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RESEARCH

Effect of Silicon and Biostimulant on Fall Armyworm Infestation in Maize (*Zea mays* L.)

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Abstract

In the Virudhunagar district's Thoppur village from *rabi* 2021–22, a field trial was carried out to examine the impact of silicon sources and growth regulator on the harm caused by maize fall armyworm (*Spodoptera frugiperda*). Basal soil application of calcium silicate at six different doses and foliar applications of silicic acid, gibberellic acid and potassium silicate in maize crop revealed that basal application of 150 kg of calcium silicate/ha + 0.2% silicic acid @ 15 DAS + 50 ppm GA @ 30 DAS was found to be effective in reducing leaf damage (42.88% per plant), whorl damage (36.05% per plot) and cob damage (26.92% per plot), followed by treatment with 75 kg of calcium silicate/ha + 0.2% silicic acid @ 15 DAS + 50 ppm GA @ 30 DAS with leaf, whorl and cob damage of 44.74% per plant, 39.24% per plot and 26.92% per plot respectively. The treatment with a basal application of 150 kg of calcium silicate/ha + 0.2% SA @ 15 DAS + 50 ppm GA @ 30 DAS produced the highest yield (7, 287 kg/ha), which was followed by the treatment with 75 kg of calcium silicate + 0.2% SA @ 15 DAS + 50 ppm GA @ 30 DAS (7, 092 kg/ha). As a result, in the current research, the basal application of calcium silicate 150 kg/ha along with foliar application of silicic acid (0.2%) and gibberellic acid (50 ppm) at 15 and 30 DAS decreased the level of leaf, whorl, and cob damage caused by fall armyworm on maize at the field condition.

Keywords Cob damage · GA · Leaf · *Spodoptera frugiperda* · Silicon · SA and Whorl

1 Introduction

The most significant cereal commodity is maize (*Zea mays* L.), which is grown on 180.63 million ha of land in 165 different nations and produces 1.134 million tonnes [1]. Since its discovery in May 2018, the fall armyworm, *Spodoptera frugiperda* (J. E. Smith), has become the most destructive pest of corn in India. In the absence of control methods, fall armyworm is expected to reduce annual maize production by 21 to 53% [2]. Farmers exclusively use synthetic insecticides, which exacerbates issues with residue, resistance, and resurgence. For its management, a variety of environmentally friendly management strategies must be created. Induced host plant resistance is one strategy that might be used in India to control fall armyworms.

By properly managing the crop's nutrient needs and modifying with the availability of mineral nutrients like silicon, insect pest harm can be decreased. Through three previously described mechanisms-biophysical, biochemical, and herbivore-induced plant volatiles (HIPVs)-silicon imparts induced resistance to herbivores [3]. Due to the accumulation of silica as opaline phytoliths in many tissues, it has been found that plant tissue is less digestible and is becoming harder and rougher [4]. The trichome undergoes changes as part of the Si-induced defence system [5]. Si accumulates in plant cell walls, activating the intrinsic chemical defences of the plant, including volatile and non-volatile chemicals as well as other physical structures like trichomes, which

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provide protection by increasing the production of lignin and phenolic compounds were reviewed by Murali Baskaran et al. [6].

Through correct crop nutrition control and modification with the availability of mineral nutrients like silicon, insect pest damage can be decreased. Three described mechanisms, namely biophysical, biochemical, and herbivore-induced plant volatiles (HIPVs), explain how silicon imparts induced resistance to herbivores [3]. Because silica has been deposited in many tissues as opaline phytoliths, it has been found that plant tissue is less digestible and is becoming harder and rougher [4]. Alterations in the trichome are another component of the Si-induced defence system [5].

2 Material and Methods

Microplot field experiment was conducted at Thoppur village, Kariyapatti block, Viruthunagar district. To evaluate the effects of foliar application of silicon fertilizers and growth regulators on Fall Army Worm. The experiment was laid out in Randomized block design with three replications and sixteen (16) treatment combinations with spacing of 60 × 25 cm and plot size of 60 m^2. The treatments comprised of T_1- Soil application of calcium silicate @ 150 kg/ ha, T_2- Soil application of calcium silicate @ 300 kg/ ha, T_3- ½ dose of T_1 + 0.2% silicic acid (SA) @ 15 DAS + 50 ppm gibberellic acid (GA_3) @ 30 DAS, T_4- ½ dose of T_2 + 0.2% SA @ 15 DAS + 50 ppm GA @ 30 DAS, T_5- ¼ dose of T_1 + 0.4% SA @ 15 DAS + 100 ppm GA @ 30 DAS, T_6- ¼ dose of T_2 + 0.4% SA @ 15 DAS + 100 ppm GA @ 30 DAS, T_7- ½ dose of T_1 + 0.5% potassium silicate @ 15 and 30 DAS, T_8- ½ dose of T_2 + 1% potassium silicate @ 15 and 30 DAS, T_9- ¼ dose of T_1 + 0.5% potassium silicate @ 15 & 30 DAS, T_{10}-¼ dose of T_2 + 1% potassium silicate @ 15 & 30 DAS, T_{11}-Foliar spray 0.2% SA @ 15 and 45 DAS + 50 ppm GA @ 30 and 60 DAS, T_{12}- Foliar spray 0.4% SA @ 15 and 45 DAS + 100 ppm GA @ 30 and 60 DAS, T_{13}- Foliar spray 0.5% potassium silicate @ 15, 30, 45 and 60 DAS, T_{14}- Foliar spray 1% potassium silicate @ 15, 30, 45 and 60 DAS, T_{15}- Standard check (Neem cake 250 kg/ha and need based application of insecticide) and T_{16}- Untreated check. Foliar spray was done at 15, 30, 45 and 60 days after sowing. All foliar sprays were applied by a 10 L volume knapsack sprayer. Foliar application of silicic acid and potassium silicate was done at 15 and 30 DAS and gibberellic acid at 45 and 60 DAS. For the cultivation of maize, all of the agronomical practices recommended by the crop production guide were followed (CPG, 2021). In all plots except the untreated control, silicon nutrients were foliar sprayed at their respective doses. FAW leaf damage (%) = No. of FAW damaged leaves/total number of leaves × 100. Whorl damage (%) = No. of FAW larva damaged whorl/total no. of whorls × 100, Cob damage (%) = No. of FAW larva damaged cob/total no. of cobs × 100. The count was taken from ten randomly selected plants per treatments in each plot.

2.1 Statistical Analysis

The statistical analysis of the field trial data were tabulated and analysis conducted. In order to determine the most effective treatments, the data on leaf, whorl, and cob damage were transformed using the arcsine and yield data using the square root methods. Means were compared using the Tukey's test at $p < 0.05$ [7]. A software, SPSS (version 22) (IBM Corp Released in 2013) was used for all kinds of statistical analyses.

