Biosilica Fertilizer Reduces Fall Armyworm Damage

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Abstract. The presence of fall armyworm (FAW), *Spodoptera frugiperda* J.E. Smith, in Indonesian corn plantations caused the farmers’ dependence on chemical insecticides increased. Since chemical pesticides have several side effects, it is necessary to develop another alternative to FAW management. This study aimed to investigate the efficacy of biosilica fertilizer against FAW incidence and its effect on maize production. A factorial experiment was arranged in two factors, the first factor was biosilica doses with varied doses of 1, 2, and 3 l/ha; the second factor was the number of applications at 1, 2, and 3 times. The results demonstrated that the application of biosilica fertilizer 2 - 3 l/ha as foliar spray three times starting from 10 days after growing reduced the fall armyworm infestation significantly as compared to control treatment. No significant differences were observed in the vegetative characteristics of corn plants, i.e. height and the number of leaves, in response to doses and application number of biosilica. Application of biosilica 2 - 3 l/ha improved the yield attributing characters of the corn plant and increased the production as compared to other treatments including control treatment. We conclude that biosilica fertilizer can be used as an alternative for FAW management.

Keywords: *Spodoptera frugiperda*, maize, nano silicon, rice husk ash

1. Introduction

Corn is the second most cultivated food crops in Indonesia, after rice. It is grown in almost all Indonesian Provinces with varying harvested areas. East Java, Central Java, South Sulawesi, North Sumatra, and Lampung, the top five corn producing Province, typically account for about 71% of the Indonesia production [1]. Most of the crop is a major component of livestock feed, and also processed for human consumption and other industrial uses. The occurrence of the fall armyworm (FAW), *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae), in Indonesia for the first time in early 2019 [2] raised concerns about the corn industry which is dominated by smallholder farmers.

FAW is native to tropical and subtropical regions of the Americas. FAW is a highly polyphagous insect pest that attacks more than 353 plant species from 76 families, especially Poaceae, Asteraceae, and Fabaceae. Furthermore, the FAW preference is very high on maize, rice, sorghum, cotton, grasses, and sugarcane [3]. This pest cause major economic impacts worldwide, including yield losses and management costs. The loss of maize yields due to FAW attacks in the USA at around US$300 million [4], while in Ghana and Zambia were estimated at US$284 and 198 million, respectively [5]. Abrahams *et al.* [6] reported that FAW infestation in maize, rice, sorghum, and sugarcane across sub-Saharan African is estimated to cause losses up to US$13 billion per annum. Since FAW has infested...
maize in Indonesia, synthetic insecticides have been widely used to minimize damage to maize fields. It will cause population resistance to the different insecticides [7] as well as other negative impacts on the environment.

The utilization of resistant maize varieties is an important component of integrated pest management. However, until now FAW-resistant maize varieties have not been developed in Indonesia. Thus there is an urgent need to develop effective and ecologically friendly control methods. Application of silica sources for the management of insect pests is one such options.

Silica has been known and reported in numerous studies to contribute to increasing plant resistance to various environmental stresses, both biotic and abiotic [8]. Silica was also found to be involved in the acquisition, absorption, and translocation of macro and micro nutrients as well as other beneficial nutrients such as Al, Na, and Se, both under deficiency and excess conditions [9]. Increased plant resistance to biotic and abiotic stress occurs through two main mechanisms, namely (i) physical and mechanical protection by the accumulation of silica in plant epidermal tissue and (ii) metabolic changes driven by biochemical responses such as activation of antioxidative defense responses, phytohormonal signaling and reactive oxygen species scavenging [8, 10]. The contribution of silica in increasing plant resistance to silica, especially insects, continues to be reported in different plants. Laboratory-scale research by Duehl et al. [11] for example, reported that plants that were applied to liquid silica had a 33% greater silica content in their tissues and produced volatile organic compound (VOC) Indole which is well-known for priming plant defenses, almost 3 times compared to control plant. In field-scale research, the application of silica was also proven to be successful in reducing pests Aphis craccivora, Liriomyza trifolii and Spodoptera littoralis on fava beans and soybeans field up to 100% at various doses and times, namely 225-425 mg/L with 5-15 days after application [12]. Si can be applied through many inorganic sources [13, 14, 15, 16] or organic sources in the form of rice husk ash [17]. The objective of this study was to determine the effect of biosilica fertilizer in different dose and intensity of its application on corn plant resistance to FAW, growth and yield of maize.

