wear in *S. exempta*. This effect was extremely rapid, occurring within a single instar, further reducing feeding efficiency and growth rates. These effects on insect growth and feeding efficiency were non-reversible, persisted after the herbivore had switched diets. They suggested that there might be destructive effects of silica on the mid-gut of caterpillars, which may reduce food utilization efficiency.

Silicon application to rice plants, grown in pots, significantly decreased larval weight gain and prolonged larval development of *C. suppressalis* (Hou and Han, 2010). Han *et al.*, (2015) studied the effect of silicon amendment @ 0.16 and 0.32 g Si/kg soil on rice leaffolder, *C. medinalis.* Silicon amendment at high and low rate significantly prolonged larval development time as compared with control. The higher rate of silicon decreased the larval weight when compared with control.

Effect on pupae

Silicon application to cotton plants decreased pupal weight and increased the pupal period of *Alabama argillacea* (Tomquelski *et al.*, 2007). Han *et al.* (2015) reported that silicon amendment @ 0.32 g Si/kg soil reduced pupal weight in rice leaffolder, *C. medinalis*, while pupal period was not significantly affected.

Effect on adults

Salim and Saxena (1992) studied the effect of silicon application to susceptible and resistant rice variety on the establishment of *S. furcifera* under glasshouse conditions. Addition of silicon @ 400 mg Si/litre of culture solution of rice plants reduced adult longevity of *S. furcifera* on susceptible rice variety. Mishra and Misra (1992) at Central Rice Research Institute, Cuttack studied the effects of silica levels (0, 50, 100 and 200 ppm SiO_2) on the growth and development of whitebacked planthopper, *S. furcifera* under pot culture. Silica levels were prepared from sodium metasilicate, while variety was TN-1. Compared to control, adult emergence was significantly reduced at silica level of 100 ppm and above. The application of sodium silicate to wheat plants adversely affected longevity and production of nymphs of greenbug, *Schizaphis graminum* (Rond.) thus, conferring resistance to wheat plants against this insect pest (Basagli *et al.,* 2003).

The effect of silicon-treated wheat plants, *T. aestivum* on the greenbug, *S. graminum* was evaluated by Goussain *et al.* (2005). Combined application of silicon (soil as well as foliar) to wheat plants significantly reduced reproductive period and adult longevity, whereas pre-reproductive and post-reproductive period were not affected. While none of periods was affected by soil application of silicon. Korndorfer *et al.* (2011) reported that silicon application in the form of potassium silicate to sugarcane plants, grown under green house conditions, decreased the longevity of males and females of Spittlebug, *Mahanarva fimbriolata* Stal. El-bendary and El-Helaly (2013) reported that application of nano-silica to tomato plants did not affect pre-reproductive and reproductive periods of cotton leaf worm, *Spodoptera littoralis* (Bosid), however longevity was reduced in nano-silica treatments compared with control.

Effect on fecundity and hatchability

Salim and Saxena (1992) reported that addition of silicon @ 400 mg Si/litre of culture solution of rice plants reduced fecundity and population increase of *S. furcifera* on susceptible rice variety. Setamou *et al.* (1993) studied the effects of nitrogen and silica application to maize plants on various aspects of the bionomics of the maize stem borer, *Sesamia calamistis* Hampson, in the laboratory. They reported that egg viability of *S. calamistis* was not affected by silica application. The application of sodium silicate to wheat plants adversely affected production of nymphs of greenbug, *S. graminum* thus, conferring resistance to wheat plants against this insect pest (Basagli *et al.,* 2003).

The effect of silicon-treated wheat plants, *T. aestivum* on *S. graminum* was evaluated by Goussain *et al.* (2005). Combined application of silicon (soil as well as foliar) to wheat plants significantly reduced fecundity. Whereas, silicon application through soil only did not affect fecundity. Silicon application to potato plants via soil and/or foliage reduced fecundity and the rate of population growth of *Myzus persicae* (Sulzer) (Gomes *et al.*, 2008).

Ranger *et al.* (2009) examined the effect of treating *Z. elegans* with soluble silicon on the performance of the green peach aphid, *M. persicae*. *Zinnia elegans* plants were irrigated every 2 days throughout the duration of the experiment with a nutrient solution amended with potassium silicate (K_2SiO_2) or a nutrient solution without K_2SiO_2. Total cumulative fecundity and the intrinsic rate of increase (r_m) were slightly reduced on *Z. elegans* plants receiving soluble silicon. Application of nano-silica to tomato plants decreased fecundity of cotton leaf warm, *S. littoralis* (El-bendary and El-Helaly, 2013). Han *et al.* (2015) reported that silicon amendment @ 0.16 and 0.32 g Si/kg soil did not significantly affect the fecundity and viability of F_1 eggs of *C. medinalis.*

Effect on sex ratio

Mishra and Misra (1992) studied the effects of silica levels (0, 50, 100 and 200 ppm SiO_2) on the growth and development of whitebacked planthopper, *S. furcifera* under pot culture. They reported that there was increase in male/female ratio with the increase in silica levels, but the difference was non-significant. Han *et al.* (2015) studied the effect of silicon amendment @ 0.16 and 0.32 g Si/kg soil on rice leaffolder, *C. medinalis.* Silicon amendment negatively affected the sex ratio of *C. medinalis,* but the difference was non-significant.

III. MATERIALS AND METHODS

Investigations on the effect of silicon application on insect pest population / damage in rice, chemical and biochemical constituents of rice plants, natural enemies of rice insect pests and oviposition preference as well as antibiosis effect on yellow stem borer, *S. incertulas* were carried out at Agricultural Research Station, Anand Agricultural University, Derol. The details of materials used, procedure followed and techniques adopted for conducting various experiments in the present investigation are presented hereinafter under following heads.

3.1 Effect of silicon application on insect pest population / damage in rice

3.2 Effect of silicon application on chemical and biochemical constituents of rice plants

3.3 Effect of silicon application on natural enemies of rice insect pests

3.4 Effect of silicon application on oviposition preference and its antibiosis effects on *S. incertulas*

3.1. EFFECT OF SILICON APPLICATION ON INSECT PEST POPULATION / DAMAGE IN RICE

In order to study the effect silicon on population/damage by various insect pests' a field experiment was conducted at Agricultural Research Station, Anand Agricultural University, Derol, Dist. Panchmahal (Gujarat) during *kharif* season for two successive years *i.e.,* 2011 and 2012 (Plate 1).

3.1.1 Details of location

Geographically, Derol is situated on 22^0 36' N latitude and 73^0 27' E longitude and has elevation of 85.36 m above the mean sea level. The research station is located 1 km away from Kalol town which is 55 km away from the Vadodara on Vadodara – Godhra state highway. It falls under middle Gujarat Agro-climatic Zone (Zone-III).

3.1.2 Climate and weather conditions

The climatic conditions of the Derol represent the subtropical conditions with semi arid climate. In general, monsoon commences by the third week of June and ceases by middle of September. July and August are the months of heavy rains. Winter is cool and dry, while summer is quite dry and hot. The average annual rainfall is 750 mm. The January is the coolest month of winter, while May is the hottest month of summer. The meteorological data recorded during *Kharif* 2011 and 2012 at the meteorological observatory at Agricultural Research Station, Anand Agricultural University, Derol are presented in Appendix 1.

3.1.3 Details of experiment

Location : Agricultural Research Station
Anand Agricultural University
Derol, Ta.: Kalol
Dist.: Panchmahal (Gujarat)

Season & Year : *Kharif* 2011 and 2012

Crop and variety : Rice, GR – 11

Treatments : 8

1) Soil application of calcium silicate @ 500 kg/ha at the time of transplanting
2) Soil application of calcium silicate @ 1000 kg/ha at the time of transplanting
3) Soil application of calcium silicate @ 1500 kg/ha at the time of transplanting
4) Soil application of calcium silicate @ 2000 kg/ha at the time of transplanting
5) Foliar application of potassium silicate 0.5 per cent at 30, 45 and 60 days after transplanting (DAT)
6) Foliar application of potassium silicate 1.0 per cent at 30, 45 and 60 DAT
7) Foliar application of potassium silicate 2.0 per cent at 30, 45 and 60 DAT
8) Control (Untreated)

Design : Randomized Block Design

Replications : Three

Spacing : 20 x 15 cm

Plot Size : **Gross** : 3.90 x 3.20 m

Net : 3.00 x 2.40 m

Method of sowing : Transplanting after raising nursery

Date of transplanting	:	6-8-2011 during *Kharif* 2011 and 10-8-2012 during *Kharif* 2012
Date of harvesting	:	18-11-2011 during *Kharif* 2011 and 20-11-2012 during *Kharif* 2012
Fertilizer dose (N:P:K)	:	100 : 25 : 00 kg/ha

All recommended agronomical practices were followed to raise the rice crop. Calcium silicate ($CaSiO_3$) contains 24 per cent silicon, whereas potassium silicate (K_2SiO_3) contains 18 per cent silicon.

3.1.4 Method of recording observations

3.1.4.1 Yellow stem borer, *S. incertulas*

The observations on tiller damage by yellow stem borer, *S. incertulas* were recorded from the ten hills selected randomly from each net plot area. For the purpose, total tillers and deadhearts were counted at 30 and 45 days after transplanting (DAT), whereas total tillers and white earheads were counted at 60 and 75 DAT. Per cent deadhearts and white earheads were calculated by using following formula:

$$\text{Deadheart/white earhead (\%)} = \frac{\text{No. of deadhearts / white earheads}}{\text{Total No. of tillers (Deadheart + healthy tillers)}} \times 100$$

3.1.4.2 Leaffolder, *C. medinalis*

Observations on leaf damage due to leaffolder, *C. medinalis* were recorded by counting total leaves and damaged leaves at 30, 45, 60 and 75 DAT on the ten hills selected randomly from each net plot area. Based on this counts per cent leaf damage was calculated using following formula.

$$\text{Leaf damage (\%)} = \frac{\text{No. of damaged leaves}}{\text{Total No. of leaves (damaged + healthy leaves)}} \times 100$$

3.1.4.3 Planthoppers and leafhopper

For recording observations on the population of brown planthopper *N. lugens*, whitebacked planthopper, *S. furcifera* as well as green leafhopper, *N. virescens* and *N. nigripictus* ten hills were randomly selected from each net plot area and total number of nymphs as well as adults were counted at weekly interval starting from 30 DAT to harvest.

3.1.4.4 Yield

Rice crop was harvested on maturity and it was allowed for sun drying in field for 2-3 days. Thereafter, it was threshed and cleaned manually. Grains and straw of each net plot was weighed separately. Yield obtained per plot was converted into kg/ha.

3.2 EFFECT OF SILICON APPLICATION ON CHEMICAL AND BIOCHEMICAL CONSTITUENTS OF RICE PLANTS

Laboratory analysis of silica (SiO_2), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) magnesium (Mg), sulphur (S) and sodium (Na) content of rice plants was carried out at Department of Agricultural Chemistry and Soil Science, B. A. College of Agriculture, Anand Agricultural University, Anand. Laboratory analysis of iron (Fe), manganese (Mn), Zinc (Zn) and copper (Cu) was carried out at AICRP on Micronutrient Research, Anand Agricultural University, Anand. Whereas, biochemical analysis of rice plants was carried out at

Department of Agricultural Biochemistry, B. A. College of Agriculture, Anand Agricultural University, Anand. The samples of rice plants for above analysis were collected from the field experiment on the effect of silicon application on the insect pests' population / damage in rice, conducted during the *Kharif* 2012. The detailed procedure followed during sampling and laboratory analysis is described hereafter.

3.2.1 Silica content

3.2.1.1 Sampling procedure and preparation of samples

To determine plant silica content, ten hills were randomly selected from each treatment per replication at 30, 45, 60 and 75 DAT. From each selected hill, one tiller was selected and it was cut at the base to separate from the hill. All the ten tillers were kept together and they were treated as one sample. The plant samples were washed with 0.03 N HCl and single deionized water in a sequence and air dried. Then samples were put in paper bags and dried in a hot air oven at 70 ^{O}C temperature till constant weight. The dried plant samples were cut and ground in stainless steel blade grinder and preserved in polythene bags for analysis.

3.2.1.2 Plant sample digestion

The powdered sample was digested by taking 0.1 g plant sample and wetted with 2 ml of 50 per cent H_2O_2 in 100 ml polypropylene tube previously rinsed with 0.1 M NaOH and double distilled water. Then 4.5 ml of 50 per cent NaOH was added at ambient temperature in each tube. The tubes were individually covered with loose fitting plastic cups. The rack of tubes was autoclaved at 20 psi (138 k Pa) for one hour. The volume of digested contents in the tubes was made up to 50 ml with double distilled water and after filtration 1 ml aliquot was taken for silica estimation.

3.2.1.3 Estimation of silica from plant samples

The silica concentration in the digested solution was determined by taking 1 ml of digested aliquot and it was transferred to a plastic centrifuge tube and 30 ml of 20 per cent acetic acid, 10 ml of ammonium molybdate (54 g/L, pH 7), 5 ml of 20 per cent tartaric acid and 1 ml of reducing *ANSA* solution (1-amino-2- naphthol-4-sulphonic acid) were added and the volume was made up to 50 ml with 20 per cent acetic acid. After 30 minute, the absorbance was measured at 650 nm with UV- spectrophotometer.

Similarly, 100 ppm SiO_2 strength and a stock solution of Si standards (0, 0.2, 0.4, 0.8 and 1.2 ppm) were prepared by following the same procedure and silica concentration was measured on spectrophotometer to find out the graph factor from standard curve by plotting silica concentration on X axis and optical density on Y axis.

3.2.2 Macronutrient and micronutrient content

For determination of rest of the plants' chemical and biochemical constituents, samples were collected at 75 DAT only. For the purpose, procedure described earlier under section 3.2.1.1 was followed. Estimation of total nitrogen content of rice plant samples was carried out by Micro-kjeldahl's method following the procedures described by the Association of Official Agricultural Chemists (1965).

For determination of other nutrient element content, treatment and replication-wise known quantity of plant sample was digested in diacid mixture as per method described by Johnson and Ulrich (1969). The different constituents like phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), sodium (Na), iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) was determined as per the procedures mentioned below.

Nutrient	**Procedure**	**Author**
Phosphorus	Vanadomolybdo phosphoric yellow colour	Jackson (1973)
Potassium and Sodium	Flame photometric method	Jackson (1973)
Calcium and Magnesium	E. D. T. A. method	Jackson (1973)
Sulphur	Turbidimetric method	Chaudhary and Cornfield (1966)
Iron, Manganese, Zinc and Copper	Automatic absorption spectrophotometric method	Jackson (1973)

3.2.3 Biochemical constituents

3.2.3.1 Total phenol

Total phenol content in rice plant samples was determined by the method given by Malik and Singh (1980).

Rice plant samples (0.2 g) were ground in mortar and pestle with 10 time volume of 80 per cent ethanol. The homogenate was centrifuged at 10,000 rpm for 15 minutes. The residue was re-extracted with 5 ml volume of 80 per cent ethanol, centrifuged and the supernatants were pooled. Supernatants were evaporated to dryness. The residue was dissolved with hot distilled water. One ml of aliquot was taken in the test tube. To this 0.5 ml of Folin-Ciocalteu reagent and 2 ml of 20 per cent sodium carbonate was added. After 1 hour the volume in each tube adjusted to 5 ml with distilled water and the absorbance was read at 650 nm.

Standard stock solution (100 mg/100 ml) of pyrocatechol was prepared in distilled water which was diluted to 10 μg/ml concentration. From this standard graph was drawn in the range of 2 to 10 μg concentration. The amount of phenol present in the sample was calculated as:

Amount of phenol (mg/g) = Sample OD x Graph factor x Dilution factor

3.2.3.2 Total soluble sugar

Total soluble sugar content was determined by phenol-sulphuric acid method described by Bhatnagar *et al.* (2006).

Sample of 200 mg was extracted for soluble sugar in 80 per cent ethanol. Five ml of extract was evaporated to dryness and dissolved in 25 ml of hot distilled water. One ml of sample was pipetted in 30 ml test tube. In a similar way, 0.2, 0.4, 0.6, 0.8 and 1.0 ml of the working standard glucose solution (0-100 μg) was pipetted into a series of tubes. The volume in each tube was made up to 1 ml with distilled water. A blank was run simultaneously by taking 1 ml of distilled water in a tube. One ml of 5 per cent phenol solution and 5 ml of concentrated sulphuric acid were added to each tube and shaken well. Again after 10 minutes, the contents in the tubes were shaken and placed in an ice bath for 20 minutes. The absorbance was read at 490 nm. The amount of total sugar was calculated by using standard graph as:

Total soluble sugar (mg/g) = Sample OD x Graph factor x Dilution factor

3.2.3.3 Crude protein

The following equation was used to work out per cent crude protein content separately.

Crude protein content (%) = N content (%) X 6.25

3.2.3.4 Free amino acids

The amount of free amino acid was determined by the method given by the Lee and Takahasi (1966).

Sample of 100 mg was transferred in homogenizer tube. Ten ml of 80 per cent ethanol was added and homogenized for 10 minutes. Then it was centrifuged and supernatant was collected. Extraction was repeated for one more time. Supernatant was combined and final volume was made 25 ml with 80 per cent ethanol. 0.1 ml of extract was taken in test tube and 5 ml of ninhydrin reagent was added into it. Then the test tube was shaken vigorously. After vigorous shaking, the test tubes were heated in boiling water bath for 12 minutes. Test tubes were cooled to room temperature under running tap water. The absorbance was read at 570 nm against blank prepared by adding 0.1 ml of ethanol in place of extract. Reference curve was prepared by using glycine (10 to 100 μg) as a standard amino acid. The amount of free amino acid present in the sample was calculated as:

Free amino acid (mg/g) = Sample OD x Graph factor x Dilution factor

3.3 EFFECT OF SILICON APPLICATION ON NATURAL ENEMIES OF RICE INSECT PESTS

3.3.1 Effect on population of spiders

Observations on the population of spiders were recorded in the experiment conducted to study the effects of silicon application on the population/damage by insect pests in rice. For this purpose, at 30, 45, 60 and 75 DAT, 10 hills in each net plot area were selected randomly and number of spiders was counted.

3.3.2 Effect on parasitism by egg parasitioids of yellow stem borer, *S. incertulas*

A separate field experiment was conducted to study the effect of silicon application on parasitism of *S. incertulas* eggs by parasitoids. The design of this experiment was large plot sampling (CRD). Each large plot was divided length wise in 3 equal size sub-plots (sectors). The length and breadth of each sector was 2.10 and 3.20 m, respectively. Each sector was considered as one repetition. Other details were similar to experimental details described earlier in 3.1.3.

3.3.2.1 Method of recording observations

The yellow stem borer, *S. incertulas* egg masses were collected along with leaf blade from each sector at 60 and 75 DAT. During both years of study at 30 and 45 DAT, egg masses of *S. incertulas* were observed in only few treatments. A minimum of 1 egg mass was collected from each sector. The collected egg masses were placed individually in specimen tubes measuring 2.5 cm in diameter and 15 cm length. Both the ends of leaf blade were raped in moist cotton wool to keep it fresh and turgid for longer time. The specimen tubes were plugged with cotton wool to prevent escape of parasitoid adults (Plate 2). The number of parasitoids and larvae emerged from each egg mass were recorded daily. After the emergence, the adult parasitoids were observed under a stereo-zoom microscope (Magnus MSZ-TR with a zoom ratio of 1 : 7), to identify the respective species and number. The per cent egg parasitism was computed based on number of live larvae and parasitoid emergence.

3.4 EFFECT OF SILICON APPLICATION ON OVIPOSITION PREFERENCE AND ITS ANTIBIOSIS EFFECTS ON *S. incertulas*

The present study on the effect of silicon application on the oviposition preferences and its antibiosis effects on *S. incertulas* was carried out in the Laboratory at Agricultural Research Station, Anand Agricultural University, Derol, Dist. Panchmahal (Gujarat), during August-October, 2014.

3.4.1 Effect of silicon application on oviposition preference of *S. incertulas*

3.4.1.1 Mass culture of *S. incertulas*

Raising of rice plants

Seeds of rice variety GR-11 were sown in earthen pots in the last week of May, 2014. A mixture of black soil taken from the rice fields and well decomposed farm yard manure at a ratio of 3 : 1 was used to fill the earthen pots. Seedlings were regularly watered for their better growth. After 25 days, seedlings were transplanted into black polythene bags (length : 30 cm, breadth : 33 cm) at one seedling per polythene bag. Before transplanting of rice seedlings, polythene bag were filled with the mixture of black soil taken from the rice fields and well decomposed farm yard manure at a ratio of 3 : 1. As rice is water loving plant, no whole was made in the polythene bags to remove excess water. This allowed maintenance of sufficient moisture/water in each polythene bag. Ammonium phosphate sulphate (N : 20 %, P_2O_5 : 20 %, K_2O : 0 % and S : 13.5 %) @ 1 g was applied in each polythene bag at 3 DAT and at 30 DAT ammonium sulphate (N : 20 %, P_2O_5 : 0 %, K_2O : 0 % and S : 21.5 %) @ 1 g was applied. No fertilizer was applied thereafter.

Rearing of *S. incertulas*

Egg masses of *S. incertulas* were collected from the rice nursery/fields, by clipping the leaves of rice plants with egg mass, from Adadara village, Ta. Kalol, Dist. Panchmahal, Gujarat. The clipped leaves with egg masses were placed to plastic bottles (length :

6 cm, diameter : 5 cm) in the laboratory for the hatching. The cap of the plastic bottles had 8-10 narrow perforations, made with needles, which allowed sufficient aeration. The base of the leaf blade was wrapped with moist cotton wool. At the bottom of the plastic bottles moist cotton wool was placed and on that round piece of filter paper having diameter equal to that of plastic bottle was placed which maintained humidity in the plastic bottle and kept leaf turgid and fresh for longer time. After emergence of larvae from the eggs, they were carefully picked up with the fine camel hair brush and placed near the auricle of top fully expanded leaf of rice plants grown in black plastic bag (Heinrichs *et al.*, 1985) (Plate 3). All the tillers in each hill were infested with larva. After infestation with larvae, the rice plants along with plastic bag were transferred into nylon mesh cage measuring 4.25 m in length, 3.75 m in breadth and 1.80 m in height (Plate 4). They were kept there until emergence of adults. The open bottom of nylon mesh was covered with soil to prevent escape of insects. Rice plants were regularly watered and timely fertilized as described under section 3.2.1.1. After adult emergence, old plants were replaced with new plants to continue life cycle of *S. incertulas.* The culture was maintained continuously; the egg masses and adults were collected as and when required for experimentation.

3.4.1.2 Oviposition preference test for *S. incertulas*

A free-choice preference test for egg laying by yellow stem borer female adults was carried out in the laboratory at Agricultural

Research Station, Anand Agricultural University, Derol-389320, Dist. Panchmahal (Gujarat) during the month of September 2014.

Silicon application and raising of rice plants

The experiment was conducted in pot culture with two treatments (1) with silicon application (Si^{+}) and (2) without silicon application (Si-). For Si+ treatment, calcium silicate @ 1 g/kg soil was thoroughly mixed with soil and mixture was used to fill the 20 black polythene bags. For Si- treatment, another 20 bags were filled with soil only. Seeds of rice of variety GR-11 were sown in the second week of July, 2014 in earthen pots. After 25 days, seedlings were transplanted in to black polythene bags (length : 30 cm, breadth : 33 cm). The other details of methodology for growing of rice plants were similar as described under section 3.4.1.1 (Mass culture of *S. incertulas*).

Free-choice preference test for egg laying

Two polythene bags (one each of Si+ and Si-) with rice plant grown in it were transferred into cage (length : 75 cm, width : 75 cm, height : 75 cm). Next day morning freshly emerged male and female adult of *S. incertulas*, collected from mass culture, were released into cage. Four cotton swabs dipped in 10 per cent honey solution were hanged with threads in the cage as food for adults. After 96 hours, the adults were removed and number of eggs masses and eggs laid on silicon treated plants and control plants were counted. The entire experiment was replicated 15 times.

3.4.2 Antibiosis effect of silicon on *S. incertulas*

The experiment was conducted in laboratory with two treatments (1) with silicon application (Si^+) (2) without silicon application (Si-).

3.4.2.1 Silicon application and raising of rice plants

Seeds of rice of variety GR-11 were sown in earthen pots thrice at 15 days interval starting from the third week of June 2014. A mixture of black soil taken from the rice fields and well decomposed farm yard manure at a ratio of 3 : 1 was used to fill the earthen pots. Seedlings were regularly watered for their better growth. After 25 days, seedlings were transplanted into black polythene bags (length : 30 cm, breadth : 33 cm) individually in 80 polythene bags. Out of 80 bags, 40 bags were filled with silicon amended soil (Si+). Silicon was applied in the form of calcium silicate @ 1 g/kg soil. For the purpose, soil was weighed and based on its weight calcium silicate was added @ 1 g/kg soil and properly mixed. For Si- treatment bags were filled with black soil only. Remaining details of methodology was similar as described earlier under section 3.4.1.1.

3.4.2.2 Rearing of *S. incertulas*

Egg

Egg masses along with the piece of leaves were collected from mass culture of yellow stem borer maintained in the laboratory and transferred to specimen tubes, measuring 2.5 cm in diameter and 15 cm length, for hatching. Both the ends of leaf lamina were raped in moist cotton wool to keep leaf lamina fresh and turgid for longer time. The specimen tubes were plugged with cotton wool to prevent newly hatched larvae from escaping. Such plugs were also useful to maintain the sufficient aeration and humidity inside specimen tube. Specimen tubes thus prepared were kept in a beaker in vertical position at room temperature in the laboaratory.

Larva

The newly hatched larvae were carefully picked up with the soft camel hair brush and transferred to tender rice stems taken from the silicon applied rice plants and control plants. For the purpose, the hollow stems of rice, about 12-15 cm in length and 0.4 cm in diameter were selected from the top portion of the plant. Stems were cut in such a way that each stem had a node about 1 to 2 cm from the bottom (Plate 5). A unique number was given to each larvae and that number was written on the stem with glass marking pen. The top of the stem was plugged with cotton wool to prevent the escape of larvae. Such stems of rice were kept in vertical position in glass beaker having capacity of 500 ml (Plate 5). Silicon applied stems and control stems, with larva inside, were kept in separate beaker. Maximum 10 stems were kept in each beaker. Distilled water, up to height of 1 cm from the bottom, was poured in to beaker so as to keep the stem fresh and turgid for longer period. The top of the beaker was covered with muslin cloth and fixed with rubber ring. Beakers having stems from silicon applied plants were kept apart from the beakers with stems from control plants. Both the set of beakers were kept at room temperature in the laboratory.

Fresh food of tender stems was provided to the younger larvae every two days interval till 10 to 12 days. Thereafter, bigger larvae were provided the stems having sufficient girth so that the larvae can easily feed inside the stem. Those larvae that were initially given stems from rice plants grown on silicon applied soil were subsequently fed with that type of rice stems only. Whereas those larvae that were initially given stems from rice plants grown on control soil were fed this type of stems as a food during their entire larval period. The larvae were transferred to fresh rice stems at every two days intervals, till they pupated.

In order to determine the number of larval instars, individual larva was observed daily and the date of moulting was noted. Moulting was confirmed by the presence of exuva. After the change of instar by each larva it was weighed. The total larval period was calculated on the basis of date of egg hatching to the date of the pupal formation.

Pre-pupa

A stage when last fully grown larvae stopped feeding and changed its colour from yellowish white to milky white was considered as pre-pupal stage.

Pupa

Pre-pupae were observed daily and date of pupal formation was recorded. After pupation, each stem was split opened from the top to the site of pupation. Then the pupa was gently removed and weighed and again put in the stem. The stems with pupae were kept in a jar covered with a muslin cloth. The cotton-wool wrapped to the basal portion of stems and it was soaked in water daily to keep them moist and soft till the adult emergence from the pupae. The pupal period was calculated on the basis of date of formation of pupa to the date of adult emergence.

Adult

Adults were separated as male and female, on the basis of sexual diamorphism. The adult having light brown colour with numerous small light brown spots on forewing and slightly smaller was a male, while the adult having yellow colour with a big distinct black dot on the centre of fore wing and anal tuft of yellowish hair on last abdominal segment was a female (Plate 6).

From the emerged adults, a pair consisting of a male and female was caged separately in a glass chimney used for lantern (height : 15 cm, diameter of base : 6.5 cm, diameter of top : 5.5 cm). Si+ female were paired only with the Si+ males while Si- females were paired with Si- males. In the glass chimney a plastic bottle (height : 6 cm, diameter : 5 cm), filled with water up to 1 cm from bottom, was placed in the centre. About 10-12 cm long 4-5 pieces of fresh leaf blades of rice were kept in upright position in plastic bottle for egg laying by the female. The pieces of leaf were cut from terminal portion of rice leaf blades of plants without silicon application. The basal portions of the pieces of leaf blades were dipped in the water to keep leaf blades fresh and turgid for longer period. The pieces of leaf blades were replaced daily with fresh ones without silicon application. The top of glass chimney was covered with a fine muslin cloth supported with rubber band to prevent the escape of adults (Plate 6). Two cotton swabs dipped in 10 per cent honey solution were hanged in the glass chimney as a food for the adults.