3 Results

3.1 Impact of Silicon and Growth Regulator on Leaf Damage by Fall Armyworm in Maize

The mean leaf damage after the first spray (15 DAS) varied between the interventions by 37.30 and 62.26%. With a minimum mean leaf damage of 37.3%, it was discovered that the treatment with a basal application of 150 kg of calcium silicate/ha + 0.2% SA @ 15 DAS + 50 ppm GA @ 30 DAS (T_4) was significantly better than other treatments. It was followed by 75 kg of calcium silicate + 0.2% SA @ 15 DAS + 50 ppm GA @ 30 DAS (39.11/plant). The T_2 + 1% potassium silicate treatment at 15 and 30 DAS (T_{10}) (51.7%/ plant) was comparable to the T_1 + 0.5% potassium silicate treatment at 15 and 30 DAS (T9) (52.85%/plant).

The treatment with foliar spray of 0.4% SA @ 15 & 45 DAS + 100 ppm GA @ 30 & 60 DAS (T_{12}) (53.66% / plant) was on par with foliar spray of 0.2% SA @ 15 & 45 DAS + 50 ppm GA @ 30 & 60 DAS (T_{11}) (55.77%/plant). The treatment with foliar spray of 1% potassium silicate @ 15, 30, 45 & 60 DAS (T_{14}) (56.98% /plant) followed by foliar spray of 0.5% potassium silicate @ 15, 30, 45 & 60 DAS (T_{13}) (58.11 per cent/plant). Soil application of calcium silicate @ 300 kg/ ha (T_2) recorded mean leaf damage per cent of 53.10/plant followed by soil application of calcium silicate @ 150 kg/ ha (57.23% /plant). The mean leaf damage per cent recorded in untreated check (T_{16}) was 62.26 / plant (Table 1).

After second spray (30 DAS), the results revealed that the treatment ½ dose of T_2 + 0.2% SA @ 15 DAS + 50 ppm GA @ 30 DAS (T_4) was found to be effective in reducing leaf damage per cent/plant (42.88) as against (74.41% /plant) in the untreated check (T_{16}). After third spray (45 DAS), the treatment with ½ dose of T_2 + 0.2% SA @ 15 DAS + 50 ppm GA @ 30 DAS (T_4) was found to be most effective and significantly superior over all other treatments by recording

Table 1 Leaf damage caused by fall armyworm in maize, as influenced by different sources of Silicon and biostimulants