2. Materials and Methods

2.1. Study Site and Experimental Design

This study was carried out from January to April 2020 at the experimental farm of North Sumatra Assessment Institute for Agricultural Technology, Deli Serdang District, North Sumatra, Indonesia (3°29′48″ N; 98°54′22″ E, and 22 m above sea level). The maize variety used in this experiment was BISI®18. The soil was a loam (85.62% sand, 10.27% silt, and 4.11% clay, 3.18 me/100 g Ca, 0.71 me/100 g Mg and 0.37 me/100 g K), with a pH of 5.3 (pH water).

A factorial randomized complete blocks design with four blocks (each block consisted of 12 experimental plots) was used for this study. Treatments comprised of a dose of biosilica fertilizer (D0= 0 l ha⁻¹; D1 = 1 l ha⁻¹; D2 = 2 l ha⁻¹ and D3 = 3 l ha⁻¹) and fertilization intensity (T1 = once; T2 = two times and T3 = three times). Biosilica fertilizer used in this study was obtained from the raw material of rice husk (soluble Si ± 10% K2O ± 13%, the Indonesian Center for Agricultural Postharvest Research and Development (ICAPOSTRD), Bogor, Indonesia). It was applied to maize at 10, 25, and 35 days after emerging (DAE). All the plots were treated with urea, TSP, KCl, and manure at a rate of 1.65, 0.5, 1.25, and 400 g/tree, respectively. Those mineral fertilizers were applied at two times (7 and 21 DAE). The cultivation method was conducted according to general guidelines for integrated plant management of maize (18).

2.2. Maize Vegetative Growth and Cob Yield

Ten plants were selected randomly from each plot to record plant height and leaf number. These were calculated at 21, 28, 35, and 42 days after emerging. At physiological maturity, all plants in each plot were investigated and hand-harvested. Cob yields were counted each plot and converted into tonnes per hectare.
2.3 Plant Damage by FAW

Plant Damage by FAW was determined by percentage of plant damage and damage severity. The damaged and undamaged maize plants per plot were counted for evaluations of leaf damage percentage by FAW. The FAW damage severity was recorded on an individual plant basis based on a visual scale of damage (0 – 9) used by Davis et al. [19] and Williams et al. [20]. Data was recorded from 14 until 49 days after the plant emerged with seven-day intervals. The number of plants evaluated was fifty plants per plot. Each plot had five sub-plots (10 plants in a row) defined for observation. Subplot location was determined systematically [21]. In each sample plant, observation was focused on the newest two or three leaves emerging from the whorl.

2.4 Data Analysis

All data were analyzed statistically by two-way (dose and fertilization intensity of biosilica fertilizer) ANOVA. The significance of differences between the mean values was verified by Duncan Multiple Range Test (DMRT) at the level p ≤ 0.05.

3. Results and Discussion

3.1. Effect of biosilica fertilizer on plant damage by FAW

Leaf and ear damage was significantly different between treatments (Table 1). FAW infestation were significantly less on maize plants fertilized with biosilica fertilizer at a dose of two and three liter per ha than did those in control and other biosilica doses (F_{3,3} = 52.85, P= 0.00). Plants were fertilized with 1 l ha^-1 biosilica, the leaves were significantly less attacked by FAW than did those in the control (Table 1). The percentage of leaves damage by FAW were significantly less on plants fertilized with three times biosilica, while ears damage were significantly less in maize that was fertilized with an intensity of two to three 3 times (F_{2,3} = 212.22, P= 0.00) (Table 1). Moreover, the effect of the interaction between dose and application intensity of biosilica was significantly different on percentage of leaf and ear damage (Table 2).