Pre-oviposition, oviposition and post-oviposition periods and adult longevity

Males and females of each pair were observed daily for start and cessation of egg laying and death of adults. Pre-oviposition period was calculated from the date of emergence of female and the date of laying of first egg mass. Oviposition period was calculated from the date of laying of first egg mass to the date of cessation of egg laying by the female. Post-oviposition period was calculated from the date of cessation of egg laying to the date of death of female. The longevity of female and male was calculated separately from the date of emergence to the death of each adult.

Fecundity and hatchability

The total number of eggs masses laid by each female was counted. Further, the egg masses along with section of leaf blade were transferred to specimen tubes measuring 2.5 cm in diameter and 15 cm in length. The specimen tubes were plugged with cotton wool to prevent newly hatched larvae from escaping. Neonate larvae emerging from each egg masses were counted daily and it was considered as number of fertile eggs. If hatching was not observed for 2 days, then the egg masse was observed under stereoscopic binocular microscope and unfertile eggs were counted. Based on these data fecundity and hatching percentage was worked out.

Statistical analysis of data

Data were statistically analysed as per the procedure given by Steel and Torrie (1980).

IV. RESULTS AND DISCUSSION

The results of the studies carried out on effect of silicon application on insect pest population / damage in rice, chemical and biochemical constituents of rice plants, natural enemies of rice insect pests and oviposition preference as well as antibiosis effect on yellow stem borer, *S. incertulas* are presented hereafter in this chapter. The results of present studies are also discussed in light of the results of research carried out elsewhere which have a direct or indirect relation with the present investigation.

4.1. EFFECT OF SILICON APPLICATION ON INSECT PEST POPULATION / DAMAGE IN RICE

Four different doses of soil application (SA) of calcium silicate (500, 1000, 1500 and 2000 kg/ha) and three concentrations of foliar application (FA) of potassium silicate (0.5, 1.0 and 2.0 %) were evaluated along with control for their efficacy against yellow stem borer, *S. incertulas,* leaffolder *C. medinalis*, whitebacked planthopper, *S. furcifera* and green leafhopper *N. virescens*.

4.1.1 Effect of silicon application on incidence of *S. incertulas*

The data on per cent deadhearts at 30 and 45 DAT as well as white earheads at 60 and 75 DAT are presented in Table 1 to 3 and the overall pooled data are graphically depicted in Fig. 1.

Table 1 : Effect of silicon application on incidence of *S. incertulas* in rice during *kharif* 2011

Treatments	Deadhearts (%)			White earheads (%)		
	30 DAT	**45 DAT**	**Pooled**	**60 DAT**	**75 DAT**	**Pooled**
SA of calcium silicate @ 500 kg/ha at TP	7.53ab (1.72)	8.04abc (1.95)	7.78ab (1.83)	10.94abc (3.60)	13.34bcd (5.32)	12.14bc (4.42)
SA of calcium silicate @ 1000 kg/ha at TP	7.49ab (1.70)	7.31ab (1.62)	7.40a (1.66)	10.04ab (3.04)	12.71abc (4.84)	11.38ab (3.89)
SA of calcium silicate @ 1500 kg/ha at TP	6.71a (1.36)	7.47ab (1.69)	7.09a (1.52)	9.57ab (2.76)	11.31ab (3.85)	10.44ab (3.28)
SA of calcium silicate @ 2000 kg/ha at TP	5.88a (1.05)	6.74a (1.38)	6.31a (1.21)	9.01a (2.45)	10.64a (3.41)	9.83a (2.91)
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT	9.61b (2.79)	10.13cd (3.09)	9.87c (2.94)	12.65c (4.79)	16.73e (8.29)	14.69d (6.43)
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT	9.62b (2.79)	9.08bcd (2.49)	9.35c (2.64)	11.92bc (4.26)	15.90de (7.50)	13.91cd (5.78)
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT	9.41b (2.68)	8.60abcd (2.24)	9.01bc (2.45)	11.74bc (4.14)	15.25cde (6.92)	13.50cd (5.45)
Control	9.66b (2.81)	10.55d (3.36)	10.11c (3.08)	13.53c (5.48)	17.05e (8.60)	15.29a (6.96)
S. Em. ± T	0.65	0.69	0.47	0.77	0.80	0.56
P	-	-	0.24	-	-	0.28
T x P	-	-	0.67	-	-	0.79
C.V. %	13.57	14.15	13.87	11.88	9.86	10.75

Figures outside parenthesis are arcsine transformed value and those inside parenthesis are retransformed values.

Treatment means followed by same letter do not differ significantly by DNMRT at 5 per cent level of significance.

TP : Transplanting, SA : Soil Application, FA : Foliar Application, DAT : Days After Transplanting

First year

Deadhearts

During first year of study, at 30 DAT, significantly the lowest (1.05 %) deadhearts was recorded in the treatment of SA of calcium silicate @ 2000 kg/ha, and it was at par with calcium silicate @ 1500 kg/ha (1.36 %), 1000 kg/ha (1.70 %) and 500 kg/ha (1.72 %). In contrast to this, FA of potassium silicate did not provide effective control of *S. incertulas.* All the three concentrations of potassium silicate evaluated were at par with the control.

At 45 DAT, differences among various treatments with respect to per cent deadhearts were statistically significant (Table 1). At this stage, SA of calcium silicate @ 2000 kg/ha was the most effective treatment as it recorded significantly the lowest per cent deadhearts (1.38 %). However, this treatment was at par with calcium silicate @ 1000 kg/ha (1.62 %), 1500 kg/ha (1.69 %) and 500 kg/ha (1.95 %). Application of potassium silicate at 0.5 to 2.0 per cent exhibited 2.24 to 3.09 per cent deadhearts due to stem borer. However, all three concentrations failed to check the incidence of this pest and found at par with control (3.36 %).

The pooled data of per cent deadhearts at 30 and 45 indicated the significant difference among various treatments (Table 1). Among the different treatments, the SA of calcium silicate @ 2000 kg/ha was the most effective with 1.21 per cent deadhearts and it was at par with SA of calcium silicate @ 1500 kg/ha (1.52 %), 1000 kg/ha (1.66 %)

and 500 kg/ha (1.83 %). Foliar application of potassium silicate (0.5 to 2.0 %) was not effective in elevating host plant resistance in rice against *S. incertulas* as they were at par with control (3.08 %).

White earheads

The data on per cent white earheads at 60 DAT (Table 1) revealed significant differences among various treatments. The SA of calcium silicate @ 2000 kg/ha (2.45 %) was the most effective and remained at par with the SA of calcium silicate @ 1500 kg/ha (2.76 %), 1000 kg/ha (3.04 %) and 500 kg/ha (3.60 %). Foliar application of potassium silicate (0.5 to 2.0 %) was not effective in reducing damage and was at par with control (5.48 %).

At 75 DAT, the differences among treatments were significant (Table 1). At this stage also, SA of calcium silicate @ 2000 kg/ha showed the lowest (3.41 %) white earheads and it was at par with calcium silicate @ 1500 kg/ha (3.85 %) and 1000 kg/ha (4.84 %). The SA of calcium silicate @ 500 kg/ha recorded 5.32 per cent white earheads and it was equally effective as calcium silicate @ 1000 and 1500 kg/ha. Foliar application of potassium silicate at 0.5 to 2.0 per cent registered 6.92 to 8.29 per cent white earheads due to stem borer and they were at par with control (8.60 %).

Pooled analysis of per cent white earheads at 60 and 75 DAT showed significant differences among treatments (Table 1). Significantly the lowest (2.91 %) white earheads was observed in the treatment of SA of calcium silicate @ 2000 kg/ha and it was at par with SA of calcium silicate @ 1500 kg/ha (3.28 %), 1000 kg/ha (3.89 %). The lowest dose (500 kg/ha) of calcium silicate noticed 4.42 per cent white earheads and it was equally effective as calcium silicate @ 1000 and 1500 kg/ha in protecting the crop against *S. incertulas*. Foliar application of potassium silicate @ 0.5 to 2.0 per cent recorded 4.45 to 6.43 per cent white earheads and they were at par with control (6.93 %).

Second year

Deadhearts

At 30 DAT, significantly the lowest (1.41 %) deadhearts was observed in the treatment of calcium silicate @ 2000 kg/ha and it was at par with SA of calcium silicate @ 1500 kg/ha (1.69 %) and 1000 kg/ha (2.42 %). The lowest dose of calcium silicate (500 kg/ha) showed 2.68 per cent deadhearts and it was equally effective as calcium silicate @ 1000 kg/ha and 1500 kg/ha. The FA of potassium silicate @ 0.5 to 2.0 per cent recorded 3.22 to 3.78 per cent deadhearts due to *S. incertulas* and they did not differ from control (3.20 %).

At 45 DAT, significant differences were found among the treatments (Table 2). The most effective treatment at this stage was SA of calcium silicate @ 2000 kg/ha which showed only 1.32 per cent deadhearts. However, it did not differ significantly from treatments of calcium silicate @ 1500 kg/ha (1.62 %) and 1000 kg/ha (2.08 %). Calcium silicate @ 500 kg/ha of recorded 2.68 per cent deadhearts

Table 2 : Effect of silicon application on incidence of *S. incertulas* in rice during *kharif* 2012

Treatments	Deadhearts (%)			White earheads (%)		
	30 DAT	45 DAT	Pooled	60 DAT	75 DAT	Pooled
SA of calcium silicate @ 500 kg/ha at TP	9.43bc (2.68)	9.42bc (2.68)	9.43cd (2.68)	10.62ab (3.39)	12.68abcd (4.82)	11.65bcd (4.08)
SA of calcium silicate @ 1000 kg/ha at TP	8.95abc (2.42)	8.30ab (2.08)	8.62bc (2.25)	9.97ab (2.99)	12.27abc (4.52)	11.12abc (3.72)
SA of calcium silicate @ 1500 kg/ha at TP	7.48ab (1.69)	7.30a (1.62)	7.39ab (1.65)	9.49a (2.72)	10.79ab (3.50)	10.14ab (3.10)
SA of calcium silicate @ 2000 kg/ha at TP	6.82a (1.41)	6.59a (1.32)	6.70a (1.36)	8.87a (2.37)	9.73a (2.86)	9.30a (2.61)
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT	9.93bc (2.97)	11.21c (3.78)	10.57d (3.37)	12.32b (4.56)	14.71cd (6.45)	13.52de (5.46)
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT	10.30c (3.20)	10.70c (3.44)	10.50d (3.32)	12.36b (4.58)	14.32cd (6.12)	13.34de (5.32)
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT	10.28c (3.18)	10.33c (3.22)	10.31d (3.20)	11.42ab (3.92)	13.52bcd (5.47)	12.47cde (4.66)
Control	9.94bc (2.98)	11.30c (3.84)	10.62d (3.40)	12.61b (4.77)	15.75d (7.37)	14.18e (6.00)
S. Em. ± T	0.77	0.58	0.48	0.80	0.92	0.61
P	-	-	0.24	-	-	0.30
T x P	-	-	0.68	-	-	0.86
C.V. %	14.50	10.66	12.68	12.61	12.30	12.47

Figures outside parenthesis are arcsine transformed value and those inside parenthesis are retransformed values.

Treatment means followed by same letter do not differ significantly by DNMRT at 5 per cent level of significance.

TP : Transplanting, SA : Soil Application, FA : Foliar Application, DAT : Days After Transplanting

and it was equally effective as calcium silicate @ 1000 kg/ha. The FA of potassium silicate (0.5 to 2.0 %) noticed 3.22 to 3.78 per cent deadhearts due to *S. incertulas*. However, these treatments failed to give protection against stem borer and they were at par with control (3.84 %).

In pooled analysis, differences between treatments with respect of per cent deadhearts were significant (Table 2). Here also, the treatment of SA of calcium silicate @ 2000 kg/ha recorded the lowest deadhearts (1.36 %) and it was at par calcium silicate @ 1500 kg/ha (1.65 %). Calcium silicate @ 1000 kg/ha (2.25 %) and 500 kg/ha (2.68 %) were equally effective against yellow stem borer. Foliar application of potassium silicate at 0.5 to 2.0 per cent registered 3.20 to 3.37 per cent deadhearts. However, these treatments failed to give protection against stem borer and they were at par with control (3.40 %).

White earheads

At 60 DAT, damage by *S. incertulas* recorded as white earheads was significantly different in various treatments. Minimum (2.37 %) white earheads was observed in the treatment of SA of calcium silicate @ 2000 kg/ha and it was at par with calcium silicate @ 1500 kg/ha (2.72 %), 1000 kg/ha (2.99 %), 500 kg/ha (3.39 %) and FA of potassium silicate @ 2.0 per cent (3.92 %). FA of potassium silicate @ 0.5 and 1.0 per cent recorded 4.56 and 4.58 per cent white earheads and they were at par with control (4.77 %).

At 75 DAT, differences among treatments with respect to white earheads were significant. The SA of calcium silicate @ 2000 kg/ha was the most effective (2.86 %) and it was at par with SA of calcium silicate @ 1500, 1000 and 500 kg/ha. Foliar application of potassium silicate @ 0.5 to 2.0 per cent had 5.47 to 6.45 per cent white earheads and they were at par with control (7.37 %).

The differences among various treatments were significant in pooled over period analysis. The lowest (2.61 %) white earheads was observed in the treatment of SA of calcium silicate @ 2000 kg/ha and it remained at par with SA of calcium silicate @ 1500 kg/ha (3.10 %) and @ 1000 kg/ha (3.72 %). SA of calcium silicate @ 500 kg/ha noticed 4.08 per cent white earheads and it was equally effective as SA of calcium silicate @ 1000 and 1500 kg/ha. All three concentrations of foliar application of potassium silicate exhibited 4.66 to 5.46 per cent white earheads but were at par with control (6.00 %).

Pooled over years

Deadhearts

Pooled analysis of two years (Table 3) revealed significant differences among treatments for deadheart formation due to *S. incertulas* in rice at 30 DAT. Minimum (1.22 %) deadhearts was observed in the treatment of SA of calcium silicate @ 2000 kg/ha and it was at par with the SA of calcium silicate @ 1500 kg/ha (1.52 %). The treatment of calcium silicate @ 1000 and 500 kg/ha recorded 2.04 and 2.17 per cent deadhearts, respectively and they were equally

Table 3 : Effect of silicon application on incidence of *S. incertulas* in rice (Pooled over years)

Treatments	Deadhearts (%)			White earheads (%)		
	30 DAT	45 DAT	Overall Pooled	60 DAT	75 DAT	Overall Pooled
SA of calcium silicate @ 500 kg/ha at TP	8.48bcd (2.17)	8.73bc (2.30)	8.60cd (2.24)	10.78bcd (3.50)	13.01c (5.07)	11.89cd (4.25)
SA of calcium silicate @ 1000 kg/ha at TP	8.22bc (2.04)	7.80ab (1.84)	8.01bc (1.94)	10.00abc (3.02)	12.49bc (4.68)	11.25bc (3.80)
SA of calcium silicate @ 1500 kg/ha at TP	7.09ab (1.52)	7.39ab (1.65)	7.24ab (1.59)	9.53ab (2.74)	11.05ab (3.67)	10.29ab (3.19)
SA of calcium silicate @ 2000 kg/ha at TP	6.35a (1.22)	6.67a (1.35)	6.51a (1.28)	8.94a (2.41)	10.18a (3.13)	9.56a (2.76)
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT	9.77cd (2.88)	10.67d (3.43)	10.22e (3.15)	12.49de (4.67)	15.72d (7.34)	14.10ef (5.94)
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT	9.96d (2.99)	9.89cd (2.95)	9.93e (2.97)	12.14de (4.42)	15.11d (6.79)	13.62ef (5.55)
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT	9.85cd (2.92)	9.47cd (2.71)	9.66de (2.81)	11.58cde (4.03)	14.39cd (6.17)	12.98de (5.05)
Control	9.80cd (2.90)	10.93d (3.59)	10.36e (3.24)	13.07e (5.11)	16.40d (7.97)	14.74f (6.47)
S. Em. ± T	0.50	0.45	0.36	0.55	0.61	0.40
P	-	-	0.18	-	-	0.20
Y	0.25	0.23	0.18	0.28	0.31	0.20
T x P	-	-	0.51	-	-	0.57
T x Y	0.71	0.64	0.51	0.78	0.86	0.57
P x Y	-	-	0.25	-	-	0.28
T x P x Y	-	-	0.72	-	-	0.80
C.V. %	14.11	12.37	14.15	12.24	11.05	11.29

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effective as calcium silicate @ 1500 kg/ha. The FA of potassium silicate @ 2.0, 1.0 and 0.5 per cent noticed 2.92, 2.99 and 2.88 per cent deadhearts due to *S. incertulas* in rice, respectively but they were at par with control (2.90 %).

The pooled data on deadhearts due to *S. incertulas* in rice recorded at 45 DAT during *kharif* 2011 and 2012 showed that there were significant differences among treatments (Table 3). SA of calcium silicate @ 2000 kg/ha was the most effective (1.35 %) in reducing deadhearts and it was at par with calcium silicate @ 1500 kg/ha (1.65 %) and 1000 kg/ha (1.84 %). The lowest dose (500 kg/ha) of calcium silicate exhibited 2.30 per cent deadhearts and it was equally effective as calcium silicate @ 1000 and 1500 kg/ha. Three concentrations of foliar application of silicon in the form of potassium silicate recorded 2.71 to 3.43 per cent deadhearts due to *S. incertulas* but they were at par with control (3.59 %).

The pooled over periods and years analysis of deadhearts revealed significant differences among treatments (Table 3 and Fig. 1). The lowest deadhearts (1.28 %) was recorded in the treatment of SA of calcium silicate @ 2000 kg/ha and it was at par with calcium silicate @ 1500 kg/ha (1.59 %). SA of calcium silicate @ 1000 and 500 kg/ha, noticed 1.94 and 2.24 per cent deadhearts, respectively. SA of calcium silicate @ 1000 kg/ha was equally effective as calcium silicate @ 1500 and 500 kg/ha, whereas the lowest dose of calcium silicate (500 kg/ha) was at par with foliar application of potassium silicate @ 2.0

per cent, in reducing the deadhearts due to *S. incertulas* in rice. Foliar application of potassium silicate @ 0.5 to 2.0 per cent recorded 2.81 to 3.15 per cent deadhearts but they were at par with control (3.24 %).

White earheads

Treatments differed significantly from one another on the basis pooled data of white earheads recorded at 60 DAT during *kharif* 2011 and 2012 (Table 3). Among the eight different treatments evaluated for their efficacy against *S. incertulas*, the lowest (2.41%) white earheads was observed in the treatment of SA of calcium silicate @ 2000 kg/ha and it was at par with the treatments of calcium silicate @ 1500 kg/ha (2.74 %) and 1000 kg/ha (3.02 %). The SA of calcium silicate @ 500 kg/ha recorded 3.50 % white earheads and it was equally effective as calcium silicate @ 1000 kg/ha and 1500 kg/ha. Foliar application of potassium silicate at 0.5 to 2 per cent exhibited 4.03 to 4.67 per cent white earheads but they were at par with control.

In case of pooled data on white earheads at 75 DAT, the differences among treatments were significant (Table 3). The white earheads was minimum (3.13 %) in the treatment of SA of calcium silicate @ 2000 kg/ha and it was at par with SA of calcium silicate @ 1500 kg/ha (3.67 %). SA of calcium silicate @1500 kg/ha and 1000 kg/ha were found to be equally effective in reducing the white earheads due to stem borer in rice. Similarly, the SA of calcium silicate @ 1000 and 500 kg/ha as well as foliar application of potassium silicate @ 2.0 per cent were equally effective against stem borer. All three concentrations of potassium silicate as foliar spray were found less effective as they recorded white earheads between 6.17 and 7.34 per cent and they were at par with control (7.97 %).

The data pooled over periods and years revealed significant differences among the treatments (Table 3 and Fig. 1). The lowest (2.76 %) white earheads was noticed in the plots treated with calcium silicate @ 2000 kg/ha and it was at par with SA of calcium silicate @ 1500 kg/ha (3.19 %). The SA of calcium silicate @ 1500 and 1000 kg/ha (3.80 %) were equally effective against *S. incertulas* in rice. Similarly, the SA of calcium silicate @ 1000 and 500 kg/ha (4.25 %) were equally effective. Among the different concentrations of foliar spray potassium silicate, the highest (5.94 %) white earheads was observed in the treatment of 0.5 per cent and it was at par with 1 per cent (5.55 %) and control (6.47 %).

Above results are in line with results of Miller *et al.* (1960), who reported that several susceptible wheat varieties developed resistance against Hessian fly, *P. destructor* when they were grown in a solution containing sodium silicate. Similarly, Sasamoto (1961) found decrease in the susceptibility to the stem borer, *C. suppressalis* when rice was grown in silicon supplied soils. Meyer and Keeping (2005) also reported that application of silicon @ 200 kg/ha to sugarcane significantly reduced damage (47 %) by stalk borer, *E. saccharina*.

Panda *et al.* (1975) observed that the larvae of the yellow rice borer, *S. incertulas* were unable to attack resistant rice plants because of the high silica content of their stems. Pan *et al.* (1979) showed that borer damage in silicon treated sugarcane was less than untreated control. Balasubramaniam *et al.* (2005) found that application of different sources of silicon *viz.,* rice straw, silicate solubilising bacteria and sodium meta silicate increased the content of silicon in rice plant, which decreased incidence of stem borer. Application of silica @ 0.56 g/plant under laboratory conditions reduced ultimate larval survival of maize stem borer, *S. calamistis* from 26.0 per cent (control) to 4.0 per cent (Setamou *et al.*, 1993). Hosseini *et al.* (2011) showed that there was decrease in white head damage with increase in silica application rate in rice.

4.1.2 Effect of silicon application on leaf damage due to *C. medinalis*

The data on per cent leaf damage due to leaffolder, *C. medinalis* at 30, 45, 60 and 75 DAT are presented in Table 4 to 6.

First year

Leaf damage by *C. medinalis,* expressed as percentage, in different treatments at 30 DAT differed significantly (Table 4). Minimum (1.94 %) leaf damage was observed in the treatment of SA of calcium silicate @ 2000 kg/ha and it remained at par with the treatments of calcium silicate @ 1500 kg/ha (2.10 %), 1000 kg/ha (2.41 %) and 500 kg/ha (2.65 %). Foliar application of potassium silicate at 0.5 and 2 per cent recorded 3.05 to 3.17 per cent leaf damage due to leaffolder, but they were at par with control (3.24 %).

Table 4 : Effect of silicon application on leaf damage due to *C. medinalis* in rice during *kharif* 2011

Treatments	Leaf damage (%)				
	30 DAT	**45 DAT**	**60 DAT**	**75 DAT**	**Pooled**
SA of calcium silicate @ 500 kg/ha at TP	9.37abc (2.65)	10.92abcd (3.59)	13.31abc (5.30)	15.06abc (6.75)	12.17cd (4.44)
SA of calcium silicate @ 1000 kg/ha at TP	8.93abc (2.41)	10.46abc (3.30)	12.87abc (4.96)	13.49ab (5.44)	11.44bc (3.93)
SA of calcium silicate @ 1500 kg/ha at TP	8.34ab (2.10)	9.80ab (2.89)	12.24ab (4.49)	13.25ab (5.25)	10.91ab (3.58)
SA of calcium silicate @ 2000 kg/ha at TP	8.01a (1.94)	9.20a (2.56)	11.77a (4.16)	12.06a (4.36)	10.26a (3.17)
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT	10.26c (3.17)	12.56cd (4.73)	14.99c (6.69)	16.87c (8.42)	13.67e (5.59)
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT	10.15bc (3.11)	12.24cd (4.50)	14.56bc (6.32)	16.35bc (7.93)	13.33de (5.31)
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT	10.06bc (3.05)	11.89bcd (4.24)	14.39abc (6.18)	15.68bc (7.30)	13.00de (5.06)
Control	10.37c (3.24)	12.88d (4.97)	15.48c (7.13)	17.24c (8.78)	13.99e (5.85)
S. Em. ± T P T x P	0.54 - -	0.67 - -	0.79 - -	0.96 - -	0.38 0.27 0.76
C.V. %	9.92	10.30	10.02	11.10	10.62

Figures outside parenthesis are arcsine transformed value and those inside parenthesis are retransformed values.

Treatment means followed by same letter do not differ significantly by DNMRT at 5 per cent level of significance.

TP : Transplanting, SA : Soil Application, FA : Foliar Application, DAT : Days After Transplanting

At 45 DAT, differences among various treatments with respect to per cent leaf damage were significant (Table 4). The lowest (2.56 %) leaf damage was recorded in the treatment of SA of calcium silicate @ 2000 kg/ha and it was at par with calcium silicate @ 1500 kg/ha (2.89 %), 1000 kg/ha (3.30 %) and 500 kg/ha (3.59 %). None of the three concentrations of potassium silicate, applied as foliar spray, could provide effective control of *C. medinalis.* All the three treatments of FA of potassium silicate were at par with the control (4.97 %).

At 60 DAT, differences among treatments were significant (Table 4) indicating effectiveness of treatments. Among the various treatments evaluated, significantly the lowest (4.16 %) leaf damage was recorded in the treatment of SA of calcium silicate @ 2000 kg/ha and it was at par with remaining three doses of calcium silicate @ 500 to 1500 kg/ha. All three concentrations of foliar application of potassium silicate noticed 6.18 to 6.69 per cent leaf damage due to *C. medinalis* in rice, but they were at par with control (7.13 %).

At 75 DAT, significant differences were observed among various treatments (Table 4). At this stage also, the treatment of SA of calcium silicate @ 2000 kg/ha was the most effective and it suffered the lowest (4.36 %) leaf damage by *C. medinalis*. Calcium silicate @ 1500, 1000 and 500 kg/ha recorded 5.25, 5.44 and 6.75 % leaf damage due to leaffolder, respectively. Foliar application of silicon in the form of potassium silicate did not provide protection to rice plants against

C. medinalis, as all the three concentrations of potassium silicate tested were at par with control plots (8.78 %).

The data pooled over periods showed the significant differences among treatments (Table 4). The most effective treatment was SA of calcium silicate @ 2000 kg/ha as it suffered the lowest (3.17 %) leaf damage and it remained at par with calcium silicate @ 1500 kg/ha (3.58 %). SA of calcium silicate @ 1500 and 1000 kg/ha as well as SA of calcium silicate @ 1000 and 500 kg/ha were at par with each other in their descending orders against *C. medinalis.* All the three concentrations of potassium silicate were at par with control (5.85 %).

Second year

During second year at 30 DAT, difference among treatments with respect leaf damage due to *C. medinalis* was non-significant (Table 5). Plots treated with different doses of calcium silicate suffered numerically lesser leaf damage (1.49 to 1.77 %) than control (2.15 %).

At 45 DAT, differences among various treatments with respect to per cent leaf damage were significant (Table 5). The lowest (1.77 %) leaf damage was recorded in the treatment of calcium silicate @ 2000 kg/ha and it was at par with the treatment of calcium silicate @ 1500 kg/ha (2.01 %), 1000 kg/ha (2.17 %) and 500 kg/ha (2.34 %) as well as FA of potassium silicate @ 2.0 per cent (2.63 %). All the concentrations (0.5 to 2.0 %) of potassium silicate as well as calcium

Table 5 : Effect of silicon application on leaf damage due to *C. medinalis* in rice during *kharif* 2012

Treatments	Leaf damage (%)				
	30 DAT	**45 DAT**	**60 DAT**	**75 DAT**	**Pooled**
SA of calcium silicate @ 500 kg/ha at TP	7.64a (1.77)	8.80abc (2.34)	10.76abc (3.49)	10.78abc (3.50)	9.49bc (2.72)
SA of calcium silicate @ 1000 kg/ha at TP	7.46a (1.69)	8.47abc (2.17)	10.36abc (3.23)	10.48abc (3.31)	9.19b (2.55)
SA of calcium silicate @ 1500 kg/ha at TP	7.32a (1.63)	8.14ab (2.01)	9.61ab (2.79)	9.89ab (2.95)	8.74ab (2.31)
SA of calcium silicate @ 2000 kg/ha at TP	7.00a (1.49)	7.64a (1.77)	9.13a (2.52)	9.26a (2.59)	8.26a (2.06)
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT	8.31a (2.09)	9.76bc (2.88)	11.98c (4.31)	12.68cd (4.82)	10.68d (3.44)
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT	8.28a (2.07)	9.57bc (2.77)	11.66bc (4.08)	12.44bcd (4.64)	10.49d (3.31)
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT	8.16a (2.01)	9.34abc (2.63)	11.46bc (3.95)	11.79abcd (4.18)	10.19cd (3.13)
Control	8.42a (2.15)	10.16c (3.11)	12.13c (4.41)	13.58d (5.51)	11.07d (3.69)
S. Em. ± T	0.46	0.51	0.64	0.80	0.31
P	-	-	-	-	0.22
T x P	-	-	-	-	0.62
C.V. %	10.23	9.89	10.25	12.19	10.97

Figures outside parenthesis are arcsine transformed value and those inside parenthesis are retransformed values.