Treatments	Per cent leaf damage*												
		I Spray- Silicic acid / Potassium silicate (15 DAS)			II Spray- Gibberellic acid/ Potassium silicate (30 DAS)			III Spray-Silicic acid / Potassium silicate (45 DAS)			IV Spray-Gibberellic acid/ Potassium silicate (60 DAS)		
	PTC	4 DAS	8 DAS	Mean	4 DAS	8 DAS	Mean	4 DAS	8 DAS	Mean	4 DAS	8 DAS	Mean
T_1	55.1 ± 0.20 (47.93)^{a}	54.32 ± 1.32 (47.48)^{ef}	60.13 ± 1.63 (50.85)^{ijk}	57.23 ± 1.07 (58.01)^{h}	65.74 ± 0.65 (54.17)^{ij}	70.35 ± 2.60 (57.02)^{i}	68.05 ± 1.49 (55.58)^{j}	66.06 ± 1.31 (54.37)^{i}	63.12 ± 0.85 (52.61)^{jk}	59.27 ± 4.61 (50.36)^{hij}	51.42 ± 1.85 (45.81)^{gh}	48.13 ± 1.08 (43.93)^{f}	49.78 ± 1.06 (44.87)^{gh}
T_2	53.1 ± 0.67 (46.78)^{a}	52.12 ± 0.47 (46.22)^{de}	54.07 ± 0.68 (47.33)^{fgh}	53.10 ± 0.50 (51.76)^{fg}	60.42 ± 2.61 (51.02)^{gh}	58.78 ± 1.06 (50.06)^{fg}	59.60 ± 0.87 (50.54)^{fg}	55.94 ± 0.61 (48.41)^{fg}	52.1 ± 1.41 (46.20)^{g}	50.41 ± 2.26 (45.24)^{efg}	45.2 ± 45.20 (42.24)^{ef}	42.1 ± 0.04 (40.45)^{e}	43.65 ± 0.88 (41.35)^{ef}
T_3	54.14 ± 1.37 (47.38)^{a}	40.12 ± 1.05 (39.30)^{a}	38.09 ± 1.37 (38.11)^{ab}	39.11 ± 0.62 (36.61)^{ab}	46.28 ± 1.21 (42.87)^{ab}	43.2 ± 0.86 (41.09$^{)bc}$	44.74 ± 0.30 (41.98)^{ab}	39.42 ± 1.67 (38.89)^{ab}	37.02 ± 1.50 (37.50)^{ab}	35.56 ± 1.08 (36.60)^{ab}	32.26 ± 32.26 (34.61)^{ab}	28.12 ± 0.51 (32.02)^{b}	30.19 ± 0.33 (33.33)^{b}
T_4	53.22 ± 1.68 (46.85)^{a}	38.42 ± 1.45 (38.30)^{a}	36.18 ± 1.21 (36.98)^{a}	37.30 ± 1.15 (33.96)^{a}	44.67 ± 1.85 (41.94)^{a}	41.09 ± 0.11 (39.87)^{a}	42.88 ± 0.97 (40.91)^{a}	37.16 ± 0.70 (37.56)^{a}	34.08 ± 1.08 (35.71)^{a}	33.20 ± 1.75 (35.18)^{a}	29.62 ± 29.62 (32.97)^{a}	24.08 ± 0.91 (29.38)^{a}	26.85 ± 0.94 (31.21)^{a}
T_5	55.27 ± 2.39 (48.03)^{a}	44.82 ± 0.65 (42.03)^{bc}	42.16 ± 1.60 (40.49)^{bc}	43.49 ± 1.09 (41.67)^{cd}	50.1 ± 1.35 (45.06)^{bcd}	57.26 ± 0.21 (49.17)^{ef}	53.68 ± 0.63 (47.11)^{cd}	43.52 ± 0.63 (41.28)^{bc}	41.62 ± 1.69 (40.17)^{cd}	40.69 ± 0.74 (39.64)^{bcd}	37.2 ± 37.20 (37.58)^{c}	35.17 ± 1.27 (36.37)^{b}	36.19 ± 0.67 (36.98)^{d}
T_6	55.19 ± 1.24 (47.98)^{a}	42.1 ± 1.82 (40.45)^{ab}	40.67 ± 0.15 (39.62)^{bc}	41.39 ± 0.97 (39.94)^{bc}	48.17 ± 1.43 (43.95)^{abc}	45.14 ± 0.94 (42.21)^{b}	46.66 ± 1.15 (43.08)^{b}	41.03 ± 0.59 (39.83)^{ab}	38.44 ± 1.25 (38.31)^{bc}	38.04 ± 2.31 (38.07)^{abc}	35.41 ± 35.41 (36.51)^{bc}	31.42 ± 1.22 (34.09)^{c}	33.42 ± 0.11 (35.31)^{c}
T_7	56.93 ± 2.05 (48.99)^{a}	49.15 ± 0.62 (44.51)^{cd}	46.87 ± 0.51 (43.21)^{de}	48.01 ± 0.29 (45.82)^{e}	54.32 ± 1.86 (47.48)^{def}	51.28 ± 1.34 (45.73)^{cd}	52.80 ± 1.54 (46.61)^{cd}	47.82 ± 0.09 (43.75)^{d}	44.6 ± 1.21 (41.90)^{de}	44.22 ± 1.89 (41.68)^{cde}	42.28 ± 42.28 (40.56)^{de}	34.03 ± 0.21 (35.69)^{cd}	38.16 ± 0.61 (38.15)^{d}
T_8	56.13 ± 1.47 (48.52)^{a}	47.23 ± 0.81 (43.41)^{c}	44.72 ± 0.20 (41.97)^{cd}	45.98 ± 0.49 (43.32)^{de}	52.29 ± 1.37 (46.31)^{cde}	50.11 ± 0.23 (45.06)^{c}	51.20 ± 0.75 (45.69)^{c}	45.76 ± 0.58 (42.57)^{cd}	42.06 ± 0.68 (40.43)^{cd}	41.49 ± 2.28 (40.10)^{bcd}	39.16 ± 39.16 (38.74)^{cd}	36.21 ± 0.65 (36.99)^{d}	37.69 ± 0.60 (37.87)^{d}
T_9	57.1 ± 0.15 (49.08)^{a}	53.77 ± 1.65 (47.16)^{ef}	51.93 ± 1.03 (46.11)^{f}	52.85 ± 1.17 (49.29)^{fg}	58.39 ± 1.53 (49.83)^{fg}	56.08 ± 0.35 (48.49)^{ef}	57.24 ± 0.87 (49.16)^{ef}	53.24 ± 0.43 (46.86)^{ef}	50.14 ± 1.85 (45.08)^{fg}	49.74 ± 1.72 (44.85)^{efg}	47.3 ± 47.30 (43.45)^{fg}	43.15 ± 0.27 (41.06)^{e}	45.23 ± 0.43 (42.26)^{f}
T_{10}	57.03 ± 0.62 (49.04)a	52.43 ± 1.89 (46.39)^{de}	50.96 ± 1.52 (45.55)^{ef}	51.70 ± 1.23 (47.96)^{f}	56.72 ± 0.82 (48.86)^{efg}	54.32 ± 0.59 (47.48)^{de}	55.52 ± 0.68 (48.17)^{de}	49.11 ± 1.55 (44.49)^{de}	47.1 ± 0.04 (43.34)^{ef}	46.47 ± 2.05 (42.97)^{def}	44.13 ± 44.13 (41.63)^{ef}	41.2 ± 0.45 (39.93)^{e}	42.67 ± 0.56 (40.78)^{e}
T_{11}	56.02 ± 0.25 (48.46)^{a}	56.39 ± 0.76 (48.67)^{efg}	55.14 ± 1.94 (47.95)^{fgh}	55.77 ± 0.68 (52.75)^{gh}	64.13 ± 0.40 (53.21)^{hij}	61.33 ± 1.49 (51.55$^{)gh}$	62.73 ± 0.93 (52.38)^{hi}	59.77 ± 0.05 (50.63)^{gh}	57.09 ± 1.39 (49.08)^{hi}	56.14 ± 2.53 (48.53)^{ghi}	52.74 ± 52.74 (46.57)^{hi}	48.51 ± 1.14 (44.15)^{f}	50.63 ± 0.43 (45.36)^{h}
T_{12}	57.1 ± 2.21 (49.08)^{a}	54.22 ± 0.44 (47.42)^{ef}	53.1 ± 1.91 (46.78)^{fg}	53.66 ± 1.08 (50.72)^{fg}	60.7 ± 2.30 (51.18)^{gh}	59.49 ± 2.57 (50.48)^{fg}	60.10 ± 0.69 (50.82)^{gh}	56.63 ± 0.10 (48.81)^{fg}	54.22 ± 1.91 (47.42)^{gh}	52.82 ± 1.35 (46.61$_{)}^{fgh}$	49.62 ± 49.62 (44.78)^{gh}	46.73 ± 1.01 (43.12)^{f}	48.18 ± 0.56 (43.95)^{g}
T_{13}	56.19 ± 0.81 (48.56$^{)a}$	58.02 ± 1.26 (49.62)^{fg}	58.19 ± 1.52 (49.72)^{hi}	58.11 ± 0.36 (57.32)^{hi}	66.33 ± 1.02 (54.53)^{ij}	64.12 ± 0.06 (53.20)^{h}	65.23 ± 0.48 (53.86)^{i}	65.32 ± 2.89 (53.93)^{i}	63.08 ± 1.42 (52.58)^{jk}	61.78 ± 1.00 (51.81)^{ijk}	58.68 ± 58.68 (50.00)^{jk}	52.1 ± 1.69 (46.20)^{g}	55.39 ± 0.57 (48.09)^{ij}
T_{14}	57.17 ± 2.01 (49.12)^{a}	57.62 ± 2.49 (49.39)^{fg}	56.33 ± 2.49 (48.64)^{ghi}	56.98 ± 1.73 (54.16)^{h}	63.42 ± 0.69 (52.79)^{hi}	62.47 ± 0.84 (52.22)^{gh}	62.95 ± 0.23 (52.50)^{i}	62.77 ± 0.06 (52.40)^{hi}	59.27 ± 0.53 (50.34)^{ij}	58.73 ± 2.07 (50.03)^{hij}	55.72 ± 55.72 (48.28)^{ij}	53.15 ± 2.25 (46.81)^{g}	54.44 ± 1.30 (47.55)^{i}
T_{15}	56.82 ± 1.08 (48.92)^{a}	59.13 ± 2.40 (50.27)^{g}	62.1 ± 1.23 (52.00)^{jk}	60.62 ± 1.33 (62.12)^{ij}	68.09 ± 2.52 (55.62)^{jk}	74.22 ± 1.27 (59.49)^{j}	71.16 ± 1.09 (57.52)^{k}	70.13 ± 2.09 (56.88)^{i}	66.55 ± 1.50 (54.67)^{kl}	64.71 ± 2.67 (53.56)^{jk}	60.11 ± 60.11 (50.83)^{k}	55.04 ± 1.09 (47.89)^{gh}	57.58 ± 0.55 (49.36)^{j}
T_{16}	57.21 ± 2.17 (49.15)^{a}	60.37 ± 1.58 (50.99)^{g}	64.14 ± 0.29 (53.21)^{k}	62.26 ± 0.67 (63.95)^{j}	71.92 ± 0.97 (58.00)^{k}	76.89 ± 0.76 (61.27)^{j}	74.41 ± 0.44 (59.61)^{l}	73.47 ± 2.58 (59.02$_{)}^{j}$	68.1 ± 2.15 (55.62)^{l}	67.02 ± 4.06 (54.98)^{k}	62.28 ± 62.28 (52.11)^{k}	58.1 ± 0.73 (49.66)^{h}	60.19 ± 1.23 (50.88)^{k}
SEd	0.69484	0.68113	0.65077	0.46477	0.74763	0.59772	0.43420	0.66686	0.66492	0.43420	0.64675	0.50943	0.43470
P	NS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