### Table 1. Effect of biosilica fertilizer doses and fertilization intensity on the damage percentage of leaf and ear maize by *Spodoptera frugiperda*

| Treatment | Leaf Damage | Ear Damage |
|-----------|-------------|------------|
| **Biosilica doses (l/ha) (D)** | | |
| 0 | 98.67 a | 78.84 a |
| 1 | 93.67 b | 56.08 b |
| 2 | 65.75 c | 44.51 c |
| 3 | 63.33 c | 42.48 c |
| F | 301.91 | 72.56 |
| P_{value} | 0.00 | 0.00 |
| **Intensity of biosilica application (T)** | | |
| 1 | 94.69 a | 61.78 a |
| 2 | 78.13 b | 54.50 b |
| 3 | 68.25 c | 50.23 b |
| F | 212.22 | 11.90 |
| P_{value} | 0.00 | 0.00 |
| **Interaction** | * | * |

Mean values followed by different letters are significantly different (Duncan Multiple range Test p≤0.05); * significantly different p≤0.05
Table 2. The interaction effect between doses and fertilization intensity of biosilica on leaves and ear maize damage by *Spodoptera frugiperda*

| Treatment | Leaf Damage * | Ear Damage * |
|-----------|---------------|--------------|
| D1T1      | 96.50 ± 0.96  | 61.18 ± 8.26 |
| D1T2      | 93.00 ± 1.73  | 54.50 ± 5.95 |
| D1T3      | 91.50 ± 2.87  | 52.55 ± 1.41 |
| D2T1      | 92.25 ± 1.03  | 55.21 ± 1.18 |
| D2T2      | 62.00 ± 0.82  | 44.00 ± 0.79 |
| D2T3      | 43.00 ± 3.11  | 34.60 ± 0.96 |
| D3T1      | 99.50 ± 0.96  | 52.85 ± 2.86 |
| D3T2      | 58.00 ± 0.82  | 40.92 ± 1.18 |
| D3T3      | 41.50 ± 2.22  | 33.68 ± 0.87 |
| Control   | 98.67 ± 0.99  | 78.84 ± 0.97 |

*p* = 0.00, 0.99

*Data are means ± SE of four replications

Leaf damage inflicted by FAW larvae was significantly different among biosilica dose treatments across three samplings. The non-treated control plants had extensive leaf injury by FAW larvae compared to the plants treated with biosilica fertilizer (Table 3). In the first sampling, plants treated with biosilica fertilizer at 2 and 3 l ha\(^{-1}\) were significantly less leaf damage than did those in the control, whereas in the second and third sampling, the lowest leaf damage was recorded in plants treated with biosilica fertilizer at dose 2 and 3 l ha\(^{-1}\) (Table 3). We found no significant effect of the biosilica application intensity on plant damage scores in first sampling, while in the second and third sampling plant damage score was significantly different between biosilica application intensity (Table 3). Moreover, the effect of the interaction between dose and application intensity of biosilica was significantly different on third sampling (Figure 1).

Table 3. Plant damage scores for maize treated with different doses and fertilization intensity of biosilica across three samplings

| Treatment | 21 days | 35 days | 49 days |
|-----------|---------|---------|---------|
|           | Biosilica doses (l/ha) (D) |        |         |
| 0         | 4.30 a  | 5.96 a  | 5.88 a  |
| 1         | 4.04 b  | 4.62 b  | 5.51 b  |
| 2         | 3.80 b  | 4.19 c  | 4.47 c  |
| 3         | 3.64 b  | 4.10 c  | 4.17 c  |
| F         | 3.82    | 61.48   | 5.49    |
| P \(_{val}\) | 0.02    | 0.00    | 0.00    |
|           | Intensity of biosilica application (T) |         |         |
| 1         | 3.93    | 4.90 a  | 5.44 a  |
| 2         | 4.01    | 4.61 b  | 4.99 b  |
| 3         | 3.89    | 4.57 b  | 4.60 c  |
| F         | 0.24    | 3.62    | 18.70   |
| P \(_{val}\) | 0.79    | 0.04    | 0.00    |
|           | Interaction |        |         |
| D x T     | ns      | ns      | *       |