Treatment means followed by same letter do not differ significantly by DNMRT at 5 per cent level of significance.

TP : Transplanting, SA : Soil Application, FA : Foliar Application, DAT : Days After Transplanting

silicate @ 500 kg/ha and 1000 kg/ha were found non-effective as these treatments recorded leaf damage between 2.17 to 2.88 per cent and they were par with control (3.11 %).

At 60 DAT, plots treated with calcium silicate @ 2000 kg/ha suffered the lowest (2.52 %) leaf damage and it was at par with calcium silicate @ 1500 kg/ha (2.79 %), 1000 kg/ha (3.23 %) and 500 kg/ha (3.49 %). All the three concentrations (0.5 to 2.0 %) of potassium silicate did not protect rice plants against *C. medinalis* as they were at par with control (4.41 %).

At 75 DAT, leaf damage due to *C. medinalis* differed significantly in various treatments (Table 5). The most effective treatment at this stage was SA of calcium silicate @ 2000 kg/ha which suffered only 2.59 per cent leaf damage. This treatment was at par with calcium silicate @ 1500 kg/ha (2.95 %), 1000 kg/ha (3.31 %) and 500 kg/ha (3.50 %). None of the three concentrations (0.5 to 2.0 %) of foliar application of potassium silicate could offer protection against *C. medinalis* and remained at par with control (5.51 %).

Pooled over periods analysis revealed significant differences among treatments (Table 5). SA of calcium silicate @ 2000 kg/ha emerged as most effective treatment and it remained at par with calcium silicate @ 1500 kg/ha (2.31 %). Calcium silicate @ 1000 and 500 kg/ha recorded 2.55 and 2.72 per cent leaf damage due to *C. medinalis,* respectively and they were equally effective as SA of calcium silicate @ 1500 kg/ha. Foliar application of silicon in the form of potassium silicate was not effective since all the three concentrations (0.5 to 2.0 %) were at par with control (3.69 %).

Pooled over years

Pooled analysis of per cent leaf damage at 30 DAT revealed significant differences among the treatments (Table 6). The treatment of SA of calcium silicate @ 2000 kg/ha emerged as the most effective with 1.71 per cent leaf damage and it was at par with the calcium silicate @ 1500 kg/ha, 1000 kg/ha and 500 kg/ha, which suffered 1.86, 2.03 and 2.19 per cent leaf damage, respectively. At this stage all three concentrations (0.5 to 2.0 %) of potassium silicate were ineffective against *C. medinalis*, as all of them did not differ significantly from control (2.66 %).

At 45 DAT there were significant differences among the treatments (Table 6). Soil application of calcium silicate @ 2000 kg/ha recorded the lowest (2.15 %) leaf damage and it was at par with calcium silicate @ 1500 kg/ha and 1000 kg/ha which suffered 2.43 and 2.70 per cent leaf damage, respectively. Remaining treatments which included calcium silicate @ 500 kg/ha and three concentrations (0.5 to 2.0 %) of potassium silicate were at par with control (3.99 %).

Pooled over years results of per cent leaf damage due to *C. medinalis* at 60 DAT indicated significant differences among the treatments (Table 6). Treatment of calcium silicate @ 2000 kg/ha emerged as most effective and recorded 3.29 per cent leaf damage.

Table 6 : Effect of silicon application on leaf damage due to *C. medinalis* in rice (Pooled over years)

Treatments	Leaf damage (%)				
	30 DAT	**45 DAT**	**60 DAT**	**75 DAT**	**Overall Pooled**
SA of calcium silicate @ 500 kg/ha at TP	8.50abc (2.19)	9.86bcd (2.93)	12.04abc (4.35)	12.92bcd (5.00)	10.83c (3.53)
SA of calcium silicate @ 1000 kg/ha at TP	8.20ab (2.03)	9.46abc (2.70)	11.61ab (4.05)	11.99abc (4.31)	10.31bc (3.21)
SA of calcium silicate @ 1500 kg/ha at TP	7.83a (1.86)	8.97ab (2.43)	10.93a (3.59)	11.57ab (4.02)	9.82ab (2.91)
SA of calcium silicate @ 2000 kg/ha at TP	7.51a (1.71)	8.42a (2.15)	10.45a (3.29)	10.66a (3.42)	9.26a (2.59)
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT	9.29bc (2.61)	11.16de (3.75)	13.49cd (5.44)	14.78de (6.51)	12.18de (4.45)
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT	9.21bc (2.56)	10.91de (3.58)	13.11bcd (5.14)	14.39de (6.18)	11.91de (4.26)
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT	9.11bc (2.51)	10.61cde (3.39)	12.93bcd (5.00)	13.73cde (5.64)	11.60d (4.04)
Control	9.39c (2.66)	11.52e (3.99)	13.81d (5.69)	15.41e (7.06)	12.53e (4.71)
S. Em. ± T	0.36	0.42	0.51	0.63	0.24
P	-	-	-	-	0.17
Y	0.18	0.21	0.26	0.31	0.12
T x P	-	-	-	-	0.47
T x Y	0.50	0.60	0.72	0.88	0.33
P x Y	-	-	-	-	0.24
T x P x Y	-	-	-	-	0.67
C.V. %	10.09	10.21	10.17	11.62	10.46

Figures outside parenthesis are arcsine transformed value and those inside parenthesis are retransformed values.
Treatment means followed by same letter do not differ significantly by DNMRT at 5 per cent level of significance.
TP : Transplanting, SA : Soil Application, FA : Foliar Application, DAT : Days After Transplanting

Remaining three doses of calcium silicate *i.e.* 1500 kg/ha (3.59 %), 1000 kg/ha (4.05 %) and 500 kg/ha (4.35 %) were all at par with the most effective treatment. FA of potassium silicate at 0.5 to 2.0 per cent registered leaf damage between 5.00 and 5.44 per cent but it was at par with control (5.69 %).

At 75 DAT, damage due to leaffolder in various treatments differed significantly (Table 6). At this stage, minimum (3.42 %) leaf damage was recorded in the plots applied with calcium silicate @ 2000 kg/ha and it was at par with SA of calcium silicate @ 1500 kg/ha (4.02 %) and 1000 kg/ha (4.31 %). SA of calcium silicate @ 500 kg/ha recorded 5.00 per cent leaf damage due to *C. medinalis* and it was equally effective as SA of calcium silicate @ 1000 kg/ha (4.31 %) and 1500 kg/ha (4.02 %). FA of silicon in the form of potassium silicate @ 0.5 to 2.0 per cent noticed 5.64 to 6.51 per cent leaf damage due to *C. medinalis* in rice and they were at par control (7.06 %).

The data on leaf damage by *C. medinalis* pooled over periods and years indicated that there were significant differences among the treatments (Table 6 and Fig. 2). Soil application of calcium silicate @ 2000 kg/ha was found to be most effective (2.59 %) among various treatments, however it remained at par with calcium silicate @ 1500 kg/ha (2.91 %). SA of calcium silicate @ 1500 and 1000 kg/ha (3.21 %) as well as SA of calcium silicate @ 1000 and 500 kg/ha (3.53 %) were found at par with each other in their descending orders in checking the leaf damage due to *C. medinalis*. FA of potassium silicate

@ 0.5 to 2.0 per cent were equally effective in suppressing the *C. medinalis* activity in rice. However, foliar application of potassium silicate @ 0.5 and 1.0 per cent were at par with control (4.71 %).

Above result is more or less accordance with the results of research work carried out by Zhou *et al.* (1993), who reported that silicon application caused 50-60 per cent reduction in the population density of rice leaffolder, *C. medinalis*. Sudhakar *et al.* (1991) found a significant negative correlation (r = -0.610) between leaf folder infestation and per cent silica content of leaves of different rice varieties. Balasubramaniam *et al.* (2005) showed that application of different sources of silicon reduced incidence of leaffolder. They observed the negative correlation between incidence of leaffolder and silicon content.

Chandramani *et al.* (2010) reported that application of silicon significantly reduced leaffolder damage in rice and correlation values between silica and leaf folder was r = -0.789. Ye *et al.* (2013) concluded that silicon treatment increased the resistant of rice plant against *C. medinalis.* Larvae fed on silicon treated plants gained lower body weight than control. They further reported that silicon enhanced or primed jasmonic acid-inducible responses to herbivory, including the enhanced induction of defense-related enzymes and proteins.

4.1.3 Effect of silicon application on population of *S. furcifera*

Population of *S. furcifera* was observed at 45, 52, 60, 67 and 75 DAT during both the years of study (Table 7 to 9). Brown planthopper, *N. lugens* was not observed during both the years of study.

First year

At 45 DAT, population of *S. furcifera* differed significantly in various treatments (Table 7). Minimum (4.89) population of *S. furcifera* was observed in the treatment of calcium silicate @ 2000 kg/ha and it was at par with calcium silicate @ 1500 kg/ha (5.13), 1000 kg/ha (5.30) and 500 kg/ha (5.45). Foliar application of potassium silicate @ 0.5 to 2.0 per cent recorded 7.26 to 7.46 *S. furcifera* per hill and they were at par with control plots (7.32).

At 52 DAT, calcium silicate @ 2000 kg/ha was the most effective treatment with lowest (6.35) population of *S. furcifera* per hill and it remained at par with calcium silicate @ 1500 kg/ha (6.81), 1000 kg/ha (7.20) and 500 kg/ha (7.56). FA of potassium silicate @ 0.5, 1.0 and 2.0 per cent noticed 9.51, 9.31 and 9.15 *S. furcifera* per hill and they were at par with control plots (9.88).

Population of *S. furcifera* differed significantly in various treatments at 60 DAT (Table 7). Calcium silicate @ 2000 kg/ha emerged as the most effective treatment by recording least population of *S. furcifera* (6.77) and it was at par with calcium silicate @ 1500, 1000 and 500 kg/ha

Table 7 : Effect of silicon application on population of *S. furcifera* in rice during *kharif* 2011

Treatments	No. of *S. furcifera* / Hill					
	45 DAT	**52 DAT**	**60 DAT**	**67 DAT**	**75 DAT**	**Pooled**
SA of calcium silicate @ 500 kg/ha at TP	2.44ab (5.45)	2.84abc (7.56)	3.02ab (8.60)	3.13abc (9.28)	3.30ab (10.42)	2.95b (8.17)
SA of calcium silicate @ 1000 kg/ha at TP	2.41ab (5.30)	2.78abc (7.20)	2.97ab (8.34)	3.01ab (8.58)	3.17ab (9.54)	2.87ab (7.72)
SA of calcium silicate @ 1500 kg/ha at TP	2.37ab (5.13)	2.70ab (6.81)	2.79a (7.29)	2.98ab (8.36)	2.98a (8.36)	2.76ab (7.14)
SA of calcium silicate @ 2000 kg/ha at TP	2.32a (4.89)	2.62a (6.35)	2.70a (6.77)	2.86a (7.68)	2.95a (8.19)	2.69a (6.73)
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT	2.82b (7.46)	3.16bc (9.51)	3.48b (11.59)	3.73d (13.42)	3.86b (14.41)	3.41c (11.14)
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT	2.79b (7.30)	3.13bc (9.31)	3.43b (11.26)	3.58cd (12.32)	3.82b (14.08)	3.35c (10.73)
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT	2.78b (7.26)	3.11bc (9.15)	3.42b (11.18)	3.47bcd (11.56)	3.77b (13.69)	3.31c (10.46)
Control	2.80b (7.32)	3.22c (9.88)	3.46b (11.49)	3.76d (13.65)	3.89b (14.66)	3.43c (11.25)
S. Em. ± T	0.13	0.14	0.18	0.16	0.22	0.08
P	-	-	-	-	-	0.06
T x P	-	-	-	-	-	0.17
C.V. %	8.94	8.29	9.70	8.42	11.15	9.52

Figures outside parenthesis are $\sqrt{X + 0.5}$ transformed value and those inside parenthesis are retransformed values.

Treatment means followed by same letter do not differ significantly by DNMRT at 5 per cent level of significance.

TP : Transplanting, SA : Soil Application, FA : Foliar Application, DAT : Days After Transplanting

which exhibited the population of 7.29, 8.34 and 8.60 *S. furcifera* per hill, respectively. Calcium silicate @ 500 and 1000 kg/ha as well as FA of potassium silicate @ 0.5 to 2.0 were all at par with control (11.49).

Calcium silicate maintained its superiority over rest of treatments at 67 DAT too (Table 7). At this stage, the population of *S. furcifera* in this treatment was 7.68 *S. furcifera* per hill and it remained at par with calcium silicate @ 1500 kg/ha (8.36), 1000 kg/ha (8.58) and 500 kg/ha (9.28). FA of potassium silicate @ 0.5 to 2.0 per cent noticed *S. furcifera* population between 11.56 and 13.42 per hill but they were at par with control plots (13.65).

At 75 DAT, differences between treatments with respect to population of *S. furcifera* were significant (Table 7). Minimum (8.19) population of *S. furcifera* was observed in the treatment of calcium silicate @ 2000 kg/ha and it remained at par with calcium silicate @ 1500 kg/ha (8.36), 1000 kg/ha (9.54) and 500 kg/ha (10.42). All the three concentrations (0.5, 1.0 and 2.0 %) of potassium silicate recorded *S. furcifera* population between 13.69 and 14.41 per hill and they were at par with control (14.66).

The data pooled over periods in first year indicated significant differences among the treatments (Table 7). SA of calcium silicate @ 2000 kg/ha with population of 6.73 *S. furcifera* per hill emerged as most effective treatment and it was at par with calcium silicate @ 1500 and 1000 kg/ha which recorded population of 7.14 and 7.72

S. furcifera per hill, respectively. Plots receiving calcium silicate @ 500 kg/ha noticed 8.17 *S. furcifera* per hill and they were equally effective as calcium silicate @ 1000 and 1500 kg/ha. Foliar application of potassium silicate (0.5 to 2.0 %) showed the population of 10.46 to 11.14 *S. furcifera* per hill, but they failed differ significantly from control (11.25).

Second year

During second year at 45 DAT, SA of calcium silicate @ 2000 kg/ha was the most effective by recording the lowest (2.98) population of *S. furcifera* per hill and it was at par with calcium silicate @ 1500 kg/ha (3.07), 1000 kg/ha (3.33) and 500 kg/ha (3.55). All the three concentrations (0.5, 1.0 and 2.0 %) of potassium silicate treated plots recorded population of *S. furcifera* between 4.70 and 4.98 per hill but they were at par with control (4.89).

At 52 DAT, differences among the treatments with respect to population of *S. furcifera* were significant (Table 8). The lowest population (4.85) was observed in the treatment of calcium silicate @ 2000 kg/ha and it was at par with calcium silicate @ 1500 kg/ha (5.39), 1000 kg/ha (5.72) and 500 kg/ha (6.06). FA of potassium silicate @ 0.5, 1.0 and 2.0 per cent treated plots exhibited 7.64, 7.39 and 7.27 *S. furcifera* per hill, respectively, but they were at par with control (8.01).

At 60 DAT, population of *S. furcifera* was significantly different in various treatments (Table 8). Calcium silicate @ 2000 kg/ha

Table 8 : Effect of silicon application on population of *S. furcifera* in rice during *kharif* 2012

Treatments	No. of *S. furcifera* / Hill					
	45 DAT	**52 DAT**	**60 DAT**	**67 DAT**	**75 DAT**	**Pooled**
SA of calcium silicate @ 500 kg/ha at TP	2.01ab (3.55)	2.56abc (6.06)	3.00abc (8.49)	3.08abc (8.96)	3.22abc (9.89)	2.77b (7.19)
SA of calcium silicate @ 1000 kg/ha at TP	1.96ab (3.33)	2.49abc (5.72)	2.89ab (7.86)	3.00ab (8.50)	3.09abc (9.07)	2.69b (6.72)
SA of calcium silicate @ 1500 kg/ha at TP	1.89a (3.07)	2.43ab (5.39)	2.82a (7.47)	2.80a (7.35)	2.89ab (7.84)	2.57ab (6.08)
SA of calcium silicate @ 2000 kg/ha at TP	1.87a (2.98)	2.31a (4.85)	2.76a (7.09)	2.69a (6.76)	2.65a (6.52)	2.46a (5.53)
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT	2.31b (4.83)	2.85bc (7.64)	3.39c (10.97)	3.46bc (11.50)	3.61c (12.56)	3.13c (9.27)
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT	2.28ab (4.70)	2.81bc (7.39)	3.37bc (10.84)	3.41bc (11.16)	3.54c (12.00)	3.08c (9.00)
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT	2.34b (4.98)	2.79bc (7.27)	3.35bc (10.74)	3.33bc (10.58)	3.41bc (11.13)	3.04c (8.76)
Control	2.32b (4.89)	2.92c (8.01)	3.41c (11.14)	3.52c (11.90)	3.68c (13.07)	3.17c (9.55)
S. Em. ± T	0.12	0.13	0.14	0.15	0.18	0.07
P	-	-	-	-	-	0.05
T x P	-	-	-	-	-	0.15
C.V. %	10.08	8.60	8.04	8.21	9.57	8.91

Figures outside parenthesis are $\sqrt{X + 0.5}$ transformed value and those inside parenthesis are retransformed values.
Treatment means followed by same letter do not differ significantly by DNMRT at 5 per cent level of significance.
TP : Transplanting, SA : Soil Application, FA : Foliar Application, DAT : Days After Transplanting

as the most effective treatment with population of 7.09 *S. furcifera* per hill and it was at par with calcium silicate @ 1500 kg/ha (7.47), 1000 kg/ha (7.86) and 500 kg/ha (8.49). All three concentrations (0.5 to 2.0 %) of potassium silicate recorded *S. furcifera* population between 10.74 and 10.97 per hill and they were at par with control (11.41).

Statistical analysis of data on population of *S. furcifera* recorded at 67 DAT in various treatments revealed significant differences (Table 8). The lowest population (6.76) was recorded in calcium silicate @ 2000 kg/ha and it remained at par with calcium silicate @ 1500 kg/ha (7.35), 1000 kg/ha (8.50) and 500 kg/ha (8.96). All concentrations (0.5 to 2.0 %) potassium silicate noticed 10.58 to 11.50 *S. furcifera* per hill and they were at par with control (11.90).

At 75 DAT, population of *S. furcifera* was significantly different in various treatments (Table 8). The most effective treatment against *S. furcifera* was calcium silicate @ 2000 kg/ha which had a population of 6.52 *S. furcifera* per hill and it remained at par with calcium silicate @ 1500 kg/ha (7.84), 1000 kg/ha (9.07) and 500 kg/ha (9.89). Foliar application of potassium silicate @ 0.5 to 2.0 per cent could not offer protection against *S. furcifera* as they were at par with control (13.07).

The data pooled over period in second year revealed significant differences among the treatments. The treatment which provided most effective control of *S. furcifera* was calcium silicate @ 2000 kg/ha (5.53/hill) and it was at par with calcium silicate @ 1500 kg/ha, 1000 kg/ha and 500 kg/ha which supported the population of 6.08, 6.72

and 7.19 *S. furcifera* per hill, respectively. Foliar application of silicon in the form of potassium silicate (0.5 to 2.0 %) was not effective against *S. furcifera* in rice as they were at par with control (9.55).

Pooled over years

Pooled data of *S. furcifera* population recorded at 45 DAT during both years of study revealed significant differences among the treatments (Table 9). Significantly the lowest (3.88) population was observed in the treatment of SA of calcium silicate @ 2000 kg/ha and it was at par with calcium silicate @ 1500 kg/ha (4.04), 1000 kg/ha (4.26) and 500 kg/ha (4.45). SA of calcium silicate @ 500-2000 kg/ha was significantly superior to FA of potassium silicate (@ 0.5-2.0 %) in checking the population of *S. furcifera* in rice. All the three concentrations (0.5, 0.1 and 2.0 %) of potassium silicate noticed 5.93 to 6.08 *S. furcifera* per hill in rice and they were at with control (6.05).

At 52 DAT, differences between treatments with respect to pooled value of population of *S. furcifera* were significant (Table 9). SA of calcium silicate @ 2000 kg/ha was most effective with population of 5.58 *S. furcifera* per hill and it was at par with calcium silicate @ 1500 kg/ha (6.08), 1000 kg/ha (6.44) and 500 kg/ha (6.79). All the three concentrations (0.5, 1.0 and 2.0 %) of potassium silicate exhibited population of *S. furcifera* between 8.18 and 8.55 per hill and they were at par with control (8.92).

Table 9 : Effect of silicon application on population of *S. furcifera* in rice (Pooled over years)

Treatments	No. of *S. furcifera* / Hill					
	45 DAT	**52 DAT**	**60 DAT**	**67 DAT**	**75 DAT**	**Overall Pooled**
SA of calcium silicate @ 500 kg/ha at TP	2.23a (4.45)	2.70ab (6.79)	3.01a (8.54)	3.10ab (9.12)	3.26bc (10.15)	2.86c (7.68)
SA of calcium silicate @ 1000 kg/ha at TP	2.18a (4.26)	2.63a (6.44)	2.93a (8.10)	3.01a (8.54)	3.13ab (9.30)	2.78bc (7.21)
SA of calcium silicate @ 1500 kg/ha at TP	2.13a (4.04)	2.57a (6.08)	2.81a (7.38)	2.89a (7.85)	2.93ab (8.10)	2.67ab (6.60)
SA of calcium silicate @ 2000 kg/ha at TP	2.09a (3.88)	2.47a (5.58)	2.73a (6.93)	2.78a (7.21)	2.80a (7.33)	2.57a (6.12)
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT	2.57b (6.08)	3.01bc (8.55)	3.43b (11.28)	3.60c (12.44)	3.74d (13.47)	3.27d (10.18)
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT	2.54b (5.93)	2.97bc (8.32)	3.40b (11.05)	3.50c (11.73)	3.68cd (13.02)	3.22d (9.84)
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT	2.56b (6.07)	2.95bc (8.18)	3.39b (10.96)	3.40bc (11.07)	3.59cd (12.38)	3.18d (9.59)
Control	2.56b (6.05)	3.07c (8.92)	3.44b (11.32)	3.64c (12.76)	3.79d (13.86)	3.30d (10.38)
S. Em. ± T	0.09	0.10	0.11	0.11	0.14	0.05
P	-	-	-	-	-	0.04
Y	0.05	0.05	0.06	0.06	0.07	0.02
T x P	-	-	-	-	-	0.11
T x Y	0.13	0.14	0.16	0.16	0.20	0.07
P x Y	-	-	-	-	-	0.06
T x P x Y	-	-	-	-	-	0.16
C.V. %	9.46	8.44	8.92	8.32	10.44	9.11

Figures outside parenthesis are $\sqrt{X + 0.5}$ transformed value and those inside parenthesis are retransformed values.
Treatment means followed by same letter do not differ significantly by DNMRT at 5 per cent level of significance.
TP : Transplanting, SA : Soil Application, FA : Foliar Application, DAT : Days After Transplanting

Pooled value of population of *S. furcifera* recorded at 60 DAT during two years of study differed significantly in various treatments. The lowest (6.93) population of *S. furcifera* was recorded in the treatment of SA of calcium silicate @ 2000 kg/ha and it was at par with calcium silicate @ 1500 kg/ha (7.38), 1000 kg/ha (8.10) and 500 kg/ha (8.54). All four doses of SA of calcium silicate were significantly more effective than all three concentrations of FA of potassium silicate in suppressing of *S. furcifera* in rice crop. Potassium silicate treated plots (@ 0.5 to 2.0 %) showed 10.96 to 11.28 *S. furcifera* per hill and they could not differ significantly from control (11.32).

At 67 DAT, the most effective treatment among all was SA of calcium silicate @ 2000 kg/ha which recorded the lowest (7.21) population of *S. furcifera* and it was at par with calcium silicate @ 1500 kg/ha (7.85), 1000 kg/ha (8.54) and 500 kg/ha (9.12). Foliar application of potassium silicate at 0.5 to 2.0 per cent concentration recorded 11.07 to 12.44 *S. furcifera* per hill in rice and they were at par with control (12.76).

Pooled data on population of *S. furcifera* recorded at 75 DAT during two years revealed significant differences among the treatments. SA of calcium silicate @ 2000 kg/ha had lowest (7.33) population of *S. furcifera* per hill and it was at par with calcium silicate @ 1500 kg/ha (8.10) as well as 1000 kg/ha (9.30). Calcium silicate @ 1500, 1000 and 500 kg/ha (10.15) were found equally effective in checking the *S. furcifera* population in rice. The lowest dose (500 kg/ha) of SA of calcium silicate was at par with FA of potassium silicate at 2.0 and 1.0 per cent. Potassium silicate treated plots noticed 12.38 to 13.47 *S. furcifera* per hill and they were at par with control (13.86).

The data on population of *S. furcifera* pooled over periods and years indicated that SA of calcium silicate @ 2000 kg/ha (6.12/hill) was the most effective treatment and it was at par with calcium silicate @ 1500 kg/ha, which recorded the population of 6.60 *S. furcifera* per hill (Table 9 and Fig. 3). SA of calcium silicate @ 1500 and 1000 kg/ha (7.21) were found equally effective in reducing the *S. furcifera* in rice. All four doses of SA of calcium silicate were significantly more effective then all three concentrations of FA of potassium silicate in controlling the *S. furcifera* in rice. Foliar application of silicon in the form of potassium silicate (0.5, 1.0 and 2.0%) recorded 9.59 to 10.18 *S. furcifera* per hill and they were at par with control (10.38).

Present findings are more or less in agreement with that of (Balasubramaniam *et al.*, 2005). They showed that application of silicon in the form sodium meta silicate to rice fields reduced the incidence of whitebacked planthopper. Further, the incidence of pest was negatively correlated with plant silicon content. Salim and Saxena (1992) observed that silicon @ 400 mg Si/litre of culture solution of rice plants reduced intake and assimilation of food, adult longevity, fecundity and population increase by *S. furcifera* on susceptible rice variety. Mishra and Misra (1992), found that silica @ 100 ppm and above in pot culture significantly reduced adult emergence.

4.1.4 Effect of silicon application on population *N. virescens*

Population of green leafhopper *N. virescens* was observed at 30, 37, 45, 52 and 60 DAT during both years of study. Data on population of *N. virescens* are presented in Table 10 to 12.

First year

During first year of study, population of *N. virescens* was significantly different in various treatments at 30 DAT (Table 10). The treatment of calcium silicate @ 2000 kg/ha was most effective with lowest population of *N. virescens* (2.46) and it was at par with calcium silicate @ 1500 kg/ha (2.90), 1000 kg/ha (3.13) and 500 kg/ha (3.36). Plots treated with potassium silicate at 0.5 to 2.0 per cent concentration registered 4.12 to 4.33 *N. virescens* per hill and they were at par with control (4.14).

At 37 DAT, minimum (3.86) population of *N. virescens* was recorded in the treatment of calcium silicate @ 2000 kg/ha and it was at par with calcium silicate @ 1500 kg/ha (4.45), 1000 kg/ha (4.60) and 500 kg/ha (4.98). All three concentrations (0.5, 1.0 and 2.0 %) of potassium silicate did not protect rice plants against *N. virescens* and they remained at par with control (6.45).

The differences between various treatments with respect to population of *N. virescens* were significant at 45 DAT (Table 10).

At this stage, SA of calcium silicate @ 2000 kg/ha emerged as the most effective treatment with the population of 5.13 *N. virescens* per hill and it remained at par with calcium silicate @ 1500, 1000 and 500 kg/ha which supported the population of 5.58, 6.78, and 7.20 *N. virescens* per hill, respectively. All the three concentrations (0.5, 1.0 and 2.0%) of potassium silicate noted the population of 8.74 to 8.94 *N. virescens* per hill and they were at par with control (9.31).