*Mean values of three replications as mean ± standard deviation; Figures in the parentheses arc sine values; means followed by the same alphabets are not significantly different from each other, Tukey's test ($p \leq 0.05$); *SEd* Standard Error of difference, *PTC* Pre-Treatment Count, *DAS* Days After Spray. Critical phases:15 DAS- Germination and establishment phase, 30 DAS- Vegetative phase, 45 DAS—Flowering phase and 60 DAS- Maturity phase lowest mean leaf damage of 33.20%, followed by the treatment with ½ dose of T_1 + 0.2% SA @ 15 DAS + 50 ppm GA @ 30 DAS (T_3) (35.56%). Application of¼ dose of T_2 + 0.4% SA @ 15 DAS + 100 ppm GA @ 30 DAS (T_6) (38.04%) was on par with ¼ dose of T_1 + 0.4% SA @ 15 DAS + 100 ppm GA @ 30 DAS (T_5) (40.69%). The application of ½ dose of T_2 + 1% potassium silicate @ 15 & 30 DAS (T_8) (41.49%) was significantly inferior among treatments but performed better over untreated check (T_{16}) (67.02%).

After fourth spray (60 days after sowing), the mean leaf damage per cent/plant ranged from 26.85 to 60.19 in all the treatments. The lowest mean leaf damage per cent/plant was recorded in ½ dose of T_2 + 0.2% SA @ 15 DAS + 50 ppm GA @ 30 DAS (T_4) (26.85%) while highest in untreated check (T_{16}) (60.19%). The next best treatment was ½ dose of T_1 + 0.2% SA @ 15 DAS + 50 ppm GA @ 30 DAS (T_3) (30.19%). Application of¼ dose of T_2 + 0.4% SA @ 15 DAS + 100 ppm GA @ 30 DAS (T_6) (33.42%) followed by ¼ dose of T_1 + 0.4% SA @ 15 DAS + 100 ppm GA @ 30 DAS (T_5) (36.19%).

3.2 Whorl Damage

After first spray (15 days after sowing), the mean whorl damage ranged from 31.21 to 80.69% among the treatments. The treatment with basal application of 150 kg of calcium silicate/ ha + 0.2% SA @ 15 DAS + 50 ppm GA @ 30 DAS (T_4) was found to be significantly superior over other treatments with minimum mean whorl damage per cent of 31.21 /plot followed by 75 kg of calcium silicate + 0.2% SA @ 15 DAS + 50 ppm GA @ 30 DAS (T_3) (35.57%). The treatment with ¼ dose of T_2 + 1% potassium silicate @ 15 & 30 DAS (T_{10}) recorded 55.16 per cent of whorl damage/plot followed by ¼ dose of T_1 + 0.5% potassium silicate @ 15 & 30 DAS (T_9) (57.46%). The treatment with foliar spray of 0.4% SA @ 15 & 45 DAS + 100 ppm GA @ 30 & 60 DAS (T_{12}) recorded 59.91 per cent of whorl damage/plot followed by foliar spray of 0.2% SA @ 15 & 45 DAS + 50 ppm GA @ 30 & 60 DAS (T_{11}) (63.37%). The treatment with foliar spray of 1% potassium silicate @ 15, 30, 45 & 60 DAS (T_{14}) recorded 65.72 per cent of whorl damage/plot followed by foliar spray of 0.5% potassium silicate @ 15, 30, 45 & 60 DAS (T_{13}) with 70.84 per cent of whorl damage. Soil application of calcium silicate @ 300 kg/ ha (T_2) recorded mean whorl damage of 61.69 per cent, followed by soil application of calcium silicate @ 150 kg/ha (71.94%). The mean whorl damage recorded in the untreated check (T_{16}) was 80.69% (Table 2). After second spray (30 DAS), the results revealed that the treatment ½ dose of T_2 + 0.2% SA @ 15 DAS + 50 ppm GA @ 30 DAS (T_4) was found to be effective in reducing whorl damage (36.05%) as against 82.63% in the untreated check (T_{16}).

3.3 Cob Damage Per Cent

After third spray (45 DAS), the treatment with basal application of 150 kg of calcium silicate/ ha + 0.2% SA @ 15 DAS + 50 ppm GA @ 30 DAS (T_4) was found to be most effective and significantly superior over all other treatments by recording lowest mean cob damage of 26.92%, followed by the treatment with ½ dose of T_1 + 0.2% SA @ 15 DAS + 50 ppm GA @ 30 DAS (T_3) (32.03%). Application of T_2 + 0.4% SA @ 15 DAS + 100 ppm GA @ 30 DAS (T_6) recorded 36.97 per cent of cob damage, followed by ¼ dose of T_1 + 0.4% SA @ 15 DAS + 100 ppm GA @ 30 DAS (T_5) (41.55%). The mean cob damage recorded in the untreated check (T_{16}) was 73.00% (Table 2).

After fourth spray (60 DAS), the mean cob damage ranged from 19.45% to 51.56% in all the treatments. The lowest mean cob damage was recorded in ½ dose of T_2 + 0.2% SA @ 15 DAS + 50 ppm GA @ 30 DAS (T_4) (19.45%) while the highest in untreated check (T_{16}) (51.56%). The next best treatment was ¼ dose of T_2 + 0.4% SA @ 15 DAS + 100 ppm GA @ 30 DAS (T_6) (25.37%), followed by ¼ dose of T_1 + 0.4% SA @ 15 DAS + 100 ppm GA @ 30 DAS (T_5) (28.77%). The mean cob damage per cent/plot recorded in the untreated check (T_{16}) was 51.56.

3.4 Yield and BC Ratio

The maize grain yield recorded was significantly different among various treatments. It was significantly high the in treatment with basal application of 150 kg of calcium silicate/ha + 0.2% SA @ 15 DAS + 50 ppm GA @ 30 DAS (7, 287 kg/ha) (Rs.1, 31,166) followed by 75 kg of calcium silicate + 0.2% SA @ 15 DAS + 50 ppm GA @ 30 DAS (7, 092 kg/ha) (Rs. 1,27,656) and 75 kg of calcium silicate + 0.4% SA @ 15 DAS + 100 ppm GA @ 30 DAS (6, 928 kg/ha) (Rs.1,24,704). The yield recorded in the untreated check was (4, 104 kg/ha) (Rs.73,872). While considering benefit cost ratio, the highest BC ratio (2.70) was observed in basal application of 75 kg of calcium silicate + 0.2% SA @ 15 DAS + 50 ppm GA @ 30 DAS (T_3) followed by the treatment with ½ dose of T_2 + 0.2% SA @ 15 DAS + 50 ppm GA @ 30 DAS (2.64) (T_4). Basal application of ½ dose of T_1 + 0.5% potassium silicate @ 15 and 30 DAS (T_7) (2.62) was significantly inferior among treatments but performed better over untreated check (T_{16}) (1.74) (Table 3). The gibberellic acid increases the leaves length, width, internodes, improving photosynthesis activity of plant and also increases the cob length, no of grain per cob and grain size treated with 50 ppm GA at 30 DAS included in the treatment of 150 kg of calcium silicate/ha + 0.2% SA @ 15 DAS. Further adding advantage, it also increases the lateral root length and also improving the silicon absorption and reducing the FAW incidence in maize.

Table 2 Whorl and cob damage caused by fall armyworm in maize, as influenced by various Silicon and biostimulants