Table 10 : Effect of silicon application on population of *N. virescens* in rice during *kharif* 2011

Treatments	No. of *N. virescens* / Hill					
	30 DAT	**37 DAT**	**45 DAT**	**52 DAT**	**60 DAT**	**Pooled**
SA of calcium silicate @ 500 kg/ha at TP	1.96ab (3.36)	2.34abc (4.98)	2.77ab (7.20)	2.22ab (4.44)	1.71a (2.42)	2.20b (4.35)
SA of calcium silicate @ 1000 kg/ha at TP	1.91ab (3.13)	2.26abc (4.60)	2.70ab (6.78)	2.19ab (4.31)	1.68a (2.33)	2.15b (4.11)
SA of calcium silicate @ 1500 kg/ha at TP	1.84ab (2.90)	2.23ab (4.45)	2.47a (5.58)	2.13a (4.04)	1.60a (2.06)	2.05ab (3.72)
SA of calcium silicate @ 2000 kg/ha at TP	1.72a (2.46)	2.09a (3.86)	2.37a (5.13)	2.09a (3.86)	1.48a (1.70)	1.95a (3.30)
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT	2.15b (4.12)	2.58bc (6.18)	3.07b (8.94)	2.58c (6.16)	2.07b (3.79)	2.49c (5.71)
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT	2.19b (4.30)	2.55bc (6.00)	3.05b (8.77)	2.51bc (5.79)	2.05b (3.72)	2.47c (5.60)
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT	2.20b (4.33)	2.53bc (5.90)	3.04b (8.74)	2.47bc (5.59)	2.00b (3.49)	2.45c (5.48)
Control	2.15b (4.14)	2.64c (6.45)	3.13b (9.31)	2.68c (6.68)	2.07b (3.81)	2.54c (5.93)
S. Em. ± T	0.12	0.12	0.13	0.10	0.07	0.05
P	-	-	-	-	-	0.04
T x P	-	-	-	-	-	0.11
C.V. %	10.18	8.55	8.09	7.41	7.00	8.38

Figures outside parenthesis are $\sqrt{X + 0.5}$ transformed value and those inside parenthesis are retransformed values.

Treatment means followed by same letter do not differ significantly by DNMRT at 5 per cent level of significance.

TP : Transplanting, SA : Soil Application, FA : Foliar Application,

DAT : Days After Transplanting

At 52 DAT, population of *N. virescens* differed significantly in various treatments (Table 10). Calcium silicate as soil application was most effective at 2000 kg/ha which supported minimum (3.86) population of *N. virescens*. This dose of calcium silicate was at par with 1500 (4.04), 1000 (4.31) and 500 kg/ha (4.44). Application of silicon in the form of potassium silicate did not provide protection against *N. virescens* as population of *N. virescens* in all three concentrations (0.5 to 2.0 %) were at par with control (6.68).

Population of *N. virescens* recorded at 60 DAT was significantly different in various treatments (Table10). SA of calcium silicate @ 2000 kg/ha recorded minimum population of *N. virescens* (1.70) and it was at par with calcium silicate @ 1500, 1000 and 500 kg/ha, which supported the population of 2.06, 2.33 and 2.42 *N. virescens* per hill, respectively. These four treatments were significantly more effective than FA of Potassium silicate in controlling the pest. Potassium silicate applied through foliage at 0.5, 1.0 and 2.0 per cent concentration could not provide protection to rice crop against *N. virescens* as each of the treatments was at par with control (3.81).

The data pooled over periods during first year revealed significant differences among the treatments (Table 10). Significantly the lowest (3.30) population of *N. virescens* was observed in the treatment of SA of calcium silicate @ 2000 kg/ha and it differed significantly from all the treatments except calcium silicate @ 1500 kg/ha (3.72). SA of calcium silicate @ 1000 and 500 kg/ha treated plots exhibited 4.11 and 4.35 *N. virescens* per hill, respectively and they were equally effective as calcium silicate @ 1500 kg/ha. These three doses of calcium silicate were significantly more effective then all three concentrations of potassium silicate. Foliar application of silicon in the form of potassium silicate could not offer protection against *N. virescens* in rice as all the three concentrations (0.5, 1.0 and 2.0 %) were at par with control plots (5.93).

Second year

During the second year at 30 DAT, there were significant differences among various treatments with respect to population of *N. virescens* (Table 11). The lowest (1.89) population of *N. virescens* was observed in the treatment of calcium silicate @ 2000 kg/ha and it followed by calcium silicate @ 1500 (2.29), 1000 (2.44) and 500 kg/ha (2.66). Potassium silicate applied as foliar spray (at 0.5 to 2.0 %) was at par control plots (2.96).

At 37 DAT, population of *N. virescens* was minimum (3.13) in the treatment of SA of calcium silicate @ 2000 kg/ha and it remained at par with remaining three doses of calcium silicate *i.e.* 1500 kg/ha (3.58), 1000 kg/ha (3.95) and 500 kg/ha (4.26). All three concentrations (0.5, 1.0 and 2.0 %) of potassium silicate supported 4.90 to 5.29 *N. virescens* per hill and they were at par with control (5.45).

At 45 DAT, differences among the treatments with respect to population of *N. virescens* were significant (Table 11). The most effective treatment at this stage was SA of calcium silicate @ 2000 kg/ha and it had a population of 4.45 *N. virescens* per hill. The treatment of calcium silicate was at par with calcium silicate @ 1500 (5.02), 1000 (5.32) and 500 kg/ha (5.75). FA of potassium silicate at 0.5 to 2.0 per cent concentration recorded 6.58 to 7.04 *N. virescens* per hill and they failed to differ significantly from control (7.22).

Table 11 : Effect of silicon application on population of *N. virescens* in rice during *kharif* 2012

Treatments	No. of *N. virescens* / Hill					
	30 DAT	37 DAT	45 DAT	52 DAT	60 DAT	Pooled
SA of calcium silicate @ 500 kg/ha at TP	1.78ab (2.66)	2.17abc (4.20)	2.50abc (5.75)	2.56abcd (6.05)	1.92abc (3.19)	2.18b (4.27)
SA of calcium silicate @ 1000 kg/ha at TP	1.71ab (2.44)	2.11abc (3.95)	2.41abc (5.32)	2.46abc (5.55)	1.86ab (2.96)	2.11b (3.96)
SA of calcium silicate @ 1500 kg/ha at TP	1.67ab (2.29)	2.02ab (3.58)	2.35ab (5.02)	2.34ab (4.99)	1.79a (2.71)	2.03ab (3.64)
SA of calcium silicate @ 2000 kg/ha at TP	1.55a (1.89)	1.91a (3.13)	2.22a (4.45)	2.28a (4.68)	1.74a (2.53)	1.94a (3.26)
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT	1.88b (3.04)	2.41c (5.29)	2.75c (7.04)	2.92d (8.01)	2.23bc (4.45)	2.44c (5.43)
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT	1.93b (3.21)	2.37bc (5.12)	2.71bc (6.85)	2.81cd (7.41)	2.17bc (4.19)	2.40c (5.25)
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT	1.88b (3.02)	2.32bc (4.90)	2.66bc (6.58)	2.74bcd (7.00)	2.08abc (3.83)	2.34c (4.96)
Control	1.86ab (2.96)	2.44c (5.45)	2.78c (7.22)	2.97d (8.34)	2.29c (4.72)	2.47c (5.59)
S. Em. ± T	0.09	0.11	0.11	0.13	0.11	0.05
P	-	-	-	-	-	0.04
T x P	-	-	-	-	-	0.11
C.V. %	9.11	8.64	7.54	8.58	9.69	8.69

Figures outside parenthesis are $\sqrt{X + 0.5}$ transformed value and those inside parenthesis are retransformed values.

Treatment means followed by same letter do not differ significantly by DNMRT at 5 per cent level of significance.

TP : Transplanting, SA : Soil Application, FA : Foliar Application

DAT : Days After Transplanting

At 52 DAT, there were significant differences in population of *N. virescens* among various treatments. SA of calcium silicate @ 2000 kg/ha recorded the lowest (4.68) population of *N. virescens* and it remained at par with calcium silicate @ 1500 kg/ha (4.99), 1000 kg/ha (5.55) and 500 kg/ha (6.05). Potassium silicate (@ 0.5 to 2.0 %) concentrations did not provide protection against *N. virescens*, as they were at par with control (8.34).

At 60 DAT, the most effective treatment was SA of calcium silicate @ 2000 kg/ha which supported minimum (2.53) population of *N. virescens*. Calcium silicate @ 1500, 1000 and 500 kg/ha exhibited 2.71, 2.96 and 3.19 *N. virescens* per hill, respectively. All the three (0.5, 1.0 and 2.0 %) concentrations of potassium silicate recorded 3.83 to 4.45 *N. virescens* per hill and they were at par with control (4.72).

The data on population *N. virescens* pooled over periods revealed significant differences among the treatments (Table11). SA of calcium silicate @ 2000 kg/ha was found significantly most effective with 3.26 *N. virescens* per hill and it differed significantly from remaining treatments, except calcium silicate @ 1500 kg/ha (3.64). SA of calcium silicate @ 1500, 1000 and 500 kg/ha recorded 3.64, 3.96, and 4.27 *N. virescens* per hill, respectively and they were significantly more effective then FA of potassium silicate. FA of potassium silicate (0.5 to 2.0 %) supported the population of 4.96 to 5.43 *N. virescens* per hill, but they were at par with control (5.59).

Pooled over years

At 30 DAT, differences between treatments with respect to population of *N. virescens* were significant (Table 12). SA of calcium silicate @ 2000 kg/ha was most effective with population of 2.17 *N. virescens* per hill and it was at par with calcium silicate @ 1500 kg/ha (2.59) and 1000 kg/ha (2.78). Calcium silicate @ 1500 and 1000 kg/ha were equally effective as calcium silicate @ 500 kg/ha (3.00). All the three concentrations (0.5, 1.0 and 2.0 %) of potassium silicate exhibited population of *N. virescens* between 3.56 and 3.74 per hill and they remained at par with control (3.53).

Pooled data of *N. virescens* population at 37 DAT revealed significant differences among the treatments (Table 12). Significantly the lowest (3.49) population was observed in the treatment of SA of calcium silicate @ 2000 kg/ha and it was at par with calcium silicate @ 1500 kg/ha (4.01), 1000 kg/ha (4.27) and 500 kg/ha (4.58). All the three concentrations (0.5, 0.1 and 2.0 %) of potassium silicate showed the population of 5.39 to 5.73 *N. virescens* per hill in rice and they were at with control (5.94).

At 45 DAT, most effective treatment was SA of calcium silicate @ 2000 kg/ha which recorded the lowest (4.78) population of *N. virescens* and it was at par with calcium silicate @ 1500 kg/ha (5.30), 1000 kg/ha (6.03). Calcium silicate @ 1500 and 1000 kg/ha were equally effective as calcium silicate @ 500 kg/ha (6.45). Foliar application of potassium silicate at 0.5 to 2.0 per cent concentration recorded 7.62 to 7.97 *N. virescens* per hill in rice and they failed to differ significantly from control (8.23).

Table 12 : Effect of silicon application on population of *N. virescens* in rice (Pooled over years)

Treatments	No. of *N. virescens* / Hill					
	30 DAT	37 DAT	45 DAT	52 DAT	60 DAT	Overall Pooled
SA of calcium silicate @ 500 kg/ha at TP	1.87bc (3.00)	2.25abc (4.58)	2.64bc (6.45)	2.39ab (5.22)	1.82b (2.80)	2.19c (4.31)
SA of calcium silicate @ 1000 kg/ha at TP	1.81abc (2.78)	2.18ab (4.27)	2.56ab (6.03)	2.33a (4.91)	1.77ab (2.64)	2.13bc (4.03)
SA of calcium silicate @ 1500 kg/ha at TP	1.76ab (2.59)	2.12a (4.01)	2.41ab (5.30)	2.24a (4.50)	1.70ab (2.38)	2.04b (3.68)
SA of calcium silicate @ 2000 kg/ha at TP	1.63a (2.17)	2.00a (3.49)	2.30a (4.78)	2.18a (4.26)	1.61a (2.10)	1.94a (3.28)
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT	2.02c (3.56)	2.50cd (5.73)	2.91cd (7.97)	2.75c (7.06)	2.15c (4.11)	2.46de (5.57)
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT	2.06c (3.74)	2.46cd (5.55)	2.88cd (7.78)	2.66c (6.58)	2.11c (3.95)	2.43de (5.42)
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT	2.04c (3.64)	2.43bcd (5.39)	2.85cd (7.62)	2.60bc (6.28)	2.04c (3.66)	2.39d (5.22)
Control	2.01c (3.53)	2.54d (5.94)	2.96d (8.23)	2.83c (7.49)	2.18c (4.25)	2.50e (5.76)
S. Em. ± T	0.08	0.08	0.09	0.08	0.07	0.03
P	-	-	-	-	-	0.03
Y	0.04	0.04	0.04	0.04	0.03	0.02
T x P	-	-	-	-	-	0.08
T x Y	0.11	0.11	0.12	0.12	0.10	0.05
P x Y	-	-	-	-	-	0.04
T x P x Y	-	-	-	-	-	0.11
C.V. %	9.74	8.60	7.86	8.09	8.58	8.14

Figures outside parenthesis are $\sqrt{X + 0.5}$ transformed value and those inside parenthesis are retransformed values.

Treatment means followed by same letter do not differ significantly by DNMRT at 5 per cent level of significance.

TP : Transplanting, SA : Soil Application, FA : Foliar Application

DAT : Days After Transplanting

The data on population of *N. virescens* pooled over years at 52 DAT revealed significant differences among the treatments (Table 12). SA of calcium silicate @ 2000 kg/ha exhibited lowest (4.26) population of *N. virescens* per hill and it was at par with calcium silicate @ 1500 kg/ha (4.50), 1000 kg/ha (4.91) and 500 kg/ha (5.22). Calcium silicate @ 500 kg/ha (10.15) and FA of potassium silicate @ 2.0 per cent (6.28) were found equally effective in checking the *N. virescens* population in rice. Potassium silicate sprayed plots noticed 6.28 to 7.06 *N. virescens* per hill and they were at par with control (7.49).

At 60 DAT, there were significant differences among various treatments with respect to population of *N. virescens* (Table 12). The lowest (2.10) population of *N. virescens* was recorded in the treatment of SA of calcium silicate @ 2000 kg/ha and it remained at par with calcium silicate @ 1500 kg/ha (2.38) and 1000 kg/ha (2.64). Calcium silicate @ 1500 and 1000 kg/ha were equally effective as calcium silicate @ 500 kg/ha (2.80). All four doses of SA of calcium silicate were significantly more effective than all three concentrations FA of potassium silicate in checking *N. virescens* population in rice crop. Potassium silicate treated plots (0.5 to 2.0 %) showed 3.66 to 4.11 *N. virescens* per hill and they did not differ significantly from control (4.25).

The data on *N. virescens* population pooled over 5 periods and 2 years indicated that SA of calcium silicate @ 2000 kg/ha (3.28) was the most effective treatment and it differed significantly from the rest of the treatments (Table 12 and Fig. 3). Calcium silicate @ 1500 kg/ha (3.68) and 1000 kg/ha (4.03) were found equally effective in reducing *N. virescens* population in rice. All four doses of SA of calcium silicate were significantly more effective then all three concentrations of FA of potassium silicate in controlling the *N. virescens* in rice. Foliar application of silicon in the form of potassium silicate @ 1.0 and 0.5 per cent recorded 5.42 and 5.57 *N. virescens* per hill, respectively and they were at par with control (5.76).

Similar result was reported by Maxwell *et al.* (1972), who observed that silicon suppressed green leafhoppers in rice.

4.1.5 Effect of silicon application on yield of rice

The grain and straw yield of rice was recorded during both years of study; their data are presented in Table 13 and graphically depicted in Fig. 4.

4.1.5.1 Effect of silicon application on grain yield of rice

First year

During the first year (Table 13), grain yield was significantly different in various treatments. SA of calcium silicate @ 2000, 1500 and 1000 kg/ha registered significantly higher grain yield as compared to control (4570 kg/ha). The highest (5544 kg/ha) grain yield was recorded in the treatment of calcium silicate @ 2000 kg/ha and it was at par with remaining three doses of calcium silicate. The grain yield in calcium silicate @ 1500, 1000 and 500 kg/ha was 5461, 5379 and 5100 kg/ha, respectively. Calcium silicate @ 500 kg/ha and all three concentrations (0.5, 1.0 and 2.0 %) of potassium silicate recorded grain yield between 4594 and 4655 kg/ha but they were at par with control.

Second year

During second year of study all the doses of calcium silicate, except 500 kg/ha produced significantly higher grain yield than control (Table 13). The highest grain yield (4487 kg/ha) was obtained in the treatment of SA of calcium silicate @ 2000 kg/ha and it was at par with calcium silicate @ 1500 kg/ha (4384 kg/ha), 1000 (4262 kg/ha) and 500 kg/ha (3991 kg/ha). Calcium silicate @ 500 and 1000 kg/ha as well as potassium silicate @ 2.0 per cent (3657 kg/ha) were equally effective in raising grain yield of rice. All three concentrations (0.5 to 2.0 %) of potassium silicate yielded between 3573 and 3657 kg/ha, but they remained at par with control (3542 kg/ha).

Pooled over years

The data on grain yield pooled over years revealed significant differences among treatments (Table 13 and Fig. 4). All four doses (500 to 2000 kg/ha) of calcium silicate significantly enhanced grain yield of rice. The highest (5015 kg/ha) grain yield was obtained in the treatment of calcium silicate @ 2000 kg/ha and it remained at par with calcium silicate @ 1500 kg/ha (4922 kg/ha) and 1000 kg/ha (4820 kg/ha).

Table 13 : Effect of silicon application on yield of rice

Treatments	Grain yield (kg/ha)			Straw yield (kg/ha)		
	2011	2012	Pooled	2011	2012	Pooled
SA of calcium silicate @ 500 kg/ha at TP	5100ab	3991abc	4545bc	5763abc	4659abc	5211ab
SA of calcium silicate @ 1000 kg/ha at TP	5379a	4262ab	4820ab	6028ab	4819ab	5423a
SA of calcium silicate @ 1500 kg/ha at TP	5461a	4384a	4922ab	6071ab	4957a	5514a
SA of calcium silicate @ 2000 kg/ha at TP	5544a	4487a	5015a	6196a	5184a	5690a
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT	4594b	3573c	4084d	5148c	4175cd	4662c
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT	4625b	3612c	4119cd	5237c	4232bcd	4734c
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT	4655b	3657bc	4156cd	5314bc	4291bcd	4803bc
Control	4570b	3542c	4056d	5063c	4002d	4533c
S. Em. ± T	202.39	181.37	135.88	228.54	188.70	148.19
Y	-	-	67.94	-	-	74.09
T x Y	-	-	192.17	-	-	209.57
C.V. %	7.02	7.98	7.45	7.07	7.20	7.16

Treatment means followed by same letter do not differ significantly by DNMRT at 5 per cent level of significance.

TP : Transplanting, SA : Soil Application, FA : Foliar Application, DAT : Days After Transplanting

Calcium silicate @ 1500, 1000 and 500 kg/ha (4545 kg/ha) were found equally effective in increasing grain yield of rice. All the three concentrations (0.5, 1.0 and 2.0 %) of potassium silicate produced grain yield between 4084 and 4156 kg/ha, but they were at par with control (4056 kg/ha).

4.1.5.2 Effect of silicon application on straw yield of rice

First year

In the first year of study, the differences among treatments for straw yield of rice were significant (Table 13). All the doses of calcium silicate except 500 kg/ha significantly increased straw yield of rice. The highest (6196 kg/ha) straw yield was recorded in the treatment of calcium silicate @ 2000 kg/ha and it remained at par with calcium silicate @ 1500, 1000 and 500 kg/ha, which recorded grain yield of 6071, 6028 and 5763 kg/ha, respectively. Calcium silicate @ 1500, 1000 and 500 kg/ha as well as FA of potassium silicate @ 2.0 per cent (5314 kg/ha) were equally effective. FA of potassium silicate @ 0.5 to 2.0 per cent concentration recorded straw yield between 5148 and 5314 kg/ha, but they were at par with control.

Second year

During second year, straw yield differed significantly among various treatments (Table 13). All the four doses (500 to 2000 kg/ha) of calcium silicate registered significantly higher straw yield as compared to control. SA of calcium silicate @ 2000 kg/ha recorded the highest (5184 kg/ha) straw yield of rice and it remained at par with calcium silicate @ 1500 kg/ha (4957 kg/ha), 1000 kg/ha (4849 kg/ha) and 500 kg/ha (4659 kg/ha). Calcium silicate @ 500 and 1000 kg/ha as well as FA of potassium silicate @ 1.0 and 2.0 per cent were all at par with each other. FA of potassium silicate yielded between 4175 and 4291 kg/ha but they were at par with control, which yielded the lowest (4002 kg/ha) straw.

Pooled over years

The data on straw yield pooled over years indicated significant differences among treatments (Table 13 and Fig. 4). All four doses of calcium silicate significantly enhanced straw yield of rice compared with control. The highest dose (2000 kg/ha) of calcium silicate yielded 5690 kg straw/ha and it was at par with remaining three doses (1500, 1000 and 500 kg/ha). The straw yield in calcium silicate @ 1500, 1000 and 500 kg/ha was 5514, 5423 and 5211 kg/ha, respectively. Calcium silicate @ 500 kg/ha was equally effective as potassium silicate @ 2.0 per cent (4803 kg/ha). All three concentrations of potassium silicate (0.5, 1.0 and 2.0 %) produced the yield between 4662 and 4803 kg/ha, however, they were at par with control (4533 kg/ha).

Present findings tally the results of Singh *et al.* (2006), who reported that the application of silicon increased grain and straw yield of rice. The highest grain and straw yield was obtained with 180 kg silicon/ha, but it was at par with 120 kg/ha. Jawahar and Vaiyapuri (2013) observed that increasing levels of silicon increased the grain and straw yield of rice up to 120 kg Si/ha. The grain yield in the treatment of silicon @ 120 kg/ha was 17.14 per cent higher than control. Jawahar *et al.* (2015) reported that application of calcium silicate @ 2000 kg/ha to rice increased grain and straw yield of rice by 13.40 and 12.61 per cent, respectively.

4.2. EFFECT OF SILICON APPLICATION ON CHEMICAL AND BIOCHEMICAL CONSTITUENTS OF RICE PLANTS

Studies on impact of silicon application on concentration of chemical and biochemical constituents of rice plants were carried out during second year of study *i.e. kharif* 2012. For this purpose, plant sample were collected from the field experiment carried out to study the effect of silicon application on insect pests' population / damage in rice.

4.2.1 Effect of silicon application on chemical constituents of rice plants

The results of effects of silicon application on the concentration of silica, macronutrients and micronutrients in rice plants are presented in Table 14 to 16 and graphically depicted in Fig. 5 to 10.

4.2.1.1 Effect of silicon application on silica content of rice plants

Silica content of rice plans was determined from plant samples collected at 30, 45, 60 and 75 DAT during second year of field experiment and the data are resented in Table 14.

At 30 DAT, differences among treatments with respect to plant silica content were significant, indicating that silicon application affected plant silica content. All doses of calcium silicate except 500 kg/ha recorded significantly higher plant silica content, whereas application of potassium silicate @ 0.5 to 2.0 per cent as a foliar spray failed to increase plant silica content. Maximum (4.42 %) silica content was observed in the treatment of SA of calcium silicate @ 2000 kg/ha and it was at par with calcium silicate @ 1500 kg/ha (4.29 %), 1000 (4.12 %) and 500 (3.90 %). Rice plants sprayed with three different concentrations (0.5, 1.0 and 2.0 %) of potassium silicate accumulated silica in the range of 3.38 to 3.44 per cent but they were at par with control (3.40 %).

At 45 DAT, plant silica content differed significantly among various treatments. The highest (5.53 %) silica content was recorded in SA of calcium silicate @ 2000 kg/ha and it was at par with calcium silicate @ 1500 and 1000 kg/ha which contained 5.19 and 4.93 per cent silica, respectively. SA of Calcium silicate @ 500 kg/ha (4.51 %) was equally effective as 1000 kg/ha and 1500 kg/ha in increasing plant silica content. All the three concentrations (0.5, 1.0 and 2.0 %) of potassium silicate accumulated silica between 4.11 and 4.15 per cent, but they were at par with control (4.10 %).

All four doses (500 to 2000 kg/ha) of SA of calcium silicate recorded significantly higher plant silica content than control, whereas all three concentrations (0.5 to 2.0 %) of potassium silicate were at par with control at 60 DAT (Table 14). The highest (6.46 %) silica content was observed in the plots applied with calcium silicate @ 2000 kg/ha and it remained at par with calcium silicate @ 1500 (6.20 %) and 1000 kg/ha (5.92 %). SA of calcium silicate @ 500 kg/ha treated plots contained 5.44 per cent silica and it was as effective as calcium silicate @ 1000 and 1500 kg/ha. Potassium silicate applied as foliar spray @ 0.5 to 2.0 per cent recorded 4.60 to 4.65 per cent silica, but they were at par with control (4.58 %).

Table 14 : Effect of silicon application on silica content of rice plants

Treatments	Silica content (%) DAT				
	30	**45**	**60**	**75**	**Pooled**
SA of calcium silicate @ 500 kg/ha at TP	3.90ab	4.51bc	5.44b	6.43b	5.07c
SA of calcium silicate @ 1000 kg/ha at TP	4.12a	4.93ab	5.92ab	6.89ab	5.46b
SA of calcium silicate @ 1500 kg/ha at TP	4.29a	5.19ab	6.20ab	7.25a	5.73ab
SA of calcium silicate @ 2000 kg/ha at TP	4.42a	5.53a	6.46a	7.50a	5.98a
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT	3.44b	4.11c	4.60c	5.53c	4.42d
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT	3.38b	4.13c	4.62c	5.56c	4.42d
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT	3.41b	4.15c	4.65c	5.60c	4.45d
Control	3.40b	4.10c	4.58c	5.50c	4.39d
Mean	3.80	4.58	5.31	6.28	4.99
S. Em. ± T	0.170	0.212	0.228	0.233	0.106
P	-	-	-	-	0.08
T x P	-	-	-	-	0.21
C.V. %	7.76	8.00	7.45	6.42	7.36

Treatment means followed by same letter do not differ significantly by DNMRT at 5 per cent level of significance.

TP : Transplanting, SA : Soil Application, FA : Foliar Application
DAT : Days After Transplanting

At 75 DAT, silica concentration in plots treated with SA of calcium silicate (500 to 2000 kg/ha) was significantly higher than FA of potassium silicate (0.5 to 2.0 %) and control. The highest (7.50 %) silica content was observed in SA of calcium silicate @ 2000 kg/ha and it was at par with calcium silicate @ 1500 kg/ha (7.25 %) and 1000 kg/ha (6.89 %). SA of calcium silicate @ 500 kg/ha (6.43 %) and 1000 kg/ha (6.89 %) had more or less equal concentration of silica. Foliar application of potassium silicate @ 0.5 to 2.0 per cent accumulated silica between 5.53 and 5.60 per cent, but they were at par with control (5.50 %).

Pooled data of plant silica content revealed significant differences among treatments (Table 14 and Fig. 5). All the four doses (500 to 2000 kg/ha) of SA of calcium silicon had significantly higher plant silica content than control indicating all four treatments increased plant silica content in rice. The highest (5.98 %) plant silica content was analysed in the treatment of calcium silicate @ 2000 kg/ha and it was at par with calcium silicate @ 1500 kg/ha (5.73 %). SA of calcium silicate @ 1000 kg/ha (5.46 %) and 1500 kg/ha accumulated more or less equal amount of silica. SA of calcium silicate @ 1000 kg/ha and more exhibited significantly higher silica content than the lowest dose (500 kg/ha) of calcium silicate as well all the three concentrations (0.5 to 2.0 %) of potassium silicate and control. FA of potassium silicate recorded silica content between 4.42 and 4.45 per cent, but they were at par with control (4.39 %).

There were significant differences in periodical mean value of plant silica content (Table 14). The mean plant silica content increased significantly with increase in plant age from 30 to 75 DAT. The plant silica content at 30 DAT was significantly lowest (3.80 %) as compared to rest of periods. At 45 DAT, the silica content was 4.58 per cent and it was significantly lower than 60 and 75 DAT, but significantly higher than 30 DAT. Silica content at 60 DAT was 5.31 per cent which was significantly lower than 75 DAT (6.28 %). Significantly the highest silica content was seen at 75 DAT.

There was significantly negative correlation (r = -0.813*) between silica content (Table 16) and per cent white earhead damage, indicating decrease in *S. incertulas* infestation with corresponding increase in silica content and *vice-versa*. Similarly, the correlation coefficient between plant silica content and leaf damage due to *C. medinalis* was also significantly negative (r = -0.669*). The population of *S. furcifera* was significantly negatively correlated (r = -0.577*) with plant silica content, indicating decrease in *S. furcifera* population with corresponding increase in silica content in rice plant and *vice-versa*.

Present findings are in accordance with the results of Islam and Saha (1969), who reported that application of silicon to rice plants grown on nutrient culture solution resulted in increase in silicon content of rice plants. Balasubramaniam *et al.* (2005) showed that the application of different sources of silicon to rice plants increased the content of this element in rice plants and decreased in pest incidence. Similarly, Chandramani *et al.* (2010) concluded that application of silicate solubilising bacteria and lignite fly ash increased silica content in rice plant and as the age of the plant increased, silica content proportionately increased in the plants. There was significant difference among treatments in silica content at 45 and 60 days after transplanting. Application of silicate solubilising bacteria and lignite fly ash along with neem cake, farm yard manure (FYM), *Azospirillum* and phosphor bacterium recorded the highest (8.10 %) silica content.