Treatments	% whorl damage*							% cob damage*					
		I Spray- Silicic acid / Potassium silicate (15 DAS)			II Spray- Gibberellic acid/ Potassium silicate (30 DAS)			III Spray-Silicic acid / Potassium silicate (45 DAS)			IV Spray-Gibberellic acid/ Potassium silicate (60 DAS)		
	PTC	4 DAS	8 DAS	Mean	4 DAS	8 DAS	Mean	4 DAS	8 DAS	Mean	4 DAS	8 DAS	Mean
T_1	38.16 ± 0.76 (38.15)^{b}	70.73 ± 1.15 (57.25)jk	73.14 ± 1.38 (58.79)i	71.94 ± 1.27 (58.01)k	71.92 ± 0.97 (58.00)j	64.74 ± 1.69 (53.58)ij	68.33 ± 0.47 (55.75)j	65.27 ± 2.88 (53.90)ij	61.73 ± 0.39 (51.78)h	63.50 ± 1.55 (52.83)ij	49.57 ± 1.61 (44.75)ij	45.2 ± 1.30 (42.24)ij	47.39 ± 1.40 (43.50)k
T_2	30.52 ± 1.10 (33.53)^{a}	63.1 ± 2.33 (52.60)g^{h}	60.28 ± 0.92 (50.93)gh	61.69 ± 1.45 (51.76)hi	67.15 ± 0.54 (55.03)hi	60.27 ± 1.14 (50.93)^{gh}	63.71 ± 0.84 (52.96)hi	61.7 ± 2.00 (51.77)hi	52.18 ± 2.16 (46.30)fg	56.94 ± 1.80 (48.99)h	46.72 ± 1.64 (43.12)hi	41.03 ± 0.52 (39.83)h	43.88 ± 0.98 (41.48)ij
T_3	45.79 ± 1.03 (42.58)ef	39.62 ± 0.79 (39.01)b	31.52 ± 0.63 (34.15)a	35.57 ± 0.36 (36.61)b	41.34 ± 0.97 (40.01)ab	37.14 ± 1.00 (37.55)ab	39.24 ± 0.96 (38.79)b	34.82 ± 0.50 (36.16)ab	29.24 ± 1.19 (32.70)b	32.03 ± 0.40 (34.47)b	24.46 ± 0.68 (29.64)ab	20.38 ± 0.61 (26.83)b	22.42 ± 0.63 (28.26)b
T_4	42.68 ± 0.73 (40.79)de	34.27 ± 0.22 (35.83)a	28.14 ± 0.74 (32.04)a	31.21 ± 0.39 (33.96)a	38.62 ± 0.94 (38.42)a	33.47 ± 1.18 (35.35)a	36.05 ± 0.75 (36.90)a	32.67 ± 0.09 (34.86)a	21.16 ± 0.82 (27.38)a	26.92 ± 0.41 (31.25)a	21.68 ± 0.25 (27.75)a	17.22 ± 0.37 (24.52)a	19.45 ± 0.16 (26.17)a
T_5	53.33 ± 1.30 (46.91)g	46.2 ± 0.29 (42.82)cd	42.2 ± 1.79 (40.51)bc	44.20 ± 1.02 (41.67)cd	48.36 ± 1.83 (44.06)cd	44.69 ± 0.64 (41.95)cd	46.53 ± 0.96 (43.01)d	43.2 ± 0.27 (41.09)cd	39.89 ± 1.19 (39.17)b	41.55 ± 0.54 (40.13)d	30.16 ± 0.33 (33.31)c	27.37 ± 0.42 (31.54)d	28.77 ± 0.32 (32.43)d
T_6	39.11 ± 0.81 (38.71)bc	43.69 ± 0.24 (41.37)c	38.74 ± 1.19 (38.49)b	41.22 ± 0.48 (39.94)c	44.57 ± 0.48 (41.88)bc	40.83 ± 0.11 (39.72)bc	42.70 ± 0.19 (40.80)c	39.15 ± 1.73 (38.73)bc	34.78 ± 1.03 (36.14)c	36.97 ± 1.34 (37.44)c	27.1 ± 0.15 (31.37)bc	23.64 ± 0.23 (29.09)c	25.37 ± 0.10 (30.24)c
T_7	44.73 ± 0.73 (41.97)^{def}	53.68 ± 1.74 (47.11)e	49.18 ± 1.60 (44.53)de	51.43 ± 1.20 (45.82)e	56.79 ± 0.82 (48.90)ef	51.02 ± 1.15 (45.58)e	53.91 ± 0.32 (47.24)f	51.22 ± 0.69 (45.70)ef	46.35 ± 0.58 (42.91)e	48.79 ± 0.18 (44.30)f	35.17 ± 0.60 (36.37)d	32.14 ± 0.46 (34.54)e	33.66 ± 0.14 (35.46)e
T_8	42.1 ± 1.33 (40.45)cd	49.12 ± 1.33 (44.50)d	45.03 ± 0.89 (42.15)cd	47.08 ± 0.97 (43.32)d	52.79 ± 0.05 (46.60)de	48.94 ± 1.50 (44.39)de	50.87 ± 0.74 (45.50)g	47.63 ± 0.04 (43.64)de	42.63 ± 0.92 (40.76)d	45.13 ± 0.46 (42.21)e	33.54 ± 1.48 (35.39)d	29.59 ± 0.21 (32.95)d	31.57 ± 0.65 (34.18)e
T_9	54.2 ± 0.44 (47.41)g	59.7 ± 1.61 (50.60)fg	55.22 ± 0.50 (48.00)fg	57.46 ± 0.96 (49.29)fg	63.47 ± 1.77 (52.82)fg	59.1 ± 1.81 (50.25)fg	61.29 ± 1.24 (51.52)h	56.17 ± 0.51 (48.54)fg	51.28 ± 0.18 (45.73)fg	53.73 ± 0.18 (47.14)gh	41.3 ± 1.27 (39.99)ef	37.1 ± 0.97 (37.52)fg	39.20 ± 1.09 (38.76)g
T_{10}	46.35 ± 0.67 (42.91)f	57.43 ± 0.62 (49.27)f	52.88 ± 0.14 (46.65)ef	55.16 ± 0.32 (47.96)f	59.83 ± 1.13 (50.67)f	55.67 ± 0.50 (48.26)f	57.75 ± 0.32 (49.46)g	54.3 ± 2.35 (47.47)f	49.1 ± 1.46 (44.48)ef	51.70 ± 1.66 (45.97)fg	38.62 ± 0.66 (38.42)e	34.83 ± 0.60 (36.17)f	36.73 ± 0.32 (37.30)f
T_{11}	64.58 ± 0.41 (53.48)i	65.31 ± 1.18 (53.92)hi	61.42 ± 2.05 (51.61)h	63.37 ± 0.89 (52.75)ij	70.3 ± 2.09 (56.99)ij	66.54 ± 0.36 (54.66)ij	68.42 ± 0.89 (55.81)j	63.34 ± 0.57 (52.74)^{hij}	58.74 ± 1.85 (50.04)h	61.04 ± 1.18 (51.38)i	45.23 ± 1.30 (42.26)gh	40.2 ± 0.11 (39.35)h	42.72 ± 0.63 (40.81)hi
T_{12}	60.17 ± 2.17 (50.87)h	62.14 ± 0.39 (52.03)^{gh}	57.68 ± 1.72 (49.42)f^{gh}	59.91 ± 0.78 (50.72)gh	67.28 ± 0.55 (55.11)gh	63.62 ± 0.57 (52.90)hi	65.45 ± 0.54 (54.00)i	59.73 ± 1.78 (50.61)^{gh}	53.11 ± 0.62 (46.78)g	56.42 ± 0.78 (48.69)h	43.12 ± 1.13 (41.04)fg	38.5 ± 0.90 (38.35)gh	40.81 ± 0.99 (39.70)gh
T_{13}	72.06 ± 1.69 (58.10)k	73.54 ± 0.66 (59.04)kl	68.14 ± 1.90 (55.64)ij	70.84 ± 0.68 (57.32)k	78.64 ± 2.06 (62.49)k	74.18 ± 2.94 (59.48)k	76.41 ± 1.31 (60.95)l	71.55 ± 2.84 (57.78)kl	65.33 ± 1.41 (53.93)i	68.44 ± 1.23 (55.82)k	49.4 ± 1.02 (44.66)ij	46.85 ± 1.98 (43.19)jk	48.13 ± 0.86 (43.93)kl
T_{14}	68.14 ± 0.92 (55.64)j	68.17 ± 0.92 (55.66)ij	63.26 ± 2.62 (52.70)hi	65.72 ± 1.15 (54.16)j	73.84 ± 3.26 (59.27)j	68.47 ± 0.25 (55.84)j	71.16 ± 1.51 (57.52)j	67.49 ± 1.16 (55.24)jk	61.7 ± 1.22 (51.77)h	64.60 ± 0.33 (53.49)j	47.84 ± 1.03 (43.76)hi	43.91 ± 1.31 (41.50)i	45.88 ± 0.82 (42.63)jk
T_{15}	70.94 ± 0.96 (57.38)jk	76.03 ± 1.03 (60.69)^{lm}	80.23 ± 1.23 (63.61)k	78.13 ± 0.29 (62.12)l	78.03 ± 0.07 (62.05)l	82.7 ± 0.67 (65.42)l	80.37 ± 0.30 (63.70)m	73.88 ± 2.13 (59.28)l	68.18 ± 0.74 (55.66)ij	71.03 ± 1.11 (57.44)kl	51.36 ± 1.81 (45.78)jk	48.73 ± 0.70 (44.27)kl	50.05 ± 0.79 (45.03)lm
T_{16}	72.1 ± 0.52 (58.12)k	77.84 ± 1.54 (61.93)m	83.54 ± 3.61 (66.15)k	80.69 ± 1.99 (63.95)l	80.22 ± 1.74 (63.61)l	85.03 ± 2.22 (67.28)l	82.63 ± 1.01 (65.37)n	76.14 ± 2.40 (60.78)l	69.85 ± 0.06 (56.70)j	73.00 ± 1.23 (58.69)l	53.14 ± 1.25 (46.80)k	49.97 ± 0.27 (44.98)l	51.56 ± 0.57 (45.89)m
SEd	0.52427	0.57722	0.89948	0.51225	0.76474	0.71423	0.44053	0.84584	0.54752	0.50985	0.53758	0.40395	0.35733
P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

*Mean values of three replications as mean ± standard deviation; Figures in the parentheses arc sine values; means followed by the same alphabets are not significantly different from each other, Tukey's test ($p \leq 0.05$); *SEd* Standard Error of difference, *PTC* Pre-Treatment Count, *DAS* Days After Spray. Critical phases:15 DAS- Germination and establishment phase, 30 DAS- Vegetative phase, 45 DAS—Flowering phase and 60 DAS- Maturity phase