Djamin and Pathak (1967) reported that silica content showed highly significant negative correlation (r = -0.617) with the percentage of dead hearts due to Asiatic rice borer. Chandramani *et al.* (2010) observed negative correlation coefficient (r = -0.930*) between stem borer damage and plant silica content. Rajamani *et al.* (2013) found negative correlation between dead hearts due to *S. incertulas* and plant silica content in rice.

Sudhakar *et al.* (1991) found a significantly negative correlation (r = -0.610) between leaffolder infestation and silica content of leaves of different rice varieties. Chandramani *et al.* (2010) reported negative correlation (r = -0.789*) between plant silica content and leaffolder damage in rice.

Balasubramaniam *et al.* (2005) observed negative correlation between incidence of whitebacked plant hopper as well as brown plant hopper and plant silicon content.

Table 15 : Correlation coefficient between silica content and mineral nutrients as well as biochemical constituents of rice plants

N	P_2O_5	K_2O	Ca	Mg	S	Na	Fe	Mn	Zn	Cu	Phenol	Total Sugar	Crude Protein	Free amino acids
-0.856*	0.772*	0.657*	0.766*	0.017	-0.209	-0.757*	-0.822*	-0.849*	-0.032	-0.093	0.834*	-0.819*	-0.856*	-0.646*

* Significant at 5 per cent level of significance.

Table 16 : Correlation coefficient between damage/population of insect pests and silica content, mineral nutrient as well as biochemical constituents of rice plants

Damage/population of insect pests	Silica	N	P_2O_5	K_2O	Ca	S	Phenol	Total Sugar	Crude Protein	Free amino acids
White earhead due to *S. incertulas*	-0.813*	0.826*	-0.593*	-0.675*	-0.770*	0.071	-0.739*	0.733*	0.826*	0.709*
Leaf damage (%) due to *C. medinalis*	-0.669*	0.746*	-0.611*	-0.482*	-0.539*	0.160	-0.738*	0.582*	0.746*	0.525*
Population of *S. furcifera*	-0.577*	0.736*	-0.649*	-0.484*	-0.585*	0.101	-0.668*	0.601*	0.736*	0.644*

* Significant at 5 per cent level of significance.

4.2.1.2 Effect of silicon application on macronutrient content of rice plants

Content of macronutrient *viz.*, Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Sulphur (S) and Sodium (Na) was determined from the samples of rice plants collected at 75 DAT during second year of field experiment. Data on the macronutrient content of rice plants are presented in Table 17 and graphically depicted in Fig. 6 to 8.

Nitrogen

Nitrogen content differed significantly among various treatments (Table 17 and Fig. 6). There was decrease in plant nitrogen content with increase in dose of calcium silicate. All four doses (500 to 2000 kg/ha) of calcium silicate showed significantly lower nitrogen content than control and all three concentrations (0.5 to 2.0 %) of potassium silicate. The lowest (0.433 %) nitrogen content was analysed from SA of calcium silicate @ 2000 kg/ha and it was at par with calcium silicate @ 1500 kg/ha (0.457 %). Calcium silicate @ 1500 and 1000 kg/ha (0.480 %) as well as SA of calcium silicate @ 1000 kg/ha and 500 kg/ha (0.503 %) showed more or less equal nitrogen content in descending orders. All three concentrations (0.5, 1.0 and 2.0 %) of potassium silicate recorded nitrogen content between 0.540 and 0.553 per cent and they were at par with control.

Table 17 : Effect of silicon application on macronutrient content of rice plants

Treatments	Macronutrient content (%)						
	N	P_2O_5	K_2O	Ca	Mg	S	Na
SA of calcium silicate @ 500 kg/ha at TP	0.503b	0.125abc	1.310abc	0.395abc	0.279a	0.130a	0.093bc
SA of calcium silicate @ 1000 kg/ha at TP	0.480bc	0.130ab	1.337abc	0.414abc	0.223a	0.132a	0.090ab
SA of calcium silicate @ 1500 kg/ha at TP	0.457cd	0.133a	1.347ab	0.426ab	0.269a	0.136a	0.083ab
SA of calcium silicate @ 2000 kg/ha at TP	0.433d	0.134a	1.373a	0.450a	0.273a	0.144a	0.080a
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT	0.553a	0.115c	1.210bc	0.355bc	0.256a	0.146a	0.107d
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT	0.540a	0.116c	1.213bc	0.350c	0.257a	0.149a	0.103cd
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT	0.540a	0.118bc	1.223bc	0.362bc	0.272a	0.143a	0.103cd
Control	0.557a	0.115c	1.203c	0.350c	0.240a	0.136a	0.110d
S. Em. ±	0.009	0.004	0.042	0.022	0.014	0.005	0.003
C.V. %	3.06	6.20	5.69	9.68	9.31	6.68	6.26

Treatment means followed by same letter do not differ significantly by DNMRT at 5 per cent level of significance.

TP : Transplanting, SA : Soil Application, FA : Foliar Application, DAT : Days After Transplanting

The correlation coefficient between plant silica content and nitrogen content was significantly negative (r = -0.856*), indicating decrease in nitrogen content with corresponding increase in plant silica content and *vice-versa*. The correlation coefficient between nitrogen content in rice plant and per cent white earheads due to *S. incertulas* (r = 0.826*) as well as leaf damage due to *C. medinalis* (r = 0.746*) were significantly positive. The population of *S. furcifera* was significantly positively correlated (r = 0.736*) with plant nitrogen content.

Present finding is supported by the Mitsui and Takatoh (1963), who reported decrease in nitrogen content in rice plant with increase in silicon application rate. Application of silicon to rice plants grown on nutrient culture solution decreased nitrogen content (Islam and Saha, 1969). Deren (1997) showed that soil application of silicon in the form of calcium silicate decreased nitrogen concentration in all parts of rice plant. Chavan (2013) observed significantly positive correlation (r = 0.884) between white earheads and plant nitrogen content.

Phosphorus

The differences among the treatments for plant phosphorus content were significant (Table 17 and Fig. 7). There was increase in plant phosphorus content with increase in the dose of calcium silicate. FA of potassium silicate did not significantly alter the phosphorus content. The highest (0.134 %) phosphorus content was observed in the treatment of calcium silicate @ 2000 kg/ha and it remained at par with calcium silicate @ 1500, 1000 and 500 kg/ha which recorded 0.133, 0.130 and 0.125 per cent phosphorus content, respectively. The phosphorus content in SA of calcium silicate @ 500 and 1000 kg/ha as well as FA of potassium silicate @ 2.0 per cent (0.118 %) was more or less equal. All three concentrations of potassium silicate @ 0.5 to 2.0 per cent showed 0.115 to 0.118 per cent phosphorus content, but they were at par with control (0.115 %).

Significantly positive correlation coefficient (r = 0.772*) was observed between plant silica content and phosphorus content. The correlation coefficient between phosphorus content and white earheads was significantly negative (r = -0.593*). Similarly, correlation coefficients between phosphorus content and leaf damage due to *C. medinalis* (r = -0.611*) as well as the population of *S. furcifera* (r = -0.649*) were significantly negative.

Islam and Saha (1969) reported that application of silicon to rice plants grown on nutrient culture solution increased phosphorus content. Deren (1997) showed that soil application of silicon in the form of calcium silicate increased phosphorus concentration in rice plant. Phosphorus contents in grain and straw significantly increased due to Si application up to 180 kg Si/ha (Singh *et al.*, 2006).

Shatrughna (1996) reported that the rice varieties having higher content of phosphorus exhibited resistant reaction against

S. incertulas. Thus, present findings are in conformity with earlier findings.

Potassium

Application of silicon significantly affected plant potassium content in rice plant (Table 17 and Fig. 6). The increasing trend in potassium content with increase in dose of calcium silicate was observed. The highest (1.373 %) plant potassium content was noticed in calcium silicate @ 2000 kg/ha and it was at par with SA of calcium silicate @ 1500 kg/ha (1.347 %), 1000 kg/ha (1.337 %) and 500 kg/ha (1.310 %). Foliar application of potassium silicate @ 0.5 to 2.0 per cent recorded potassium content between 1.210 and 1.223 per cent, but they were at par with control (1.203 %).

Significantly positive correlation (r = 0.657*) was observed between plant silica content and potassium content. The correlation coefficient between potassium content and white earheads due to *S. incertulas* was significantly negative (r = -0.675*). Leaf damage due to *C. medinalis* was significantly negatively correlated (r = -0.482*) with potassium content. The correlation coefficient between potassium content and population of *S. furcifera* was also significantly negative (r = -0.482*).

Present findings are in line with the earlier research findings. Singh *et al.* (2006) observed increase in potassium concentration when silicon was applied to rice under field conditions. Wright *et al.* (2013) observed increase in potassium content in one of the three varieties of St. Augustine grass with the application of silicate slag. Chavan (2013) observed significantly negative correlation (r = -0.922*) between white earheads and potassium content in rice plant.

Calcium

Differences among treatments with respect to plant calcium content were significant (Table 17 and Fig. 7). There was increase in calcium content in plant with increase in dose of calcium silicate. Foliar application of potassium silicate did not significantly affect calcium content. The highest (0.450 %) calcium content was observed in the treatment of calcium silicate @ 2000 kg/ha and it was at par with calcium silicate @ 1500 kg/ha (0.426 %), 1000 kg/ha (0.414 %) and 500 kg/ha (0.395 %). The calcium content in rice plant was between 0.350 and 0.362 per cent in FA of potassium silicate and they were at par with control (0.350 %).

Plant calcium content was significantly positively correlated (r = 0.766*) with silica content. Significantly negative correlation coefficient (r = -0.770*) was observed between calcium content and white earheads due to *S. incertulas*. The correlation coefficients between calcium content and leaf damage due to *C. medinalis* (r= -0.539*) as well as the population of *S. furcifera* (r = -0.585*) were significantly negative.

Present finding is in conformity with Islam and Saha (1969), who reported that application of silicon to rice plants grown on nutrient culture solution increased calcium content of rice plants. In present study calcium silicate was used as a silicon source which also contained calcium, which might have increased calcium availability in soil and contributed to increase in calcium content in plant.

Magnesium

The differences among the treatments for plant magnesium content were non-significant indicating that silicon application did not significantly affect content of this element (Table 17 and Fig. 8). The magnesium content in different treatments varied from 0.223 to 0.279 per cent. Non-significantly positive correlation coefficient (r = 0.017) was observed between silica content and magnesium content.

Present findings tally with the results of McCray and Ji (2013), who observed that application of electric furnace slag, which contained silicon in the form of calcium silicate, to sugarcane crop did not increase leaf magnesium content.

Sulphur

Similar to magnesium, the content of this element in plant was not affected significantly by silicon application either in the form of calcium silicate or potassium silicate (Table 17 and Fig. 8). The sulphur content varied from 0.130 to 0.149 per cent in different treatments.

There was non-significantly positive relationship (r = -0.209) between plant silica content and sulphur content (Table 15). The correlation coefficients between sulphur content and white earheads due to *S. incertulas* (r = 0.071), leaf damage due to *C. medinalis* (r = 0.160) as well as the population of *S. furcifera* (r = 0.101) were all non-significantly positive (Table 16).

Sarto *et al.* (2014) found that application of calcium silicate to wheat plants grown under pot culture did not affect the concentration of sulphur in wheat flag leaves. Thus, present finding is in confirmity with earlier findings.

Sodium

Sodium content in rice plant differed significantly among various treatments (Table 17 and Fig. 8). There was decrease in plant sodium content with increase in dose of SA of calcium silicate, whereas FA of potassium silicate did not significantly affect concentration of sodium in plant. All four doses (500 to 2000 kg/ha) of calcium silicate recorded significantly lower concentration of sodium than control. The lowest (0.080 %) concentration of sodium was observed in the treatment SA of calcium silicate @ 2000 kg/ha and it was at par with calcium silicate @ 1500 kg/ha (0.083 %) and 1000 kg/ha (0.090 %). Calcium silicate @ 500, 1000 and 1500 kg/ha recorded more of less equal concentration of sodium. The concentration of sodium in FA of potassium silicate @ 0.5 to 2.0 per cent varied from 0.103 to 0.107 per cent and they were at par with control (0.110 %). The correlation coefficient between silica and sodium content was significantly negative (r = -0.757*).

Similar results were reported by Matoh *et al.* (1986), they showed that silicon application to culture solution of rice plants, grown hyroponically under salt stress, reduced the sodium concentration of the shoots by 54 per cent of that recorded in the plants that did not receive silicon. This function of Si may be ascribed to the Si-induced decrease in transpiration (Matoh *et al.*, 1986) and to the partial blockage of the transpirational bypass flow, the pathway by which a large proportion of the uptake of Na in rice occurs (Yeo *et al.*, 1999). Gong *et al.* (2006) suggested that silicon application to rice grown under sodium chloride (NaCl) stress reduced sodium uptake in rice seedlings through a reduction in transpirational bypass flow.

4.2.1.3 Effect of silicon application on micronutrient content of rice plants

Content of micronutrients *viz.*, iron (Fe), manganese (Mn), Zinc (Zn) and Copper (Cu) was determined from the samples of rice plants collected from field experiment at 75 DAT. Their results are presented in Table 18 and graphically depicted in Fig. 9 to 10.

Iron

The differences among treatments for iron content were significant (Table 18 and Fig. 9). Decreasing trend in plant iron content with increasing dose of calcium silicate was observed. Spray application of silicon in the form of potassium silicate did not significantly affect plant iron content. The lowest (295 ppm) concentration of iron was observed in the treatment of calcium silicate @ 2000 kg/ha and it remained at par with calcium silicate @ 1500 kg/ha (309 ppm) and 1000 kg/ha (323 ppm). The iron concentration in the treatment of calcium silicate @ 500 (347 ppm) was more or less equal to the treatments of calcium silicate @ 1000 and 1500 kg/ha. FA of potassium silicate @ 0.5 to 2.0 per cent recorded iron content from 382 to 395 ppm and they remained at par with control (390 ppm). Significantly negative correlation coefficient (r = -0.822*) was observed between silica content and plant iron.

Table 18 : Effect of silicon application on micronutrient content of rice plants

Treatments	Micronutrient content (ppm)			
	Fe	Mn	Zn	Cu
SA of calcium silicate @ 500 kg/ha at TP	347ab	213bc	30.3a	9.3a
SA of calcium silicate @ 1000 kg/ha at TP	323bc	198cd	31.3a	9.0a
SA of calcium silicate @ 1500 kg/ha at TP	309bc	186cd	28.3a	10.3a
SA of calcium silicate @ 2000 kg/ha at TP	295c	177d	31.7a	10.7a
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT	391a	240ab	31.7a	10.0a
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT	395a	238ab	31.0a	10.3a
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT	382a	246a	30.7a	10.3a
Control	390a	244a	29.0a	10.7a
S. Em. ±	15.59	8.40	1.02	0.42
C.V. %	7.63	6.68	5.80	7.22

Treatment means followed by same letter do not differ significantly by DNMRT at 5 per cent level of significance.

TP : Transplanting, SA : Soil Application, FA : Foliar Application
DAT : Days After Transplanting

Present finding is in line with the results of Okuda and Takahashi (1961), Islam and Saha (1969) as well as Ma and Takahashi (1990). All of them observed decrease in iron content in rice plant with addition of silicon in growing medium. Okuda and Takahashi (1961) concluded that addition of silicon to nutrient solution increased the oxidation power of rice roots leading to an oxidation of Fe^{2+} and subsequent precipitation on the root surface and hence to a reduced Fe uptake in rice plant.

Manganese

Silicon application significantly affected plant manganese content (Table 18 and Fig. 9). There was decrease in plant manganese content with increase in the dose of SA of calcium silicate, whereas the concentration of manganese was not significantly affected by foliar application of potassium silicate. All four doses (500 to 2000 kg/ha) of calcium silicate showed significantly lower manganese content than control (244 ppm). The lowest (177 ppm) concentration of manganese was observed in the treatment of calcium silicate @ 2000 kg/ha and it remained at par with calcium silicate @ 1500 kg/ha (186 ppm) and 1000 kg/ha (198 ppm). Manganese concentration in plots applied with calcium silicate @ 500kg/ha (213 ppm) was more or less equal to that of calcium silicate @ 1000 and 1500 kg/ha. Foliar application of potassium silicate @ 0.5 to 2.0 per cent concentration registered manganese content between 238 and 246 ppm and they were at par with control. Plant manganese content was significantly negatively correlated (r = -0.849*) with silica content.

Decrease manganese content in rice plant with addition of silicon in growing medium was also reported by Okuda and Takahashi (1961) and Islam and Saha (1969). Ma and Takahashi (1990) noticed that application of silicon to nutrient solution of rice plants @ 1.66 mM reduced uptake of manganese by 50 per cent. Okuda and Takahashi (1961) suggested that addition of silicon to nutrient solution increased the oxidation power of rice roots leading to an oxidation of Mn^{2+} and subsequent precipitation on the root surface and hence to a reduced Mn uptake in rice plant. Thus, present finding is in conformity with earlier findings.

Zinc

The differences among treatments for zinc content were not significant (Table 18 and Fig. 10). The zinc content of rice plant varied from 28.3 to 31.7 ppm in different treatments. Non-significantly negative correlation (r = -0.032) was observed between silica and zinc content in rice plant.

Similar result was noticed by Masarovic *et al.* (2012), who reported that silicon treatment did not significantly influence zinc accumulation in sorghum roots and shoots. Wright *et al.* (2013) reported that zinc content was not influenced by the addition of silicon in the form of silicate slag in St. Augustine grass.

Copper

The concentration of copper in rice plant was not significantly affected by the application of silicon in present studies (Table 18 and Fig. 10). The copper concentration in rice plants varied between 9.0 and 10.7 ppm. The correlation coefficient between silica and copper content in rice plant was non-significantly negative (r = -0.093).

Present finding is in confirmity with the results of Sarto *et al.* (2014), who reported that application of calcium silicate to wheat plants grown in pot culture did not affect the concentration of copper in wheat flag leaves.

4.2.2 Effect of silicon application on biochemical constituents of rice plants

Content of various biochemicals *viz.*, total phenol, total sugar content, crude protein and free amino acid were determined from the samples of rice plants collected at 75 DAT during second year of field experiment. Data on the biochemical constituents of rice plants are presented in Table 19 and graphically depicted in Fig. 11 to 12.

Total phenol

Total phenol content of rice plant at 75 DAT during the second year of study differed significantly among various treatments (Table 19 and Fig. 11). Increasing trend in total phenol content was seen with increase in doses of SA of calcium silicate. All four doses (500 to 2000 kg/ha) of SA of calcium silicate recorded significantly higher total phenol content than control. The highest (4.31 mg/g) total phenol content was analysed from calcium silicate @ 2000 kg/ha and it was at par with calcium silicate @ 1500 kg/ha (4.24 mg/g) and calcium silicate @ 1000 kg/ha (4.16 mg/g). The phenol content in calcium silicate @ 500 kg/ha (4.07 mg/g) was more or less equal to that of calcium silicate @ 1000 and 1500 kg/ha. All three concentration (0.5, 1 and 2 %) of FA of potassium silicate recorded total phenol content between 3.84 to 3.95 mg/g and they were at par with each other. Potassium silicate @ 2.0 per cent concentration showed significantly higher phenol content than control (3.70 mg/g), whereas its lowest (0.5 %) and medium (1.0 %) concentration was at par with control.

Table 19 : Effect of silicon application on biochemical constituents of rice plants

Treatments	Total phenol (mg/g)	Total sugar (%)	Crude protein (%)	Free amino acid (mg/g)
SA of calcium silicate @ 500 kg/ha at TP	4.07bcd	0.74abc	3.15c	1.70abc
SA of calcium silicate @ 1000 kg/ha at TP	4.16abc	0.73ab	3.00bc	1.66ab
SA of calcium silicate @ 1500 kg/ha at TP	4.24ab	0.72ab	2.85ab	1.63a
SA of calcium silicate @ 2000 kg/ha at TP	4.31a	0.70a	2.71a	1.61a
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT	3.84de	0.80cd	3.46d	1.77bc
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT	3.90de	0.78bcd	3.38d	1.76bc
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT	3.95cd	0.77bcd	3.38d	1.76bc
Control	3.70e	0.81d	3.48d	1.78c
S. Em. ±	0.07	0.02	0.06	0.03
C.V. %	3.02	4.02	3.06	3.43

Treatment means followed by same letter do not differ significantly by DNMRT at 5 per cent level of significance.

TP : Transplanting, SA : Soil Application, FA : Foliar Application,
DAT : Days After Transplanting

The correlation coefficient between silica and total phenol content (r = 0.834*) in plant was significantly positive (Table 15), while the correlation coefficient between total phenol content and white earheads due to *S. incertulas* was significantly negative (r = -0.739*). Significantly negative correlation coefficient was observed between total phenol content and leaf damage due to *C. medinalis* (r = -0.738*) as well as the population of *S. furcifera* (r = -0.638*).

Present finding is in conformity with Bekker *et al.* (2007), who reported that application of silicon to avocado trees resulted in higher glucoside bound phenolic acid concentrations in root tissue as compared to the untreated control. Eswaran and Manivannan (2007) reported that foliar application of lignite fly ash dust, the higher silica containing by-product of thermal power plants, @ 2 kg per plant to papaya plants at 90 and 120 days after transplanting increased phenol content of leaves. Dallagnol *et al.* (2010) observed that total soluble phenolics in silicon supplied rice plants was greater compared with plants not supplied with silicon. Chavan (2013) reported significantly negative correlation (r = -0.905*) between total phenol content and white earheads damage due to *S. incertulas* in rice.

Total sugar

Significant differences were observed among treatments for total sugar content (Table 19 and Fig. 12). There was decrease in total sugar content with increase in dose of SA of calcium silicate. The total sugar content in all four doses (500 to 2000 kg/ha) of SA of calcium silicate was significantly lower than control. Significantly the lowest (0.70 mg/g) total sugar content was noticed in calcium silicate @ 2000 kg/ha and it was at par with remaining doses of calcium silicate. Calcium silicate @ 500, 1000 and 1500 kg/ha exhibited total sugar content of 0.74, 0.73 and 0.72 mg/g, respectively. FA of potassium silicate @ 0.5 to 2.0 per cent concentration showed total sugar content between 0.77 and 0.80 mg/g and they were at par with control (0.81 mg/g).

The total sugar content in rice plants was significantly negatively correlated (r = -0.819*) with plant silica content (Table 15). The white earhead damage due to *S. incertulas* was significantly positively correlated with total sugar content (r = 0.733*). Similarly, the leaf damage due to *C. medinalis* was significantly positively correlated with total sugar content (r = 0.582*). The correlation coefficient between total sugar content and the population of *S. furcifera* was significantly positive (r = 0.601*).

Present finding tally the results of Eswaran and Manivannan (2007), who reported that foliar application of lignite fly ash dust, the higher silica containing by-product of thermal power plants, @ 2 kg per papaya plant at 90 and 120 days after transplanting reduced sugar content of leaves. Chandramani *et al.* (2009) observed significantly positive correlation between total sugar content and population of *S. furcifera* (r = 0.604) in rice.

Crude protein

There were significant differences among treatments for crude protein content (Table 19 and Fig. 11). Decreasing trend in crude protein content was observed with increase in the dose of SA of calcium silicate. SA of calcium silicate @ 500 to 2000 kg/ha recorded significantly lower crude protein content than control and all three concentrations of potassium silicate. Calcium silicate @ 2000 kg/ha showed the lowest (2.71 %) crude protein content and it was at par with calcium silicate @ 1500 kg/ha (2.85 %). Calcium silicate @ 1500 kg/ha and 1000 kg/ha (3.00 %) recorded more or less equal crude protein content. All three concentrations (0.5, 1.0 and 2.0 %) of potassium silicate exhibited crude protein content between 3.38 and 3.46 per cent and they were at par with control (3.48 %).

The correlation coefficient between silica and crude protein in plant (r = -0.856*) was significantly negative (Table 15). White earheads due to *S. incertulas* was significantly positively correlated (r = 0.826*) with crude protein content (Table 15). Significantly positive correlation coefficient (r = 0.746*) was observed between crude protein content and leaf damage due to *C. medinalis*. Similarly, the correlation coefficient between crude protein content and the population of *S. furcifera* was significantly positive (r = 0.736*).

Islam and Saha (1969) reported that the application of silicon decreased protein content of rice plants. Souza *et al.* (2011) also reported that application of calcium silicate to palisade grass decreased concentration and accumulation of crude protein. Chavan (2013) found significantly positive correlation (r = 0.884*) between protein content in rice plant and white earheads due to *S. incertulas*. Punithavalli *et al.* (2013) reported positive correlation between leaf protein content and the damage by rice leaffolder. Thus, present finding is in conformity with earlier reports.

Free amino acids

Differences among treatments for free amino acid content were significant (Table 19 and Fig. 12). There was decreasing trend in free amino acids content with increasing in the dose of SA of calcium silicate. SA of calcium silicate @ 1000 kg/ha and more recorded significantly lower free amino acids content than control. The lowest (1.61 mg/g) free amino acids content was observed in the treatment of SA of calcium silicate @ 2000 kg/ha and it was at par with calcium silicate @ 1500 kg/ha (1.63 mg/g), 1000 kg/ha (1.66 mg/g) and 500 kg/ha (1.70 mg/g). FA of potassium silicate @ 0.5 to 2.0 per cent showed free amino acids content between 1.76 and 1.77 mg/g and they were at par with control (1.78 mg/g).

Significantly negative correlation coefficient (r = -0.646*) was observed between silica content and free amino acid content in rice plant (Table 15). The correlation coefficient between free amino acid content and white earhead damage due *S. incertulas* (r = 0.709*) was significantly positive (Table 16). Similarly, the correlation coefficient between free amino acid content and leaf damage due to *C. medinalis* was significantly positive (r = 0.525*). The population of *S. furcifera* was significantly positively correlated (r = 0.644*) with free amino acid content of rice plant.

Similar result was reported by Eswaran and Manivannan (2007), who showed that foliar application of lignite fly ash dust @ 2 kg per papaya plant at 90 and 120 days after transplanting reduced amino nitrogen content of papaya leaves. Chandramani *et al.* (2009) reported that plots treated with FYM, biofertilizers, neem cake and lignite fly ash, the higher silica containing by-product of thermal power plants, showed lower free amino acids content than recommended dose of fertilizer.

4.3 EFFECT OF SILICON APPLICATION ON NATURAL ENEMIES OF RICE INSECT PESTS

Effects of silicon application on the population of spider as well egg parasitism by egg parasitoids of *S. incertulas* were studied during the *Kharif* season of year 2011 and 2012 under field conditions.

4.3.1 Effect of silicon application on the population of spider

Observations on the population of spider were recorded at 30, 45, 60 and 75 DAT in the field experiment conducted to study the effects of silicon application on the population/damage by insect pest in rice. The data on population of spiders are presented in Table 20 to 22 and graphically depicted in Fig. 13.

First year

The data on population of spiders, at 30, 45, 60 and 75 DAT during the first year of study, indicated that the differences between treatments were non-significant at all stages (Table 20). Further, the pooled over periods data also revealed that the differences among treatments were non-significant. This shows that the spider population in rice crop ecosystem was not affected by application of silicon during the first year of study.

At 30 DAT, the spider population varied from 0.19 to 0.32 spider per hill. The spider population in different treatments recorded at 45 DAT ranged between 0.46 and 0.60 spider per hill, whereas at 60 DAT and 75 DAT it varied from 0.62 to 0.90 and 0.59 to 0.78 spider per hill, respectively. The pooled data of spider population in different treatments varied between 0.46 and 0.64 spider per hill.

Second year

Differences between treatments with respect to spider population recorded at 30, 45, 60 and 75 DAT were non-significant indicating that the spider population was not affected by silicon application (Table 21). The pooled results of spider population also revealed non-significant differences between treatments. The spider population in different treatments recorded at 30, 45, 60 and 75 DAT varied from 0.16 to 0.26, 0.36 to 0.53, 0.52 to 0.75 and 0.39 to 0.66, respectively. The pooled over periods data ranged from 0.46 to 0.64 spider per hill.