Table 3 Impact of silicon and growth regulator on yield in maize

Treatments	Yield (kg/ha)	BC ratio
T_1	5002 $(70.72)^{ij}$	1.91
T_2	5158 $(71.81)^{ij}$	1.80
T_3	7092 $(84.21)^{ab}$	2.70
T_4	7287 $(85.36)^{a}$	2.64
T_5	6906 $(83.10)^{abc}$	2.55
T_6	6928 $(83.23)^{abc}$	2.50
T_7	6383 $(79.89)^{de}$	2.62
T_8	6698 $(81.83)^{bcd}$	2.60
T_9	6314 $(79.46)^{def}$	2.58
T_{10}	6534 $(80.83)^{cde}$	2.57
T_{11}	5935 $(77.04)^{fg}$	2.24
T_{12}	6097 $(78.08)^{efg}$	2.08
T_{13}	5322 $(72.95)^{hi}$	2.20
T_{14}	5714 $(75.59)^{gh}$	2.31
T_{15}	4908 $(70.06)^{j}$	2.05
T_{16}	4104 $(64.06)^{k}$	1.74
SE	0.758	-
P	0.000	-

*Mean values of three replications as mean ± standard deviation; Figures in the parentheses are square root transformed values; means followed by the same alphabets are not significantly different from each other, Tukey's test ($p \leq 0.05$); *SEd* Standard Error of difference

4 Discussion

The findings of a field experiment showed that plants treated with silicon sources and growth regulator suffered from fall armyworm damage to leaves, whorls, and cobs significantly less frequently than untreated control plants. (Fig. 1). Fall armyworm damage to maize was greatly reduced by a base application of 150 kg of calcium silicate/ha + 0.2% SA on 15 DAS + 50 ppm GA on 30 DAS (T4), followed by a treatment with 75 kg of calcium silicate/ha + 0.2% SA on 15 DAS + 50 ppm GA on 30 DAS (44.74%). Whorl damage was found to be reduced (36.05%) by a base coating of 150 kg of calcium silicate/ha along with foliar application of 0.2% silicic acid on 15 DAS and 50 ppm GA on 30 DAS. (Fig. 2). Liu et al. [8], who discovered that silicon-fertilization in maize significantly exhibited negative impact on immature stages of *S. frugiperda* and supported the current finding.

The results of the current research are consistent with those of Jeer et al. [9], who found that pink stem borer damage to wheat plots treated with K and Si was substantially reduced (66% less than control) when compared to untreated control and insecticidal check. Similar research was done by Nagaratna et al. [10], who found that Si application, and plant growth regulators all had a significant impact on larval survival, with the lowest larval survival rate (70%) being the outcome. According to Perdomo et al. [11], silicate soil fertilization raised the amount of silicate in maize leaves or stocks and encouraged the plant's resistance to FAW attack in outdoor settings. Si doses between 600 and 1,200 kg ha-1 decreased FAW defoliation while having no impact on maize production. According to Ganapathy et al. [12], potassium silicate @ 0.5% + gibberellic acid @ 50 ppm treatment resulted in the highest percentage reduction of the green gram pod borer (54.87%), followed by potassium silicate @ 1% + gibberellic acid @ 100 ppm (51.79%) and foliar application of silicic acid @ 0.2% + gibberellic acid @ 100 ppm (49.35%). The growth of FAW larvae from the maize strain was disrupted by Si-treated plants, but not those from the rice strain, according to Nuambote Yobila et al.'s research [13]. According to Tarikul Islam et al. [14], high polyphenol oxidase activity in the haemolymph caused larvae to develop more slowly and reduced integument resistance of larvae fed on Si-supplemented plants may have contributed to their vulnerability to natural enemies. The effects of different silicon sources on field crop herbivores and their mechanisms for transferring tolerance to crops were reviewed by Murali Baskaran et al. [6].

Phytoalexins, phenolics, and chlorogenic acid are among the defensive compounds whose accumulation is altered by Si treatment, according to mounting data [15, 16]. The population of immature whiteflies and tomato leaf miners on the tomato crop in the greenhouse was greatly reduced as a result of silicon applications; Si-foliar spraying was more successful in doing this than Si-soil drench application [17]. Pereira et al. [18] demonstrated the larval mortality of *S. frugiperda* on Si supplemented plants and got similar confirmatory results. They noticed that after 48 h of feeding, plants treated with Si applications had about a six-fold greater rate of larval mortality than plants not treated with Si. According to Nagaratna et al. [10], Si application had a detrimental effect on life style parameters of *S. frugiperda* like larval weight and survival. Increased plant absorption and consequent resistance to chewing insect infestation result from adding Si to the soil [19]. The efficacy of silicic acid treatment on the yellow mite damage to two commercial sugarcane varieties was discovered by Nikpay and Laane [20]. Lepidopteran sugarcane borers and suction pests were less common as a result of the application