Table 20 : Effect of silicon application on population of spider in rice during *kharif* 2011

Treatments	No. of spider / Hill				
	30 DAT	45 DAT	60 DAT	75 DAT	Pooled
SA of calcium silicate @ 500 kg/ha at TP	0.86a (0.23)	1.01a (0.52)	1.12a (0.76)	1.07a (0.65)	1.02a (0.53)
SA of calcium silicate @ 1000 kg/ha at TP	0.85a (0.23)	0.99a (0.48)	1.10a (0.72)	1.06a (0.62)	1.00a (0.50)
SA of calcium silicate @ 1500 kg/ha at TP	0.84a (0.20)	0.99a (0.48)	1.09a (0.69)	1.06a (0.62)	0.99a (0.49)
SA of calcium silicate @ 2000 kg/ha at TP	0.83a (0.19)	0.98a (0.46)	1.06a (0.62)	1.05a (0.59)	0.98a (0.46)
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT	0.89a (0.29)	1.01a (0.52)	1.15a (0.83)	1.12a (0.75)	1.04a (0.59)
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT	0.87a (0.26)	1.03a (0.56)	1.14a (0.79)	1.12a (0.75)	1.04a (0.58)
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT	0.89a (0.29)	1.03a (0.56)	1.14a (0.79)	1.10a (0.72)	1.04a (0.58)
Control	0.91a (0.32)	1.05a (0.60)	1.18a (0.90)	1.13a (0.78)	1.07a (0.64)
S. Em. ± T	0.06	0.07	0.07	0.09	0.04
P	-	-	-	-	0.03
T x P	-	-	-	-	0.07
C.V. %	11.61	12.18	10.29	14.26	12.25

Figures outside parenthesis are $\sqrt{X + 0.5}$ transformed value and those inside parenthesis are retransformed values.

Treatment means followed by same letter do not differ significantly by DNMRT at 5 per cent level of significance.

TP : Transplanting, SA : Soil Application, FA : Foliar Application
DAT : Days After Transplanting

Table 21 : Effect of silicon application on population of spider in rice during *kharif* 2012

Treatments	No. of spider / Hill				
	30 DAT	45 DAT	60 DAT	75 DAT	Pooled
SA of calcium silicate @ 500 kg/ha at TP	0.84a (0.20)	0.96a (0.42)	1.06a (0.62)	0.99a (0.49)	0.96a (0.42)
SA of calcium silicate @ 1000 kg/ha at TP	0.84a (0.20)	0.95a (0.40)	1.04a (0.59)	0.98a (0.46)	0.95a (0.40)
SA of calcium silicate @ 1500 kg/ha at TP	0.81a (0.16)	0.93a (0.36)	1.04a (0.59)	0.96a (0.42)	0.94a (0.38)
SA of calcium silicate @ 2000 kg/ha at TP	0.81a (0.16)	0.93a (0.36)	1.01a (0.52)	0.94a (0.39)	0.92a (0.36)
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT	0.87a (0.26)	1.00a (0.49)	1.10a (0.72)	1.06a (0.62)	1.01a (0.51)
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT	0.87a (0.26)	0.98a (0.46)	1.09a (0.70)	1.05a (0.59)	1.00a (0.49)
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT	0.85a (0.23)	0.98a (0.46)	1.09a (0.69)	1.05a (0.60)	0.99a (0.48)
Control	0.87a (0.26)	1.02a (0.53)	1.12a (0.75)	1.08a (0.66)	1.02a (0.54)
S. Em. ± T	0.05	0.06	0.07	0.07	0.03
P	-	-	-	-	0.02
T x P	-	-	-	-	0.06
C.V. %	10.27	11.15	11.70	12.42	11.56

Figures outside parenthesis are $\sqrt{X + 0.5}$ transformed value and those inside parenthesis are retransformed values.

Treatment means followed by same letter do not differ significantly by DNMRT at 5 per cent level of significance.

TP : Transplanting, SA : Soil Application, FA : Foliar Application
DAT : Days After Transplanting

Pooled over years

The data pooled over years indicated that differences among treatments with respect to spider population at 30, 45, 60 and 75 DAT were non-significant suggesting that application of silicon did not affect the population of spiders (Table 22 and Fig. 13). Similarly, the overall pooled data on spider population revealed non-significant differences among treatments. The spider population in various treatments at 30, 45, 60 and 75 DAT ranged from 0.18 to 0.29, 0.41 to 0.56, 0.57 to 0.82 and 0.49 to 0.72, respectively. The overall data on population of spiders ranged between 0.41 and 0.59 per hill in different treatments.

Moraes *et al.* (2004) reported non-significant effect of silicon application to wheat plant on development of *C. externa*, the predator of wheat greenbug, *S. graminum.* They further reported that, the duration and survival of instars, adult longevity and total life cycle as well as sex ratio *C. externa* was not affected when the insect developed on aphids reared on plants treated with silicon or without silicon. Connick (2011) through Y-tube olfactometer bioassays found that *M. signata*, a neuropteran predator, was equally attracted to *P. glycinae* damaged grapevines from silicon applied and without silicon treatments. Thus, present findings are in conformity with earlier research findings.

Table 22 : Effect of silicon application on population of spider in rice (Pooled over years)

Treatments		No. of spider / Hill				
		30 DAT	45 DAT	60 DAT	75 DAT	Overall Pooled
SA of calcium silicate @ 500 kg/ha at TP		0.85a (0.21)	0.98a (0.47)	1.09a (0.69)	1.03a (0.57)	0.99a (0.48)
SA of calcium silicate @ 1000 kg/ha at TP		0.84a (0.21)	0.97a (0.44)	1.07a (0.65)	1.02a (0.54)	0.98a (0.45)
SA of calcium silicate @ 1500 kg/ha at TP		0.82a (0.18)	0.96a (0.42)	1.07a (0.64)	1.01a (0.51)	0.96a (0.43)
SA of calcium silicate @ 2000 kg/ha at TP		0.82a (0.18)	0.95a (0.41)	1.04a (0.57)	1.00a (0.49)	0.95a (0.41)
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT		0.88a (0.27)	1.00a (0.51)	1.13a (0.77)	1.09a (0.69)	1.03a (0.55)
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT		0.87a (0.26)	1.00a (0.51)	1.11a (0.74)	1.08a (0.67)	1.02a (0.54)
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT		0.87a (0.26)	1.00a (0.51)	1.11a (0.74)	1.07a (0.66)	1.02a (0.53)
Control		0.89a (0.29)	1.03a (0.56)	1.15a (0.82)	1.11 (0.72)	1.04 (0.59)
S. Em. ±	T	0.04	0.05	0.05	0.06	0.02
	P	-	-	-	-	0.02
	Y	0.02	0.02	0.02	0.03	0.01
	T x P	-	-	-	-	0.05
	T x Y	0.05	0.07	0.07	0.08	0.03
	P x Y	-	-	-	-	0.02
	T x P x Y	-	-	-	-	0.07
C.V. %		10.98	11.71	10.99	13.45	11.52

Figures outside parenthesis are $\sqrt{X + 0.5}$ transformed value and those inside parenthesis are retransformed values.

Treatment means followed by same letter do not differ significantly by DNMRT at 5 per cent level of significance.

TP : Transplanting, SA : Soil Application, FA : Foliar Application
DAT : Days After Transplanting

4.3.2 Effect of silicon application on parasitism by egg parasitoids of *S. incertulas*

During both years of study at 30 and 45 DAT, egg masses of *S. incertulas* were observed in only few treatments. Therefore observations on the parasitism of eggs of *S. incertulas* could not be recorded during these periods. The data on parasitism egg of *S. incertulas* in different treatments at 60 and 75 DAT are presented in Table 23 to 25. Egg parasitoids were identified as *Tetrastichus schoenobii* Ferriere (Hymenoptera : Eulophidae) and *Telenomus dignus* (Gahan), (Hymenoptera : Scelionidae) (Plate 7).

First Year

During the first year, the differences among treatments with respect to parasitism of eggs of *S. incertulas* by *T. schoenobii* were non-significant (Table 23). It shows that the parasitism of eggs of *S. incertulas* by *T. schoenobii* in rice crop ecosystem was not affected by application of silicon. At 60 DAT, the per cent egg parasitism by *T. schoenobii* ranged from 4.22 to 6.26, whereas at 75 DAT it varied from 6.92 to 8.86 per cent. The pooled data of per cent egg parasitism by *T. schoenobii* in different treatments varied between 5.61 and 6.80.

The parasitism of *S. incertulas* eggs by *T. dignus* was not significantly different among various treatments at 60 and 75 DAT as well as in pooled analysis (Table 23). At 60 DAT, the per cent parasitism in different treatments varied from 2.38 to 3.04, while at 75 DAT it ranged from 3.84 to 4.99 per cent. The pooled per cent parasitism in different treatment ranged from 3.24 to 3.68.

Table 23 : Effect of silicon application on parasitism of eggs of *S. incertulas* by *T. schoenobii* and *T. dignus* in rice during *kharif* 2011

Treatments	Egg parasitism (%)					
	T. schoenobii			*T. dignus*		
	60 DAT	**75 DAT**	**Pooled**	**60 DAT**	**75 DAT**	**Pooled**
SA of calcium silicate @ 500 kg/ha at TP	12.68a (4.82)	16.73a (8.29)	14.71a (6.44)	9.51a (2.73)	12.17a (4.44)	10.84a (3.54)
SA of calcium silicate @ 1000 kg/ha at TP	12.93a (5.01)	17.31a (8.86)	15.12a (6.80)	8.87a (2.38)	11.85a (4.22)	10.36a (3.24)
SA of calcium silicate @ 1500 kg/ha at TP	11.94a (4.28)	16.07a (7.67)	14.01a (5.86)	10.04a (3.04)	11.30a (3.84)	10.67a (3.43)
SA of calcium silicate @ 2000 kg/ha at TP	11.85a (4.22)	16.05a (7.64)	13.95a (5.81)	9.31a (2.62)	12.31a (4.55)	10.81a (3.52)
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT	12.92a (5.00)	16.54a (8.10)	14.73a (6.46)	9.22a (2.57)	12.91a (4.99)	11.07a (3.68)
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT	14.49a (6.26)	15.97a (7.57)	15.23a (6.90)	9.13a (2.52)	12.35a (4.58)	10.74a (3.47)
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT	11.87a (4.23)	15.52a (7.16)	13.70a (5.61)	8.96a (2.42)	11.95a (4.29)	10.45a (3.29)
Control	12.62a (4.78)	15.26a (6.92)	13.94a (5.80)	9.32a (2.62)	12.79a (4.90)	11.05a (3.67)
S. Em. ± T	1.08	1.21	0.81	0.75	0.84	0.56
P	-	-	0.41	-	-	0.28
T x P	-	-	1.15	-	-	0.79
C.V. %	14.73	12.96	13.76	13.89	11.91	12.79

Figures outside parenthesis are arcsine transformed value and those inside parenthesis are retransformed values.
Treatment means followed by same letter do not differ significantly by DNMRT at 5 per cent level of significance.
TP : Transplanting, SA : Soil Application, FA : Foliar Application, DAT : Days After Transplanting

Second Year

At 60 and 75 DAT, differences among treatments with respect to parasitism of *S. incertulas* eggs by *T. schoenobii* were non-significant (Table 24). The pooled data also revealed non-significant differences among treatments. The per cent egg parasitism by *T. schoenobii* in different treatments at 60 and 75 DAT varied from 4.76 to 6.25 and 8.51 to 10.27, respectively. The pooled over periods data of per cent egg parasitism by *T. schoenobii* ranged from 6.51 to 8.15.

There were non-significant differences among treatments for parasitism of *S. incertulas* eggs by *T. dignus* at 60 and 75 DAT (Table 24). The pooled over periods data also indicated non-significant differences among treatments. The egg parasitism by *T. dignus* in different treatments at 60 and 75 DAT ranged from 2.65 to 4.11 and 2.79 to 4.17 per cent, respectively. The pooled over periods data of per cent egg parasitism by *T. dignus* ranged between 3.04 and 3.77.

Pooled Over Years

The pooled over years data of per cent parasitism of *S. incertulas* eggs by *T. schoenobii* at 60 and 75 DAT revealed non-significant differences among treatments indicating that application of silicon did not affect the activity of *T. schoenobii* (Table 25 and Fig. 14). Similarly, the pooled over periods and years data on per cent parasitism indicated non-significant differences among treatments. The per cent parasitism of *S. incertulas* eggs by *T. schoenobii* in various treatments at 60 and 75 DAT ranged from 4.52 to 6.35 and 7.99 to 9.34, respectively. The pooled over periods and years egg parasitism ranged between 6.18 and 7.13 per cent in different treatments.

Table 24 : Effect of silicon application on parasitism of eggs of *S. incertulas* by *T. schoenobii* and *T. dignus* in rice during *kharif* 2012

Treatments	Egg parasitism (%)					
	T. schoenobii			*T. dignus*		
	60 DAT	**75 DAT**	**Pooled**	**60 DAT**	**75 DAT**	**Pooled**
SA of calcium silicate @ 500 kg/ha at TP	13.16a (5.19)	18.30a (9.86)	15.73a (7.35)	9.37a (2.65)	11.78a (4.17)	10.57a (3.37)
SA of calcium silicate @ 1000 kg/ha at TP	13.05a (5.10)	18.67a (10.24)	15.86a (7.47)	10.87a (3.55)	9.61a (2.79)	10.24a (3.16)
SA of calcium silicate @ 1500 kg/ha at TP	12.60a (4.76)	16.96a (8.51)	14.78a (6.51)	10.71a (3.46)	11.16a (3.75)	10.94a (3.60)
SA of calcium silicate @ 2000 kg/ha at TP	13.98a (5.84)	18.24a (9.80)	16.11a (7.70)	11.00a (3.64)	11.06a (3.68)	11.03a (3.66)
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT	13.67a (5.58)	18.70a (10.27)	16.18a (7.77)	11.70a (4.11)	11.14a (3.74)	11.42a (3.92)
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT	14.70a (6.44)	16.87a (8.43)	15.79a (7.40)	10.85a (3.54)	10.97a (3.62)	10.91a (3.58)
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT	13.84a (5.72)	18.45a (10.01)	16.14a (7.73)	9.37a (2.65)	10.70a (3.45)	10.04a (3.04)
Control	14.48a (6.25)	18.69a (10.26)	16.58a (8.15)	10.88a (3.56)	11.53a (3.99)	11.20a (3.77)
S. Em. ± T	0.88	1.12	0.71	0.60	0.85	0.52
P	-	-	0.35	-	-	0.26
T x P	-	-	1.00	-	-	0.74
C.V. %	11.08	10.68	10.93	9.78	13.43	11.82

Figures outside parenthesis are arcsine transformed value and those inside parenthesis are retransformed values.
Treatment means followed by same letter do not differ significantly by DNMRT at 5 per cent level of significance.
TP : Transplanting, SA : Soil Application, FA : Foliar Application, DAT : Days After Transplanting

Table 25 : Effect of silicon application on parasitism of eggs of *S. incertulas* by *T. schoenobii* and *T. dignus* in rice (Pooled over years)

Treatments	Egg parasitism (%)					
	T. schoenobii			*T. dignus*		
	60 DAT	**75 DAT**	**Overall Pooled**	**60 DAT**	**75 DAT**	**Overall Pooled**
SA of calcium silicate @ 500 kg/ha at TP	12.92a (5.00)	17.51a (9.06)	15.22a (6.89)	9.44a (2.69)	11.97a (4.30)	10.71a (3.45)
SA of calcium silicate @ 1000 kg/ha at TP	12.99a (5.05)	17.99a (9.54)	15.49a (7.13)	9.87a (2.94)	10.73a (3.47)	10.30a (3.20)
SA of calcium silicate @ 1500 kg/ha at TP	12.27a (4.52)	16.51a (8.08)	14.39a (6.18)	10.38a (3.24)	11.23a (3.79)	10.80a (3.51)
SA of calcium silicate @ 2000 kg/ha at TP	12.92a (5.00)	17.14a (8.69)	15.03a (6.73)	10.16a (3.11)	11.68a (4.10)	10.92a (3.59)
FA of potassium silicate 0.5 % at 30, 45 and 60 DAT	13.29a (5.29)	17.62a (9.16)	15.45a (7.10)	10.46a (3.30)	12.03a (4.34)	11.24a (3.80)
FA of potassium silicate 1.0 % at 30, 45 and 60 DAT	14.59a (6.35)	16.42a (7.99)	15.51a (7.15)	9.99a (3.01)	11.66a (4.08)	10.83a (3.53)
FA of potassium silicate 2.0 % at 30, 45 and 60 DAT	12.86a (4.95)	16.99a (8.53)	14.92a (6.63)	9.16a (2.54)	11.33a (3.86)	10.25a (3.16)
Control	13.55a (5.49)	16.97a (8.52)	15.26a (6.93)	10.10a (3.07)	12.16a (4.43)	11.13a (3.72)
S. Em. ± T	0.69	0.82	0.54	0.48	0.60	0.38
P	-	-	0.27	-	-	0.19
Y	0.35	0.41	0.27	0.24	0.30	0.19
T x P	-	-	0.76	-	-	0.54
T x Y	0.98	1.16	0.76	0.68	0.85	0.54
P x Y	-	-	0.38	-	-	0.27
T x P x Y	-	-	1.08	-	-	0.77
C.V. %	12.91	11.77	12.31	11.77	12.63	12.31

Figures outside parenthesis are arcsine transformed value and those inside parenthesis are retransformed values.
Treatment means followed by same letter do not differ significantly by DNMRT at 5 per cent level of significance.
TP : Transplanting, SA : Soil Application, FA : Foliar Application, DAT : Days After Transplanting

The pooled over years result of per cent parasitism of *S. incertulas* eggs by *T. schoenobii* at 60 and 75 DAT revealed that differences among treatments were non-significant. The pooled over periods and years results also indicated non-significant differences among treatments. The per cent parasitism of *S. incertulas* eggs by *T. schoenobii* at 60 and 75 DAT varied from 2.54 to 3.30 and 3.47 to 4.43 per cent. The pooled over periods and years egg parasitism ranged from 3.16 to 3.80 per cent.

Moraes *et al.* (2004) reported that silicon application to wheat plant did not affect the parasitism of wheat greenbug, *S. graminum* by *A. colemani*, a parasitoid of greenbug. They further reported that, the duration of immature stage, adult longevity and total life cycle as well as sex ratio of *A. colemani* was not affected when the insect developed on aphids reared on plants treated with silicon or without silicon. Thus, present findings are in conformity with earlier research report.

4.4 EFFECT OF SILICON APPLICATION ON OVIPOSITION PREFERENCE AND ITS ANTIBIOSIS EFFECTS ON *S. incertulas*

Studies on the effect of silicon on the oviposition preference and biology of *S. incertulas* were carried out under laboratory.

4.4.1 Effect of silicon application on oviposition preference of *S. incertulas*

The free-choice test on egg laying preference of *S. incertulas* females on silicon applied (Si+) and not applied (Si-) plants was carried in the laboratory. Silicon was applied in the form of calcium silicate @ 1 g/kg soil. Silicon application to rice plants did not affect the egg laying preference of *S. incertulas* females (Table 26). Single female of *S. incertulas* on an average laid 1.20 ± 0.40 egg masses on silicon applied (Si+) rice plant and 1.27 ± 0.44 egg masses on control (Si-) plant. The difference between Si+ and Si- plants for number of egg masses laid was non-significant, indicating that the silicon application to rice plant did not affect the egg laying preference of *S. incertulas* females in free-choice.

Table 26 : Egg masses and eggs laid by *S. incertulas* females on Si+ and Si-plants

Particulars	Si^+			Si^-		
	Min.	Max.	Mean ± SD	Min.	Max.	Mean ± SD
No. of egg masses laid	1	2	1.20 ± 0.40a	1	2	1.27 ± 0.44a
No. of egg laid	39	107	62.33 ± 21.33a	42	114	69.20 ± 21.49a

In a row, average ± SD followed by same letter do not differ significantly from each other by Two sample T-test (two tailed) at 5 per cent level of significance.

A female of *S. incertulas* on an average laid 62.33 ± 21.33 eggs on Si+ plant and 69.20 ± 21.49 eggs on Si- plant. The difference between number of eggs laid by single female on Si+ plant and Si- was non-significant indicating that the silicon application did not affect egg laying preference of *S. incertulas* female in free-choice.

Djamin and Pathak (1967) concluded that higher amounts of silica present in the host plants affected larval survival adversely and reduced the incidence of dead hearts on the plants, but it did not affect the oviposition preference of Asiatic rice borer. Correa *et al.* (2005) reported that soil application of silicon in the form calcium silicate to cucumber did not affect the egg laying preference of *B. tabaci* in no-choice test. Thus, present finding in conformity with earlier findings.

4.4.2 Antibiosis effects of silicon application on *S. incertulas*

The present study on the antibiosis effects of silicon application was carried out under laboratory conditions by feeding rice stems collected from silicon applied (Si+) and untreated plants (Si-) to *S. incertulas* larvae. Their data are presented in Table 27 and 28.

Effect on larvae

The duration of first instar of *S. incertulas* was significantly higher (Table 27) when larvae were fed with rice stems from silicon treated plants (Si+) compared with rice stems from untreated plants (Si-). The duration of first instar on silicon treated stems varied from 6 to 7 days with an average of 6.27 ± 0.44 days, whereas the same on untreated stems varied from 5 to 6 days with average of 5.47 ± 0.50 days. The weight of the first instar larva fed with Si+ stems was 0.38 ± 0.05 mg (Table 28) and it was at par with that of larva fed with Si-stems (0.37 ± 0.06 mg).

Table 27 : Antibiosis effect of silicon on *S. incertulas*

Stage	Si+			Si-		
	Min.	Max.	Mean ± SD	Min.	Max.	Mean ± SD
Larva period						
Instar I	6	7	6.27 ± 0.44a	5	6	5.47 ± 0.50b
Instar II	5	6	5.40 ± 0.49a	4	5	4.67 ± 0.47b
Instar III	5	6	5.67 ± 0.47a	4	6	4.80 ± 0.65b
Instar IV	6	7	6.20 ± 0.40a	4	6	5.13 ± 0.50b
Instar V	7	9	7.93 ± 0.77a	6	8	6.80 ± 0.65b
Total	29	33	31.47 ± 1.31a	24	29	26.87 ± 1.67b
Pre-pupal period	1	2	1.47 ± 0.50a	1	2	1.33 ± 0.47a
Pupal period	7	9	8.20 ± 0.54a	6	8	7.40 ± 0.71b
Adult period						
Pre-oviposition	1	2	1.13 ± 0.33a	1	2	1.22 ± 0.42a
Oviposition	1	2	1.13 ± 0.33a	1	2	1.44 ± 0.50a
Post-oviposition	0	1	0.50 ± 0.50a	0	1	0.56 ± 0.50a
Female longevity	2	3	2.75 ± 0.43a	3	4	3.22 ± 0.42b
Male longevity	2	3	2.20 ± 0.40a	2	3	2.60 ± 0.49a
Fecundity and hatchability						
No. of egg mass laid	2	3	2.13 ± 0.33a	2	3	2.44 ± 0.50a
Fecundity	77	157	101.13 ± 26.16a	92	203	139.00 ± 38.18b
Hatching percentage	82.26	92.31	87.17 ± 3.63a	85.42	93.43	90.31 ± 2.91a
Sex Ratio	-	-	1 : 1.60	-	-	1 : 1.80

In a row, mean ± SD followed by different letter differ significantly from each other by Two sample T-test (two tailed) at 5 per cent level of significance.

The duration of second instar was significantly higher (5.40 ± 0.49 days) on Si+ stems as compared to Si- stems (4.67 ± 0.47 days). The weight of second instar larva was significantly reduced by silicon application as compared with control. The weight of larva varied from 3.3 to 3.8 mg with an average of 3.52 ± 0.14 mg when fed with Si+ stems, whereas they weighed 3.5 to 4.3 mg with an average of 3.89 ± 0.22 mg when fed with Si- stems (Table 28).

Table 28 : Effect of silicon on body weight of immature stages of *S. incertulas*

Stage	Weight (mg)					
	Si^+			Si^-		
	Min.	Max.	Mean ± SD	Min.	Max.	Mean ± SD
Instar I	0.3	0.5	0.38 ± 0.05a	0.3	0.5	0.37 ± 0.06a
Instar II	3.3	3.8	3.52 ± 0.14a	3.5	4.3	3.89 ± 0.22b
Instar III	16.2	19.9	17.93 ± 1.05a	18.5	24.3	20.81 ± 1.82b
Instar IV	31.3	38.2	34.78 ± 1.96a	36.4	44.4	40.41 ± 2.85b
Instar V	60.5	71.6	66.46 ± 3.15a	69.7	86.8	78.86 ± 5.66b
Pupa	43.2	51.1	47.47 ± 2.25a	49.8	62.0	56.27 ± 4.05b

In a row, mean ± SD followed by different letter differ significantly from each other by Two sample T-test (two tailed) at 5 per cent level of significance.

Silicon application significantly increased duration of third instar of *S. incertulas* when compared with control. The duration of third instar on Si+ stems ranged from 5 to 6 days with an average of 5.67 ± 0.47 days, while that on Si- stems varied from 4 to 6 days with an average of 4.80 ± 0.65 days. The larvae reared on Si+ stems weighed significantly lower (17.93 ± 1.05 mg) than Si- stems (20.81 ± 1.82 mg).

The duration of fourth instar larvae of *S. incertulas* on Si+ stems ranged from 6 to 7 days with an average of 6.20 ± 0.40 and it was significantly higher than that on Si- stems, which ranged 4 to 6 days with an average of 5.13 ± 0.50 days (Table 27). The fourth instar larvae fed with Si+ stems weighed significantly lower (34.78 ± 1.96 mg) than the larvae fed with Si- stems (40.41 ± 2.85 mg) (Plate 8).

The duration of fifth instar was significantly longer (7 to 9 days with an average of 7.93 ± 0.77 days) on Si+ stems as compared to Si- stems (6 to 8 days with an average of 6.80 ± 0.65 days). The weight of fifth instar larvae reared on Si+ stems ranged from 60.5 to 71.6 mg with an average of 66.46 ± 3.15 mg and it was significantly lower than the larvae reared on Si- stems (69.7 to 86.8 mg with an average of 78.86 ± 5.66 mg).

The larval period of *S. incertulas* was significantly prolonged on Si+ stems (29 to 33 days with an average of 31.47 ± 1.31 days) as compared to Si- stem (24 to 29 days with an average of 26.87 ± 1.67 days).

Present finding is in line with the results of Massey *et al.* (2006), who reported that silica addition reduced larval growth rate on each of the four grass species studied and increased developmental time of African army worm, *S. exempta*. Massey and Hartley (2009) reported that silica reduced the efficiency with which *S. exempta* converted ingested food into body mass and the amount of nitrogen absorbed from their food, leading to reduced insect growth rates. Silicon application to rice plants, grown in pots, significantly decreased larval weight gain and prolonged larval development of *C. suppressalis* (Han and Hou, 2011). Han *et al.* (2015) observed that silicon amendment @ 0.16 and 0.32 g Si/kg soil significantly prolonged larval development period in *C. medinalis*. They also reported that higher rate of silicon (0.32 g Si/kg) decreased the larval weight when compared with control.

Effect on pre-pupae and pupae

The duration of pre-pupa on Si+ stems ranged from 1 to 2 days with an average of 1.47 ± 0.50 days (Table 27 and Plate 9) and it was at par with Si- stems (1 to 2 days with an average of 1.33 ± 0.47 days). Significantly longer pupal period (7 to 9 days with an average of 8.20 ± 0.54) was observed on Si+ stems as compared to Si- stems (6 to 8 days with an average of 7.40 ± 0.71 days). There was significant reduction in pupal weight when larvae of *S. incertulas* were fed with Si+ stems as compared to Si- stems (Table 28). The pupae of *S. incertulas* weighed 43.2 to 51.1 mg with an average of 47.47 ± 2.25 mg when reared on Si+ stems, whereas it weighed 49.8 to 62.0 mg with an average of 56.27 ± 4.05 mg when reared on Si- stems.

Present finding is in accordance with the results of Tomquelski *et al.* (2007), who reported that silicon application to cotton plants decreased pupal weight and increased the pupal period of *A. argillacea*. Han *et al.* (2015) showed that silicon amendment @ 0.32 g Si/kg soil reduced pupal weight in rice leaffolder, *C. medinalis*.

Effect on adults

The pre-oviposition period of female adults that fed with Si+ stems during larval stage ranged from 1 to 2 days with an average of 1.13 ± 0.33 days (Table 27) and it was statistically at par with female adults fed with Si- stems during larval stage (1 to 2 days with an average of 1.22 ± 0.42 days). The difference between oviposition period of Si+ and Si- females was non-significant. The oviposition period of female adults, fed with Si+ stems during larval stage, ranged from 1 to 2 days with an average of 1.13 ± 0.33 days, while the same for the female adults, fed with Si- stems during larval stage, ranged from 1 to 2 days with an average of 1.44 ± 0.50 days. Post-oviposition period was not significantly affected by the type of food received by *S. incertulas* during larval stage. The post-oviposition period of Si+ females varied from 0 to 1 day with an average of 0.50 ± 0.50 day, whereas the same for Si- females varied from 0 to 1 day with an average of 0.56 ± 0.50 day.

There was significant difference in female longevity between Si+ and Si- treatment (Table 27). Longevity of females, that received Si+ stem during larval stage as food, was significantly lower (2 to 3 days with an average of 2.75 ± 0.43 days) than the females that received Si- stem during larval stage as food (3 to 4 days with an average of 3.22 ± 0.42 days).