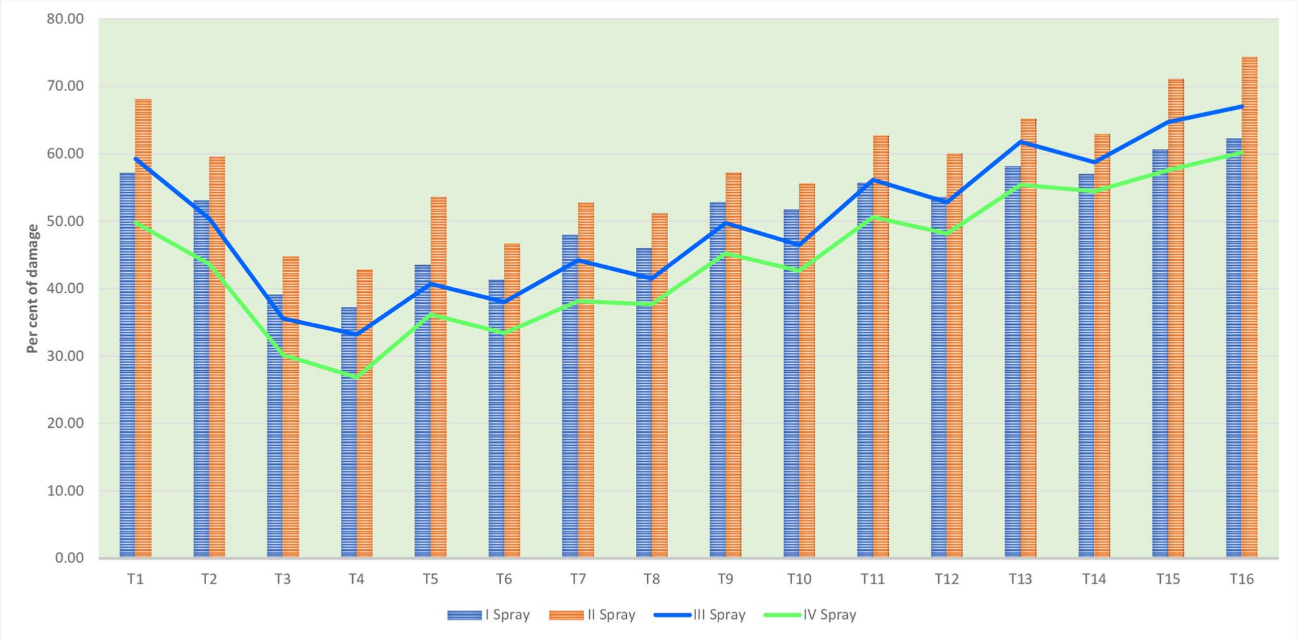

Fig. 1 Impact of Si and GA on the leaf damage per cent of fall armyworm in maize

of calcium silicate at a rate of 1000 kg/ha [5]. According to Hall et al. [21], Si increased the mechanical plant resistances and served as a primary defence mechanism against herbivores with chewing mouth parts.

It is interesting to note that when permitted to feed on maize leaves treated with silicon as opposed to leaves without silicon, the larval mortality of the true armyworm *Pseudaletia unipuncta* increased [22]. Rice plants fertilized with Si showed less damage from the Scirpophagaincertulas (Walker) caterpillar during the vegetative and reproductive phases, according to Jeer et al. [23]. Furthermore, the stomach mesentery of these insects revealed ruptured perithrophic

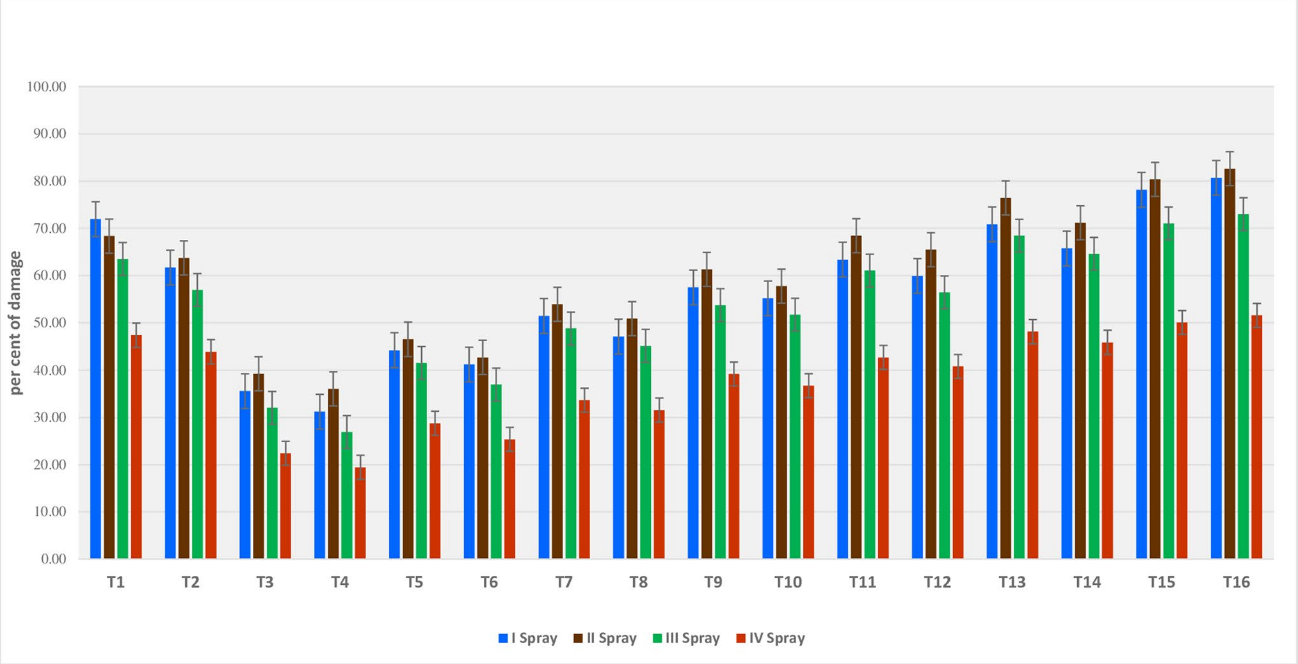

Fig. 2 Impact of Si and GA on the whorl and cob damage per cent of fall armyworm in maize

membranes, and caterpillar mandibles taken from Si-fertilized plants were harmed. According to Alvarenga et al. [24], gibberellic acid can change the vegetative characteristics and silicon uptake of maize plants, which reduces *S. frugiperda* larvae consumption and reduces oviposition.

Additionally, Melo et al. [25] found that foliar applications of 1% silicic acid solution (SiO_2xH_2O) significantly decreased the populations of whitefly eggs and nymphs on chrysanthemum plants. The incidence of stem borer, *Scirpophaga incertulas* damage was greatly reduced in the basal application of calcium silicate 2 t/ha with foliar spray of 1% sodium metasilicate sprayed during the critical stages of rice crop, according to Arivuselvi [26]. According to Swedhapriya [27] the basal application of calcium silicate 200 kg/ha with foliar spray of 0.25% sodium metasilicate significantly reduced the damage incidence of stem borer and leaf folder in rice. This is again in consonance with the findings of Santos et al. [3] who found that *T. absoluta* reared on tomato plants accumulating silicon showed decrease in larvae and pupae survival and male and female weight. Reduced fecundity in *Bactrocera cucurbitae* (Coquillett) and *S. frugiperda*, when fed on plants treated with gibberellic acid [28, 29].

5 Conclusion

The amount of damage caused by larvae on the leaf, whorl, and cob of the maize crop was greatly reduced by applying 150 kg/ha of calcium silicate as a base along with foliar applications of silicic acid at a rate of 0.2% at 15 DAS and gibberellic acid at a rate of 50 ppm at 30 DAS. The use of silicon-based products and different biostimulant analogues open a new gate in the era of Integrated Pest Management (IPM) in organic farming and are generally accepted. As a result, exogenous application of silicon and crop biostimulant are seen as an environmentally sound strategy because, in addition to reducing the use of chemical pesticides, fall armyworm population and damage to different sections of maize were both greatly reduced.

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Data Availability All relevant data and materials are within the research paper.

Declarations

Ethics Approval Not applicable.

Consent to Participate All authors were highly cooperative and involved equally in research activities and preparation of this article.

Consent for Publication All authors agreed to publish this research article.

Conflict of Interest The authors have declared that no competing interests exist.

Competing Interests The authors declare that they have no competing of interest.

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