The difference between male longevity for Si+ and Si- treatment was non-significant (Table 27). Males developed from the larvae that received Si+ stem during larval stage as food survived for 2 to 3 days with an average of 2.20 ± 0.40 days. Similarly, males developed from the larvae fed with Si- stem during larval stage survived for 2 to 3 days with an average of 2.60 ± 0.49 days.

Salim and Saxena (1992) reported that addition of silicon @ 400 mg Si/litre of culture solution of rice plants reduced adult longevity of *S. furcifera* on susceptible rice variety. Basagli *et al.* (2003) showed that application of sodium silicate to wheat plants adversely affected longevity of greenbug, *S. graminum*. Combined application of silicon (soil and foliar) to wheat plants significantly reduced reproductive period and adult longevity of greenbug, *S. graminum*, whereas pre-reproductive and post-reproductive period were not affected (Goussain *et al.*, 2005). Korndorfer *et al.* (2011) observed that silicon application in the form of potassium silicate to sugarcane plants, grown under green house conditions, decreased the longevity of males and females of spittlebug, *M. fimbriolata*. El-bendary and El-Helaly (2013) mentioned that application of nano-silica to tomato plants did not affect pre-reproductive and reproductive periods of cotton leaf worm, *S. littoralis*, however longevity was reduced in nano-silica treatments compared with control. Thus, present findings are in conformity with earlier findings.

Effect on fecundity and hatchability

The difference between number of egg masses laid by a female fed with Si+ and Si- stems during larval stage was non-significant (Table 27). Si+ female laid numerically lesser egg masses (2 to 3 with an average of 2.13 ± 0.33) than Si- females (2 to 3 with an average of 2.44 ± 0.50). Si+ females laid significantly lesser number of eggs (77 to 137 with an average of 101.13 ± 26.16) than Si- females (92 to 203 with an average of 139.00 ± 38.18). The difference between hatching percentage of Si+ and Si- female was non-significant. The mean hatching percentage of eggs laid by Si+ female was 87.27 ± 3.63, whereas the same for eggs laid by Si- females was 90.31 ± 2.91.

Present finding is more or less in line with earlier findings. Salim and Saxena (1992) reported that addition of silicon @ 400 mg Si/litre of culture solution of rice plants reduced fecundity and population increase by *S. furcifera* on susceptible rice variety. Setamou *et al.* (1993) mentioned that egg viability of maize stem borer, *S. calamistis* was not affected by silica application. Basagli *et al.* (2003) showed that application of sodium silicate to wheat plants adversely affected production of nymphs of greenbug, *S. graminum*. Goussain *et al.* (2005) mentioned that combined application (soil and foliar) of silicon to wheat plants significantly reduced fecundity of *S. graminum.* Gomes *et al.* (2008) concluded that silicon application to potato plants via soil and/or foliage reduced fecundity and the rate of population growth of *M. persicae*. Application of soluble silicon to *Z. elegans* reduced total cumulative fecundity of green peach aphid, *M. persicae* (Ranger *et al.*, 2009). Nano-silica application to tomato plants decreased fecundity of cotton leaf warm, *S. littoralis* (El-bendary and El-Helaly, 2013). Han *et al.* (2015) reported that silicon amendment @ 0.16 and 0.32 g Si/kg soil did not significantly affect the viability of F1 eggs of *C. medinalis.*

Effect on sex ratio

The sex ratio (male : female) of adults developed from Si+ treatment was 1 : 1.60, whereas the same for Si- treatment was 1 : 1.80. Present findings are in line with the results of Han *et al.* (2015), who reported that silicon amendment negatively affected the sex ratio of *C. medinalis*, but the difference was non-significant.

V. SUMMARY AND CONCLUSION

Investigations on effect of silicon application on insect pest population / damage in rice, chemical and biochemical constituents of rice plants, natural enemies of rice insect pests and oviposition preference as well as antibiosis effect on yellow stem borer, *S. incertulas* were carried out at Agricultural Research Station, Anand Agricultural University, Derol, Dist. Panchmahal, Gujarat during 2011 to 2014. The results of investigation are summarized in this chapter.

5.1 EFFECT OF SILICON APPLICATION ON INSECT PEST POPULATION / DAMAGE IN RICE

Four doses of calcium silicate (500, 1000, 1500 and 2000 kg/ha), applied at the time of transplanting into soil and three concentrations (0.5, 1.0 and 2.0 %) of potassium silicate, applied as foliar spray at 30, 45 and 60 days after transplanting were evaluated along with control for their efficacy against yellow stem borer, *S. incertulas,* leaffolder, *C. medinalis*, whitebacked planthopper, *S. furcifera* and green leafhopper, *N. virescens* under field conditions.

Effect of silicon application on incidence of *S. incertulas*

Deadhearts

All the four doses (500, 1000, 1500 and 2000 kg/ha) of SA of calcium silicate were effective in reducing deadhearts due to *S. incertulas* in rice, whereas potassium silicate applied as foliar spray (at 0.5, 1.0 and 2.0 %) was not effective. The most effective treatment was SA of calcium silicate @ 2000 kg/ha and it was at par with calcium silicate @ 1500 kg/ha. All three concentrations (0.5 to 2.0 %) of potassium silicate were at par with control.

White earheads

SA of calcium silicate @ 500 to 2000 kg/ha and FA of potassium silicate @ 2.0 per cent were found effective in reducing the white earheads due to *S. incertulas* in rice. Calcium silicate @ 2000 kg/ha was found to be the most effective treatment against *S. incertulas* and it was at par with calcium silicate @ 1500 kg/ha. Potassium silicate at 0.5 and 1.0 per cent concentration was not effective as both concentrations were at par with control.

Effect of silicon application on leaf damage due to *C. medinalis*

SA of calcium silicate (500 to 2000 kg/ha) and FA of potassium silicate @ 2.0 per cent was effective, whereas potassium silicate @ 0.5 and 1.0 per cent failed to give protection against *C. medinalis*. SA of calcium silicate @ 2000 kg/ha was found to be most effective and it remained at par with calcium silicate @ 1500 kg/ha.

Effect of silicon application on population of *S. furcifera*

All the four doses (500, 1000, 1500 and 2000 kg/ha) of calcium silicate applied at the time of transplanting in soil reduced the population of *S. furcifera*, whereas potassium silicate applied as foliar spray at three different concentration (0.5 to 2.0 %) at 30, 45 and 60 DAT could not effectively control *S. furcifera*. SA of calcium silicate @ 2000 kg/ha was the most effective treatment and it was at par with calcium silicate @ 1500 kg/ha.

Effect of silicon application on population of *N. virescens*

SA of calcium silicate @ 2000 kg/ha was found significantly superior to remaining doses of calcium silicate and FA of potassium silicate in suppressing the *N. virescens* in rice. The next effective doses of calcium silicate were 1500 and 1000 kg/ha. FA of potassium silicate @ 0.5 and 1.0 per cent failed to check the incidence of *N. virescens* in rice.

Effect of silicon application on yield of rice

Grain yield

All four doses (500 to 2000 kg/ha) of calcium silicate enhanced grain yield of rice. The highest (5015 kg/ha) grain yield of rice was obtained in the treatment of calcium silicate @ 2000 kg/ha and it was at par with calcium silicate @ 1500 kg/ha (4922 kg/ha) and 1000 kg/ha (4820 kg/ha). All the three concentrations (0.5, 1.0 and 2.0 %) of potassium silicate failed to check incidence of insect pests which was reflected in the grain yield.

Straw yield

All four doses of calcium silicate increased straw yield of rice. Calcium silicate @ 2000 kg/ha yielded 5690 kg straw/ha and it was at par calcium silicate @ 1500 (5514 kg/ha), 1000 (5423 kg/ha) and 500 (5211 kg/ha). All three concentrations of potassium silicate (0.5, 1.0 and 2.0 %) produced the rice straw between 4622 and 4803 kg/ha and they were at par with control (4533 kg/ha).

5.2 EFFECT OF SILICON APPLICATION ON CHEMICAL AND BIOCHEMICAL CONSTITUENTS OF RICE PLANTS

Effect of silicon application on chemical constituents of rice plants

Under field conditions, nitrogen, sodium, iron and manganese content in rice plant decreased with increase in the dose of SA of calcium silicate, whereas phosphorus, potassium, calcium and magnesium content increased with increase in the dose of SA of calcium silicate. Concentration of all these nutrient elements was not affected by all the three concentrations (0.5, 1.0 and 2.0 %) of potassium silicate tested. Sulphur, zinc and copper content in plant was not affected by silicon application in the form either calcium silicate or potassium silicate.

Plant silica content showed significantly negative correlation with nitrogen, sodium, iron and manganese content, while it showed significantly positive correlation with phosphorus, potassium and calcium content. The correlation coefficient of silica content with sulphur, zinc and copper was non-significant.

Silica, phosphorus, potassium and calcium content in plant showed significantly negative correlation with white earheads due to *S. incertulas,* leaf damage due to *C. medinalis* and population of *S. furcifera* in rice. Nitrogen content was significantly positively correlated with white earheads due to *S. incertulas,* leaf damage due to *C. medinalis* and population of *S. furcifera* in rice. The correlation coefficient between sulphur content and incidence of *S. incertulas, C. medinalis* as well as *S. furcifera* was non-significant.

Effect of silicon application on biochemical constituents of rice plants

There was increase in total phenol content of rice plant with increase in the dose of SA calcium silicate, whereas total sugar, crude protein and free amino acid content decreased with increase in the dose of SA of calcium silicate. FA of potassium silicate did not affect the biochemical constituents, except phenol.

The correlation coefficient between plant silica and phenol content was significantly positive, while the correlation coefficients between silica and total sugar, crude protein as well as free amino acid content were significantly positive. Plant phenol content was significantly negatively correlated with white earheads due to *S. incertulas,* leaf damage due to *C. medinalis* and population of *S. furcifera* in rice. On the contrary, total sugar, crude protein and amino acid were significantly positively correlated with incidence of *S. incertulas, C. medinalis* and *S. furcifera.*

5.3 EFFECT OF SILICON APPLICATION ON NATURAL ENEMIES OF RICE INSECT PESTS

Effect of silicon application on spider population in rice

Application of silicon in the form of either calcium silicate or potassium silicate did not affect the activity of spider in the rice crop ecosystem.

Effect of silicon application on parasitism by egg parasitoids of *S. incertulas*

Soil as well as foliar application of silicon to rice plants did not affect the parasitism of *S. incertulas* eggs by two hymenopteran egg parasitoids *viz.*, *T. schoenobii* and *T. dignus*.

5.4 EFFECT OF SILICON APPLICATION ON OVIPOSITION PREFERENCE AND ITS ANTIBIOSIS EFFECT ON *S. incertulas*

Effect of silicon application on oviposition preference of *S. incertulas*

In free-choice preference test, *S. incertulas* females laid more or less equal number of egg masses and eggs on silicon applied (1 g/kg soil) and non-applied plants, indicating that the silicon application to rice plant did not affect the egg laying preference of *S. incertulas* females in free-choice.

Antibiosis effect of silicon application on *S. incertulas*

Larval period and duration of individual instars of *S. incertulas* was significantly higher when larvae were fed with rice stems from silicon applied (1 g/kg soil) plants (Si+) compared with rice stems from control plants (Si-). The body weight of second, third, fourth and fifth instar larva was significantly lower when they were fed with rice stems from Si+ plants compared to rice stems from Si- plants. The weight of first instar larva was not affected by silicon application.

The duration of pre-pupa was not affected by the type of food received by the larvae, while pupal period was significantly longer when larvae received Si+ stems as food as compared to Si- stems. There was significant reduction in pupal weight when larvae of *S. incertulas* were fed with Si+ stems as compared to Si- stems.

The pre-oviposition, oviposition and post-oviposition period of female adults fed with Si+ stems during larval stage was at par with that of females fed with Si- stems during larval stage. In contrast to this, the longevity of females that received Si+ stem during larval stage as food was significantly shorter than the females that received Si- stem during larval stage as food. The male longevity was not affected by the type of food received during the larval stage.

The difference between number of egg masses laid by a female fed with Si+ and Si- stems during larval stage was non-significant. In contrast to this, Si+ females laid significantly lesser number of egg than Si- females. The mean hatching percentage of eggs laid by Si+ female was at par with eggs laid by Si- females.

The sex ratio (male : female) of adults that received Si+ stems during larval stage was 1 : 1.60, whereas for Si- treatment it was 1 : 1.80.

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Appendix 1 : Weather data recorded during the period of experimentation

Std. week	Temperature (˚C)				Relative Humidity (%)				Rain-fall (mm)		Rainy days		Sunshine hours	
	2011		2012		2011		2012							
	Min.	**Max.**	**Min.**	**Max.**	**RH_1**	**RH_2**	**RH_1**	**RH_2**	**2011**	**2012**	**2011**	**2012**	**2011**	**2012**
27	25.5	34.4	25.6	32.8	83	52	88	76	0.0	41.5	0	2	8.7	6.3
28	25.3	29.6	24.7	32.1	59	74	91	74	183.0	137.0	2	2	6.5	5.3
29	26.0	31.7	25.9	33.4	84	67	93	76	2.0	52.0	0	2	8.4	4.8
30	25.8	32.1	24.9	30.1	86	68	93	79	66.0	0.0	1	0	8.4	6.7
31	25.8	31.2	24.6	31.6	86	71	92	84	12.0	6.0	2	1	8.3	3.9
32	25.0	28.4	24.3	30.8	87	78	94	89	208.0	76.5	5	4	3.4	3.4
33	24.9	29.7	23.3	30.5	87	76	97	93	181.0	147.0	5	2	7.5	2.9
34	24.7	30.4	23.1	30.5	87	75	96	90	57.0	27.0	3	1	6.9	3.0
35	24.7	31.1	24.1	31.3	88	73	95	82	90.0	38.0	5	1	7.3	3.1
36	25.2	30.5	24.4	29.7	87	73	96	82	24.0	187.0	3	5	7.1	2.3
37	24.9	30.1	24.8	31.1	87	73	93	72	52.0	40.0	3	2	8.1	3.7
38	24.0	30.5	23.9	32.1	87	65	81	64	17.0	0.0	1	0	9.5	6.8
39	23.3	31.8	24.3	32.3	87	59	79	63	0.0	0.0	0	0	10.0	8.1
40	21.0	33.5	22.8	31.8	87	48	82	54	0.0	0.0	0	0	10.2	8.1
41	21.2	36.1	21.9	30.7	86	38	81	47	0.0	0.0	0	0	9.6	9.3
42	19.6	35.4	18.4	30.1	85	36	83	35	0.0	0.0	0	0	9.9	9.2
43	16.6	34.5	16.0	30.0	85	31	71	33	0.0	0.0	0	0	9.6	8.9
44	17.4	33.2	16.5	30.0	84	35	76	51	0.0	0.0	0	0	9.3	8.6
45	17.2	33.7	16.1	29.0	85	34	83	67	0.0	0.0	0	0	9.4	8.3
46	16.5	33.5	17.0	29.8	67	31	79	62	0.0	0.0	0	0	8.9	8.9
47	20.7	33.4	16.1	28.7	85	46	85	68	0.0	0.0	0	0	7.4	9.2
Total	-	-	-	-	-	-	-	-	**892**	**752**	**30**	**22**	-	-

C E R T I F I C A T E

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Place : ANAND **(S. D. Patel)**
Date : /01/2016

Plate 1 : General view of experimental plot

Plate 2 : Egg masses of *S. incertulas* kept for emergence of parasitoids

Plate 3 : Infesting rice plant with freshly hatched larvae of *S. incertulas*

Plate 4 : Mass culture of *S. incertulas*

Plate 5 : Technique used for rearing of *S. incertulas*

Plate 6 : Female of *S. incertulas* and glass chimney used for egg laying

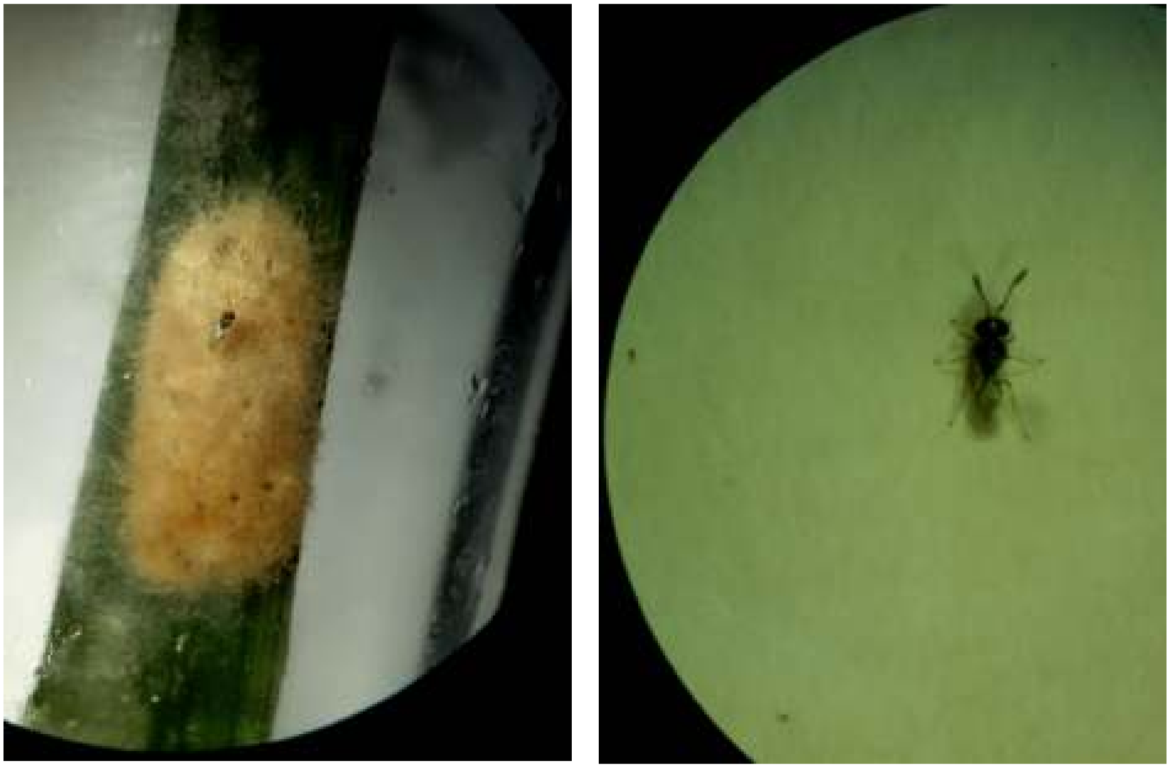

Plate 7 : Egg parasitoid,*T. dignus*

Plate 8 : Effect of silicon on growth of 4th instar larva of *S. incertulas*

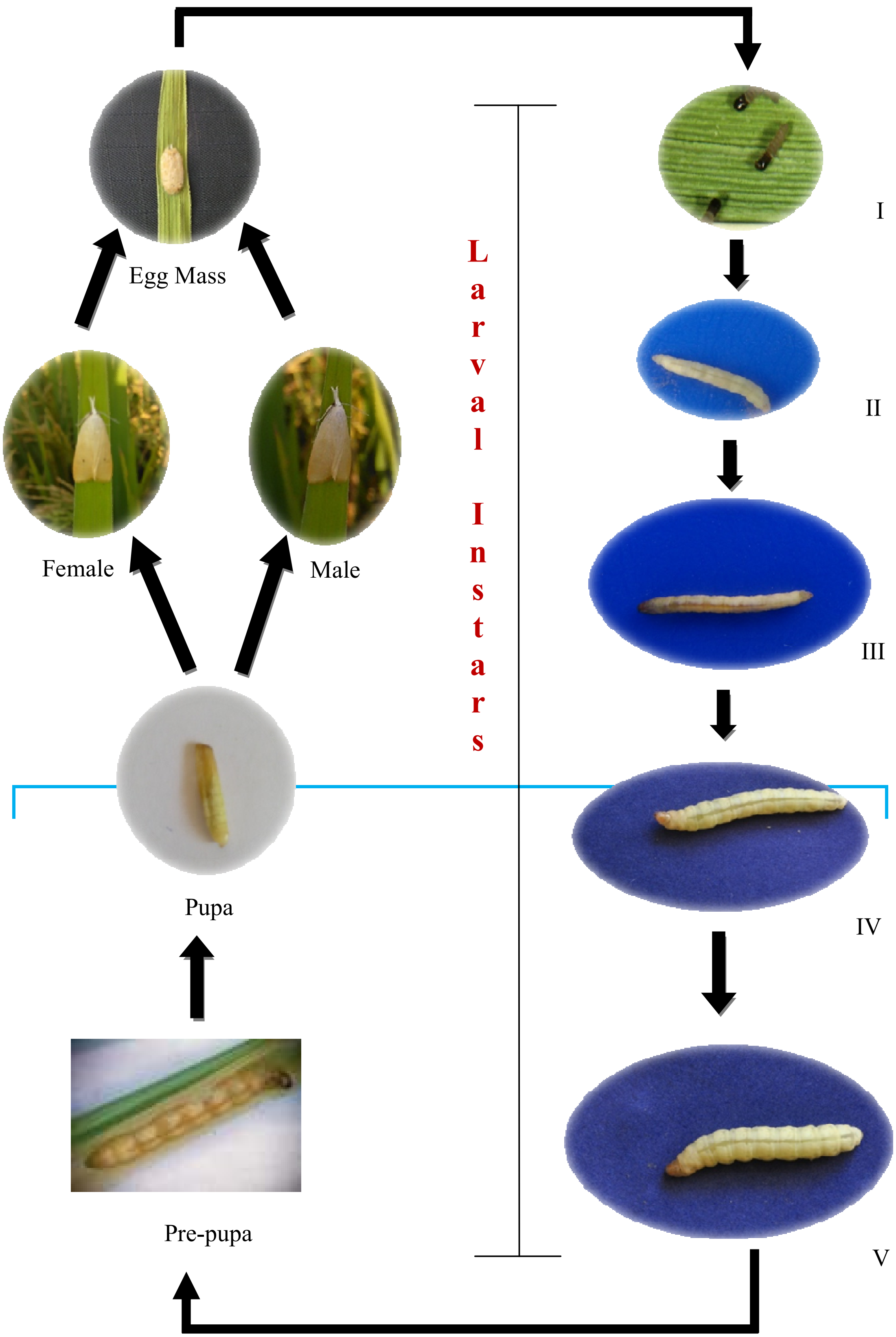

Plate 9 : Different stages of *S. incertulas*

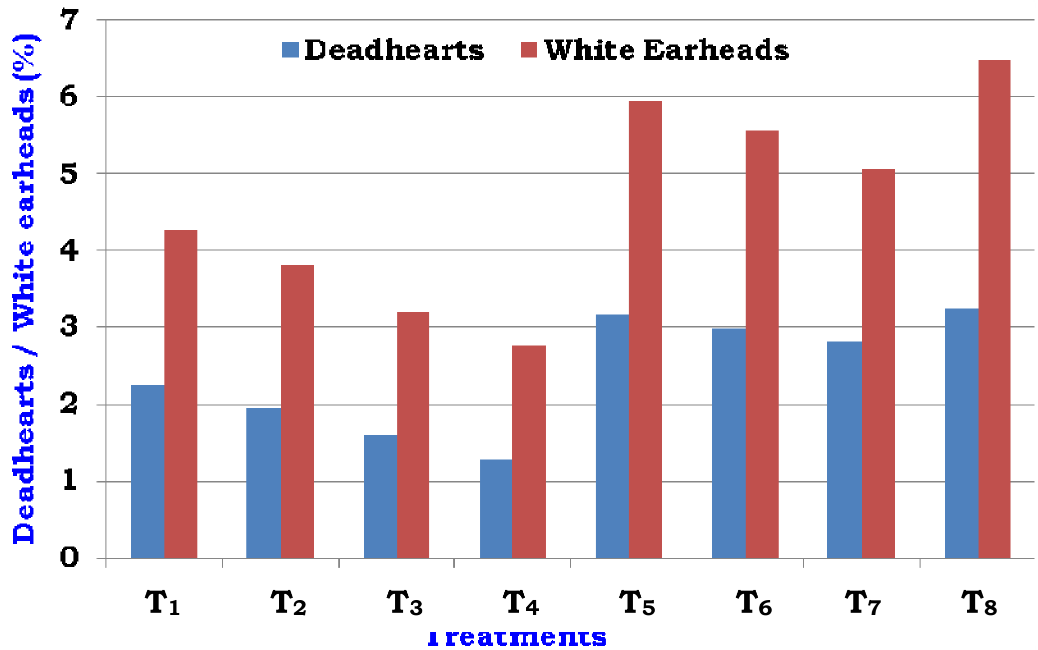

Fig. 1 : Effect of silicon application on incidence of *S. incertulas* in rice (Pooled over years)

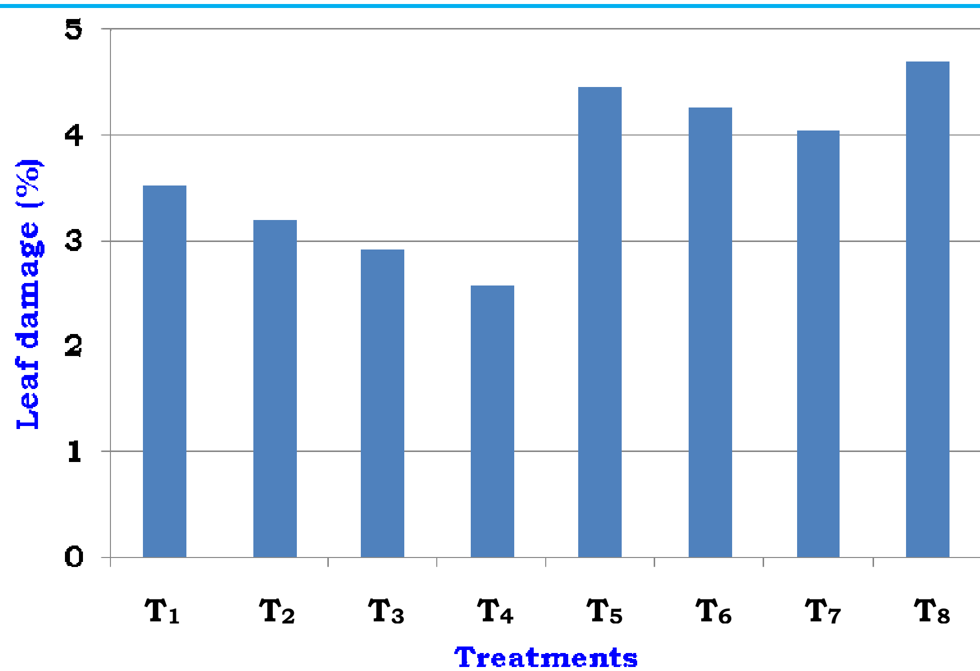

Fig. 2 : Effect of silicon application on leaf damage due to *C. medinalis* in rice

T_1 : SA of $CaSiO_3$ @ 500 kg/ha at TP
T_2 : SA of $CaSiO_3$ @ 1000 kg/ha at TP
T_3 : SA of $CaSiO_3$ @ 1500 kg/ha at TP
T_4 : SA of $CaSiO_3$ @ 2000 kg/ha at TP
T_5 : FA of K_2SiO_3 0.5 % at 30, 45 and 60 DAT
T_6 : FA of K_2SiO_3 1.0 % at 30, 45 and 60 DAT
T_7 : FA of K_2SiO_3 2.0 % at 30, 45 and 60 DAT
T_8 : Control

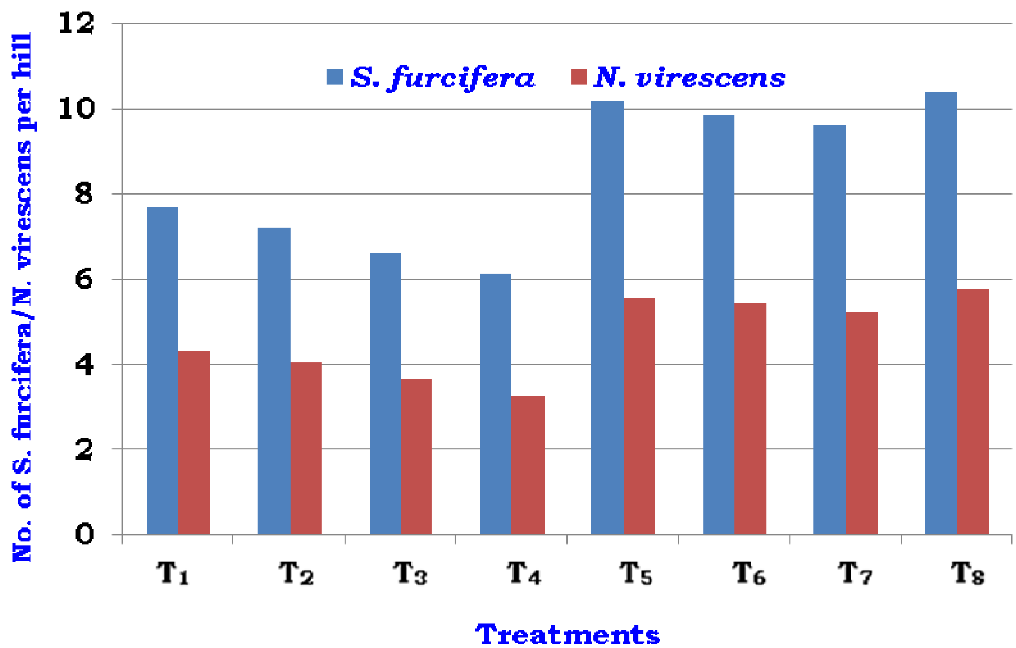

Fig. 3 : Effect of silicon application on population of *S. furcifera* and *N. virescens* in rice (Pooled over years)

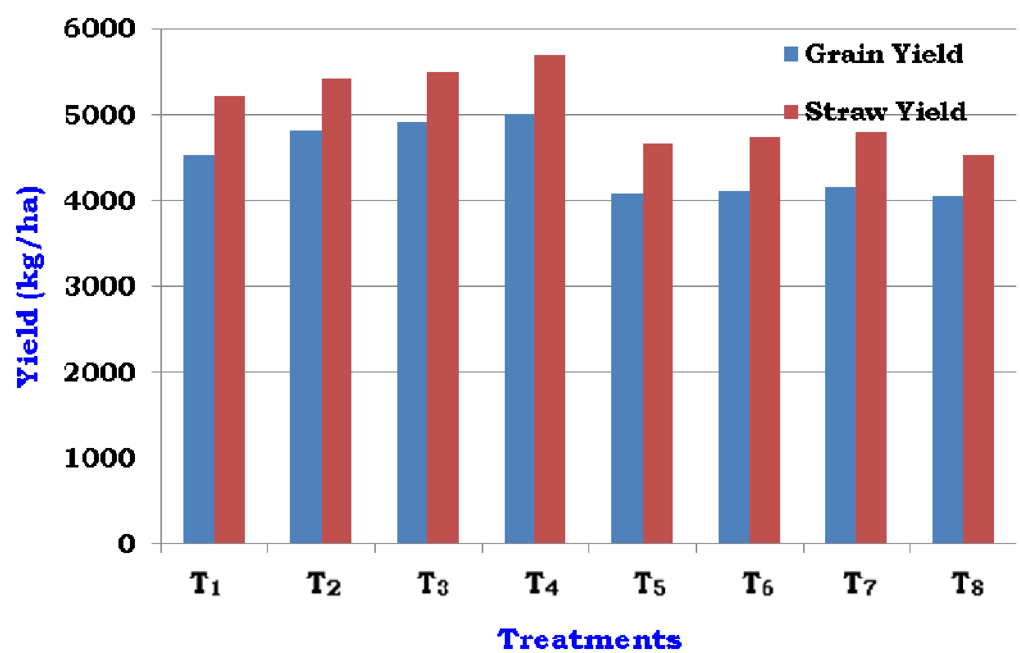

Fig. 4 : Effect of silicon application on yield of rice

T_1 : SA of $CaSiO_3$ @ 500 kg/ha at TP
T_2 : SA of $CaSiO_3$ @ 1000 kg/ha at TP
T_3 : SA of $CaSiO_3$ @ 1500 kg/ha at TP
T_4 : SA of $CaSiO_3$ @ 2000 kg/ha at TP
T_5 : FA of K_2SiO_3 0.5 % at 30, 45 and 60 DAT
T_6 : FA of K_2SiO_3 1.0 % at 30, 45 and 60 DAT
T_7 : FA of K_2SiO_3 2.0 % at 30, 45 and 60 DAT
T_8 : Control

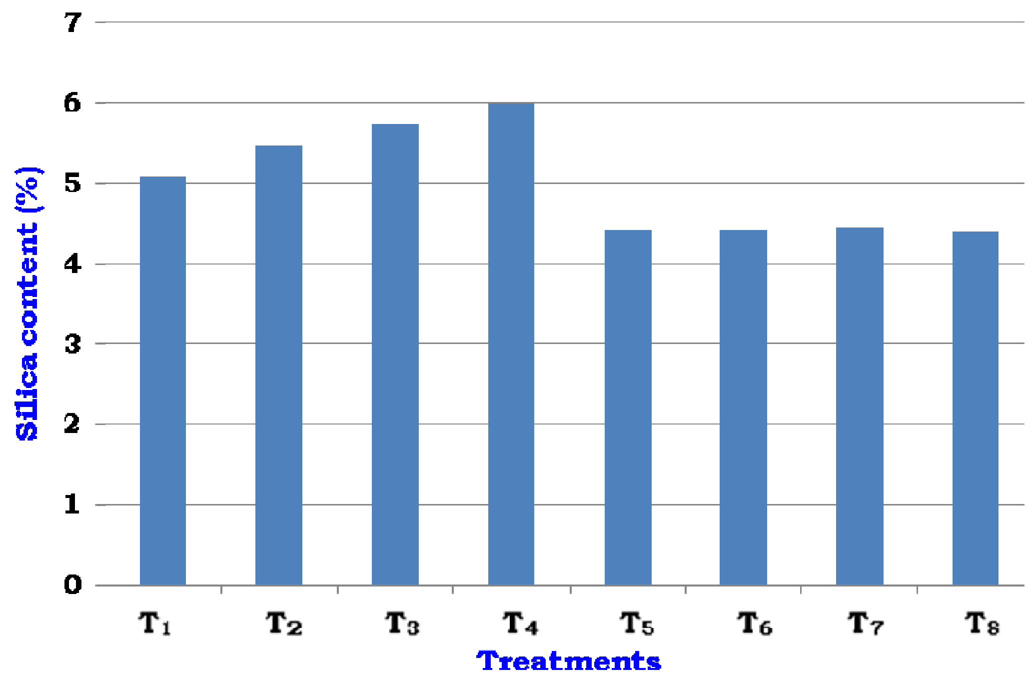

Fig. 5 : Effect of silicon application on silica content of rice plants (Pooled over periods)

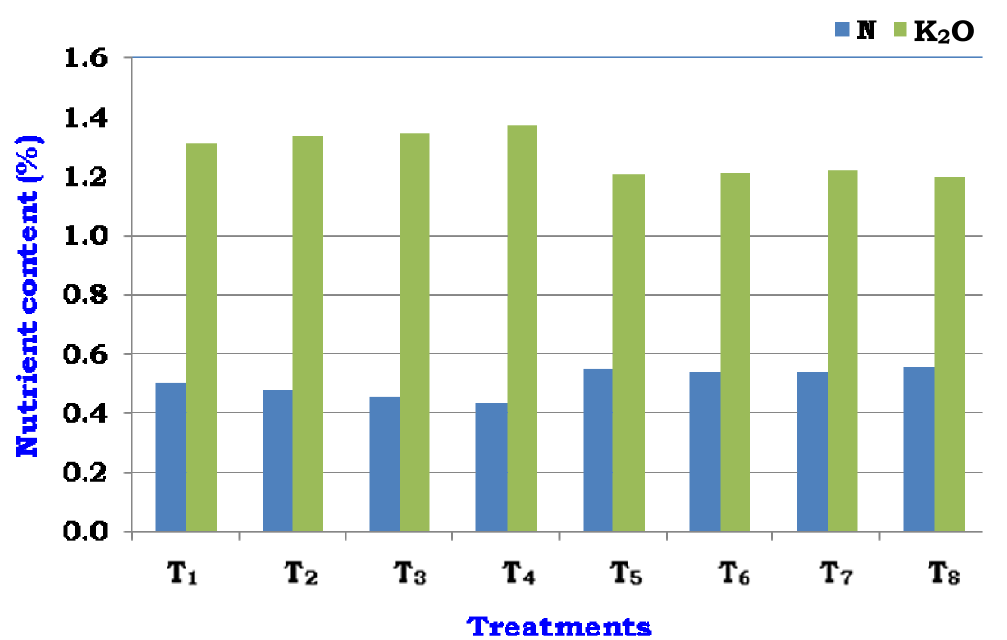

Fig. 6 : Effect of silicon application on nitrogen and potassium content of rice plants

T_1 : SA of $CaSiO_3$ @ 500 kg/ha at TP
T_2 : SA of $CaSiO_3$ @ 1000 kg/ha at TP
T_3 : SA of $CaSiO_3$ @ 1500 kg/ha at TP
T_4 : SA of $CaSiO_3$ @ 2000 kg/ha at TP
T_5 : FA of K_2SiO_3 0.5 % at 30, 45 and 60 DAT
T_6 : FA of K_2SiO_3 1.0 % at 30, 45 and 60 DAT
T_7 : FA of K_2SiO_3 2.0 % at 30, 45 and 60 DAT
T_8 : Control

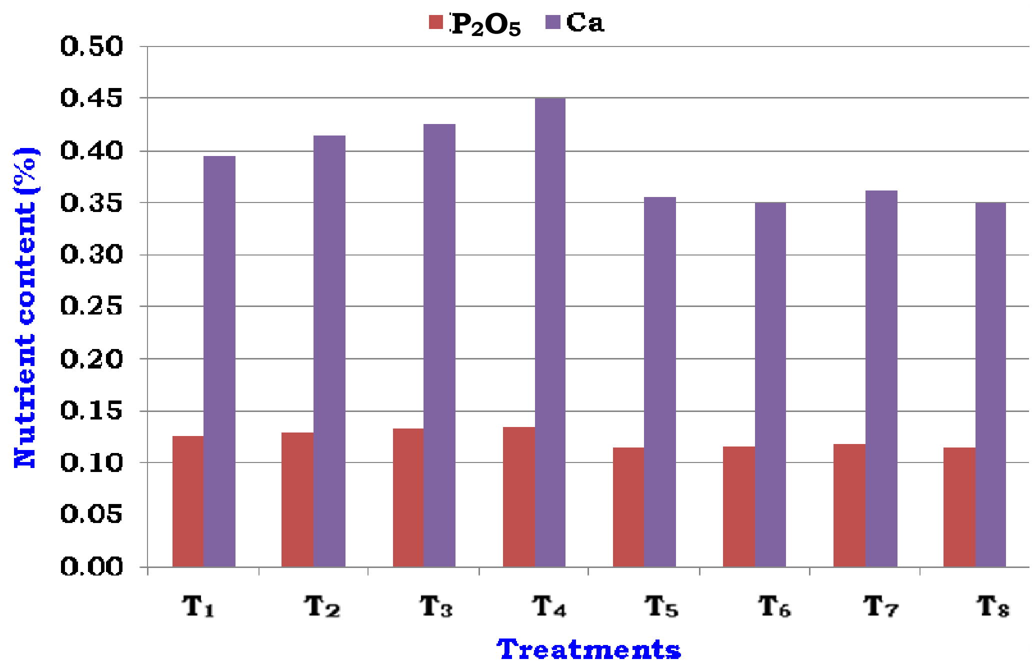

Fig. 7 : Effect of silicon application on phosphorus and calcium content of rice plants

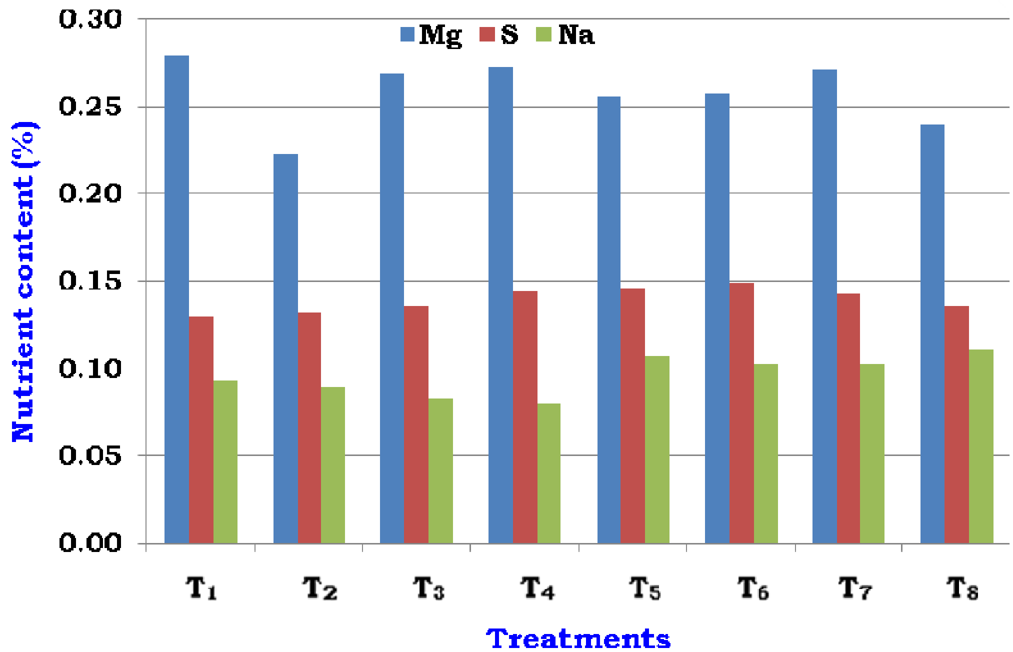

Fig. 8 : Effect of silicon application on magnesium, sulphur and sodium content of rice plants

T_1 : SA of $CaSiO_3$ @ 500 kg/ha at TP
T_2 : SA of $CaSiO_3$ @ 1000 kg/ha at TP
T_3 : SA of $CaSiO_3$ @ 1500 kg/ha at TP
T_4 : SA of $CaSiO_3$ @ 2000 kg/ha at TP
T_5 : FA of K_2SiO_3 0.5 % at 30, 45 and 60 DAT
T_6 : FA of K_2SiO_3 1.0 % at 30, 45 and 60 DAT
T_7 : FA of K_2SiO_3 2.0 % at 30, 45 and 60 DAT
T_8 : Control

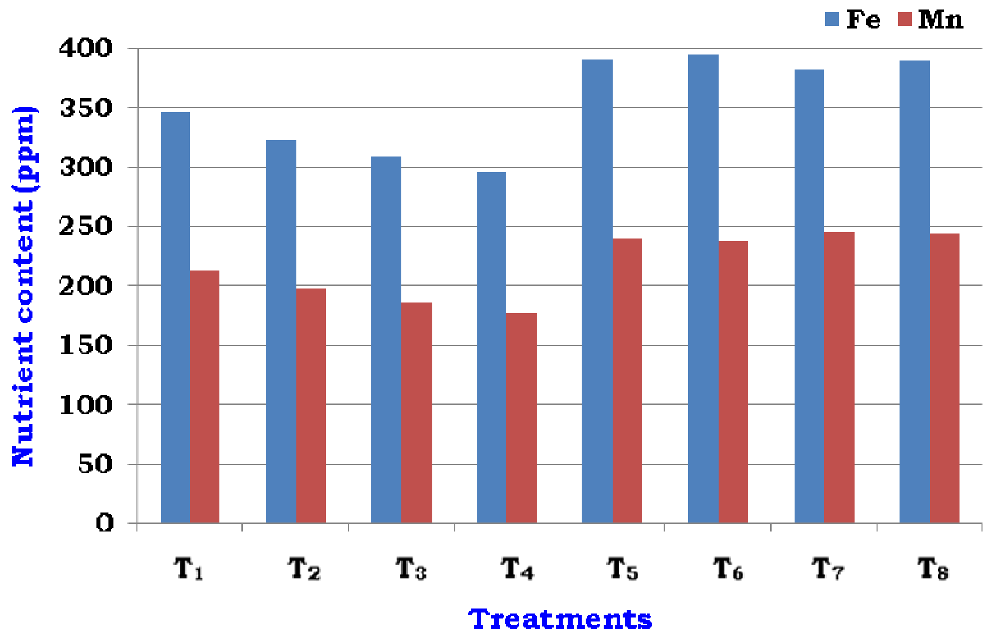

Fig. 9 : Effect of silicon application on iron and manganese content of rice plants

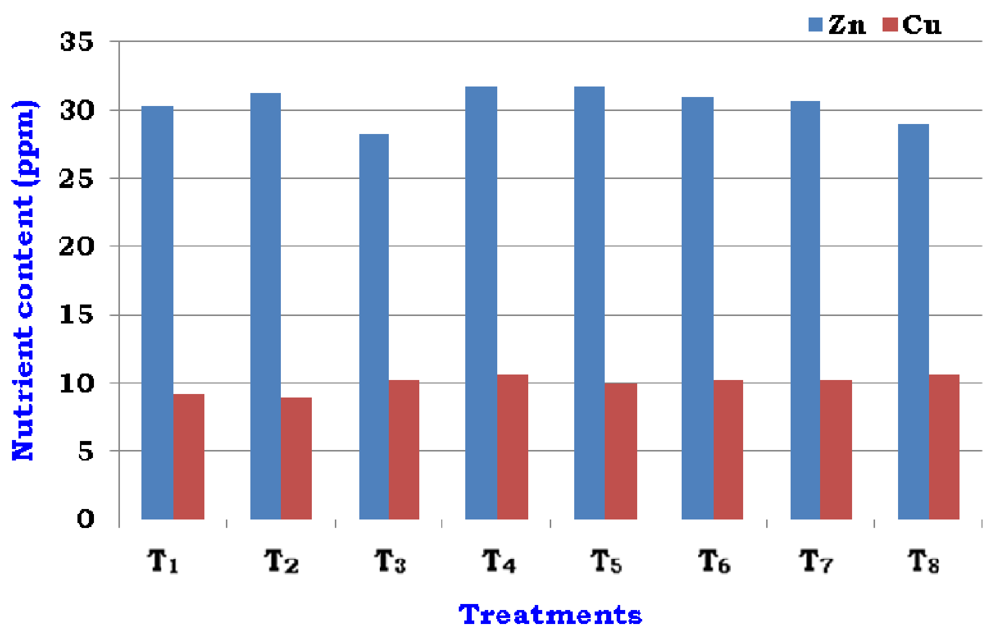

Fig. 10 : Effect of silicon application on zinc and copper content of rice plants

T_1 : SA of $CaSiO_3$ @ 500 kg/ha at TP
T_2 : SA of $CaSiO_3$ @ 1000 kg/ha at TP
T_3 : SA of $CaSiO_3$ @ 1500 kg/ha at TP
T_4 : SA of $CaSiO_3$ @ 2000 kg/ha at TP
T_5 : FA of K_2SiO_3 0.5 % at 30, 45 and 60 DAT
T_6 : FA of K_2SiO_3 1.0 % at 30, 45 and 60 DAT
T_7 : FA of K_2SiO_3 2.0 % at 30, 45 and 60 DAT
T_8 : FA of Control

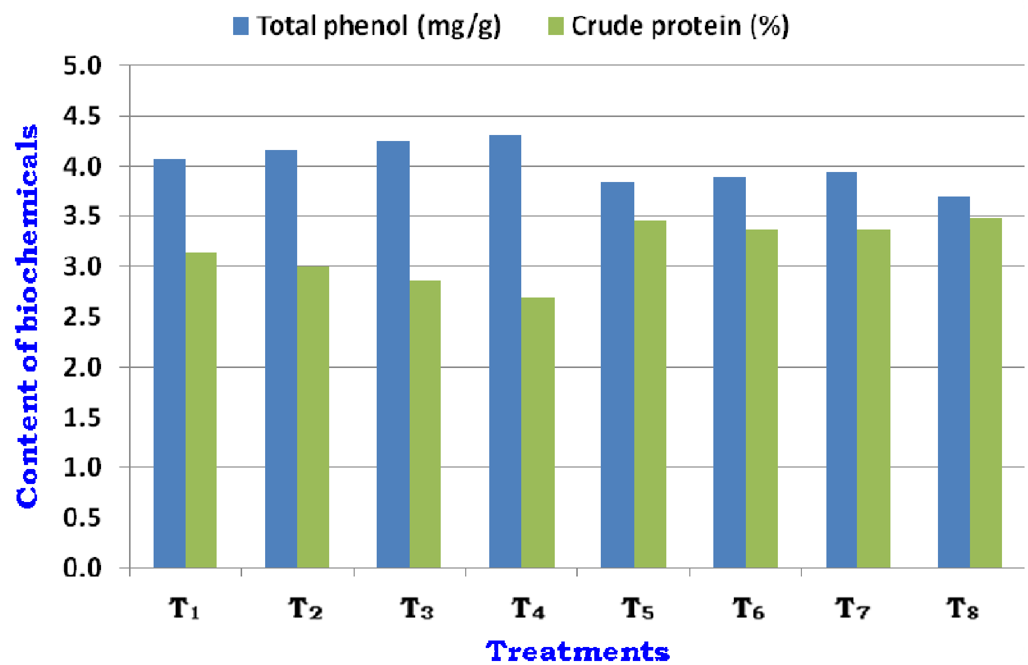

Fig. 11 : Effect of silicon application on total phenol and crude protein of rice plants

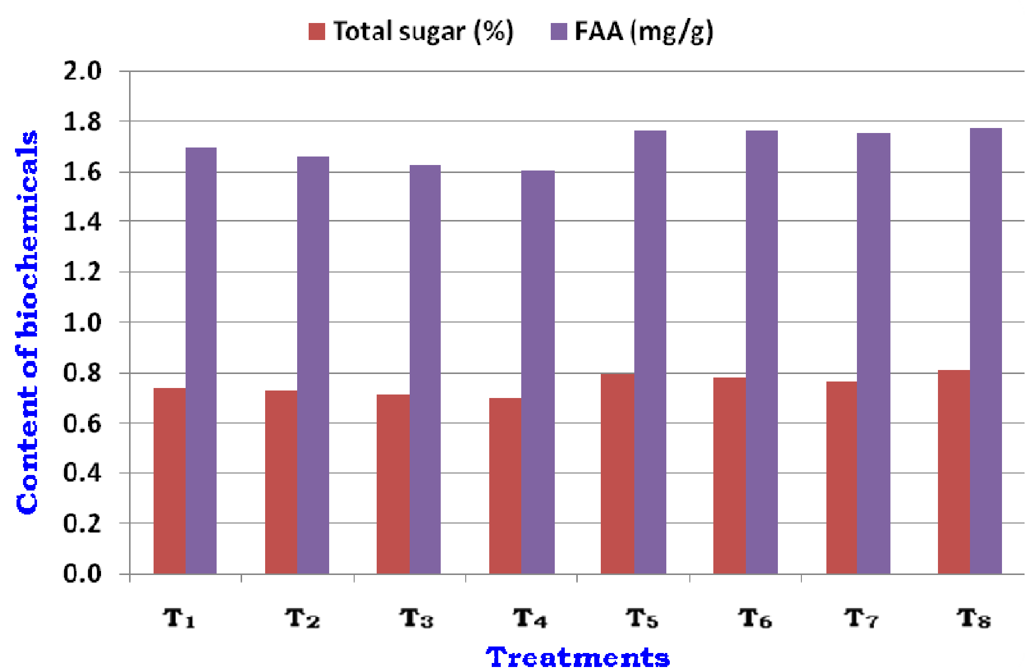

Fig. 12 : Effect of silicon application on total sugar and free amino acid (FAA) content of rice plants

T_1 : SA of $CaSiO_3$ @ 500 kg/ha at TP
T_2 : SA of $CaSiO_3$ @ 1000 kg/ha at TP
T_3 : SA of $CaSiO_3$ @ 1500 kg/ha at TP
T_4 : SA of $CaSiO_3$ @ 2000 kg/ha at TP
T_5 : FA of K_2SiO_3 0.5 % at 30, 45 and 60 DAT
T_6 : FA of K_2SiO_3 1.0 % at 30, 45 and 60 DAT
T_7 : FA of K_2SiO_3 2.0 % at 30, 45 and 60 DAT
T_8 : Control

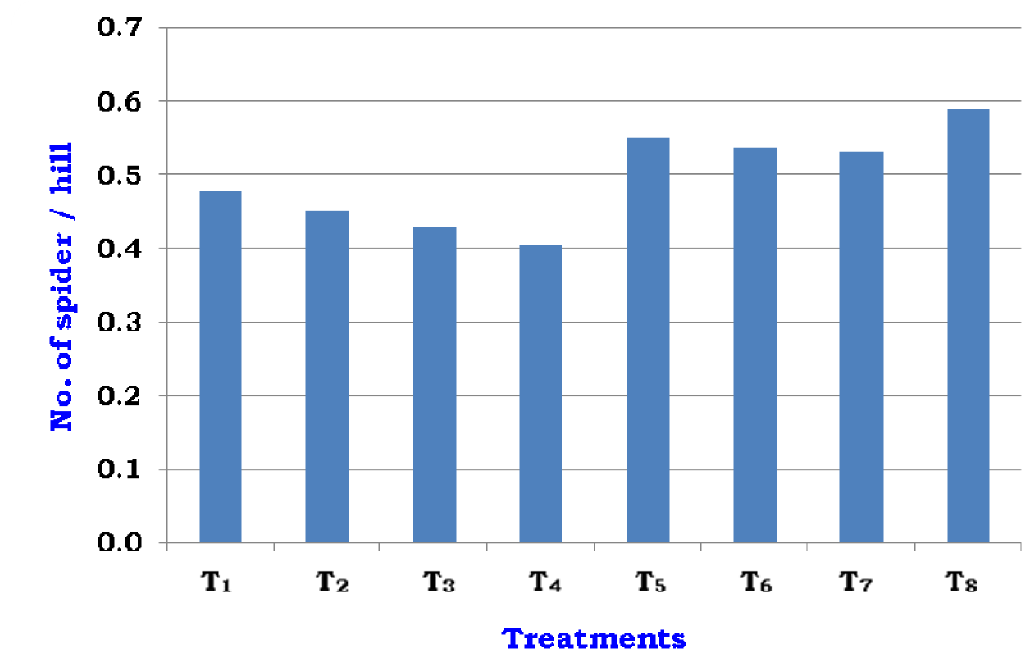

Fig. 13 : Effect of silicon application on spider population

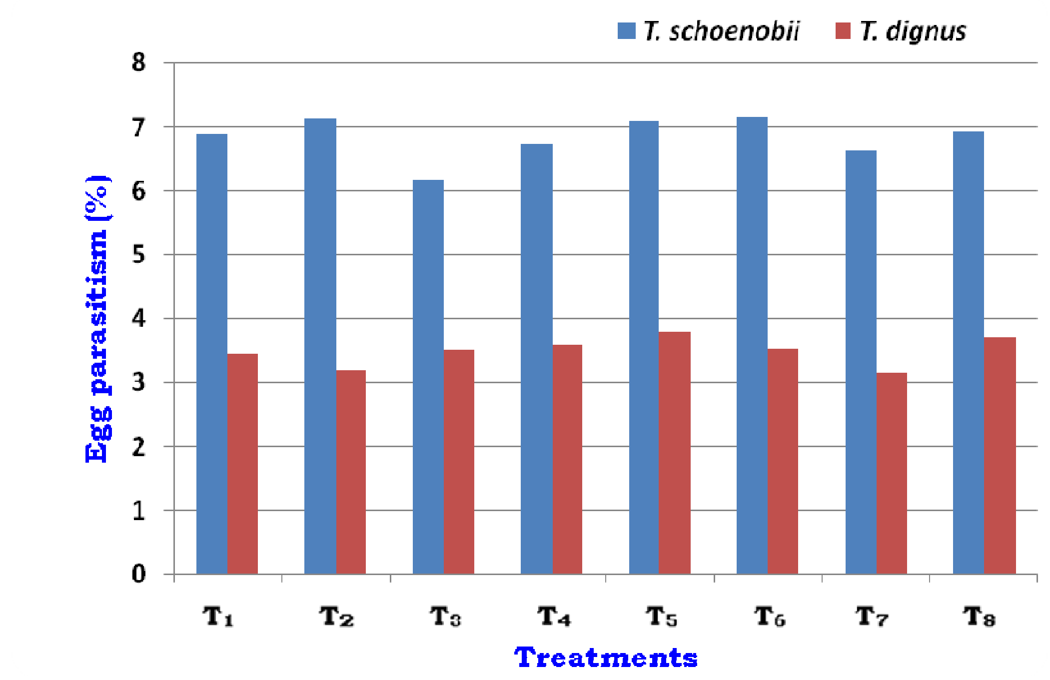

Fig. 14 : Effect of silicon application on parasitism of eggs of *S. incertulas* by *T. schoenobii* and *T. dignus*

T_1 : SA of $CaSiO_3$ @ 500 kg/ha at TP
T_2 : SA of $CaSiO_3$ @ 1000 kg/ha at TP
T_3 : SA of $CaSiO_3$ @ 1500 kg/ha at TP
T_4 : SA of $CaSiO_3$ @ 2000 kg/ha at TP
T_5 : FA of K_2SiO_3 0.5 % at 30, 45 and 60 DAT
T_6 : FA of K_2SiO_3 1.0 % at 30, 45 and 60 DAT
T_7 : FA of K_2SiO_3 2.0 % at 30, 45 and 60 DAT
T_8 : Control