Mean values followed by different letters are significantly different (Duncan Multiple range Test, *p*≤0.05), ns = non significant, * significantly different *p*≤0.05
Figure 1. The interaction effect between doses and fertilization intensity of biosilica on maize damage score by *Spodoptera frugiperda*

Silicon is a beneficial substance that can increase plant tolerance to biotic and abiotic stresses, including pathogens, insect herbivores, drought, heat, cold, salinity, metal toxicity, and nutrient deficiency [22, 23, 24, 25, 26]. Silicon application has been shown improved maize resistance to various insect pests such as stalk-borer *Chilo zoneellus* Swinhoe (Lepidoptera: Pyralidae) [27], European corn borer *Ostrinia nubilalis* Hubner (Lepidoptera: Pyralidae) [28], stem borer *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) [29], fall armyworm *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae) [30,31], Asian corn borer *Ostrinia furnacalis* Guenee (Lepidoptera: Crambidae) [32], and leaf corn aphid *Rhopalosiphum maidis* Fitch (Hemiptera: Aphididae) [33]. However, the increasing artificial resistance using biosilica in field scale are unexplored.

Our study clearly demonstrated the application of biosilica reduced FAW damage to maize. Both the percentage of leaves damage and the ears damage by FAW were significantly less on plants fertilized with biosilica. The severity of FAW attack was also seen to be lower in the plants treated with biosilica. The present studies were well supported by Alvarenga et al [34] in *Zea mays* and Jeer et al [35] in *Oryza sativa*. They reported that applications of Si significantly decreased plant damage by herbivory. The silicon treatment increased foliar Si content in maize [33, 36]. This causes an resistance to herbivores through the physical and biochemical mechanisms [36, 37] and affect the development of herbivore [38]. Haq et al [39] reported that FAW fed on maize treated with Si showed a significant negative effect on various biological parameters of FAW. Insect ingested silicon will cause midgut epithelium of the yellow stem borer, *Scirpophaga incertulas* Walker (Lepidoptera: Crambidae), was completely ruptured the peritropic membrane and columnar cell and release of cell granules into the lumen due to abrasion of the midgut epithelium of larvae [35].
3.2. Effect of biosilica fertilizer on plant growth and yield

There was no significant fertilization intensity effect on maize plant height and number of leaf (Table 4). Similarly, number of leaf did not respond to biosilica dose treatment. On the other hand, a significant effect of biosilica dose was observed in maize plant height. Plants which received 1 l Si ha$^{-1}$ had a highest plant height, whereas plant height which received 2 l Si ha$^{-1}$ was no significant different with control (without Si application). There was no clear effect of the interaction between dose and application intensity of biosilica on maize plant height and leaf number (Figure 2).

| Table 4. Effect of biosilica fertilizer doses and fertilization intensity on maize height and number of leaves |
|--------------------------------------------------|
| Treatment | Plant height (cm) | Number of leaf |
| Biosilica doses (l/ha) (D) | | |
| 0 | 170.79 a | 10.55 |
| 1 | 191.35 c | 10.60 |
| 2 | 169.39 a | 10.47 |
| 3 | 174.19 b | 10.55 |
| $P_{\text{row}}$ | **0.00** | **0.98** |
| Intensity of biosilica application (T) | | |
| 1 | 176.77 | 10.55 |
| 2 | 175.73 | 10.44 |
| 3 | 176.74 | 10.63 |
| $P_{\text{row}}$ | **0.69** | **0.24** |
| $D \times T$ | * | * |

Cob yield was significantly different between treatments (Table 5). The yield was significantly less on maize plants that are not fertilized with bio-silica than did those in plants fertilized with biosilica fertilizer. Plants were fertilized with 3 l biosilica ha$^{-1}$, the cob yield was significantly higher than
did those in the others. There are clear effects of both biosilica dose and fertilization intensity on cob yield (Figure 3).

Table 5. Effect of biosilica fertilizer doses and fertilization intensity on maize yield (t/ha)

| Treatment | Biosilica doses (t/ha) (D) | Yield (t/ha) |
|-----------|---------------------------|-------------|
| 0         |                           | 3.68 a      |
| 1         |                           | 4.58 b      |
| 2         |                           | 5.93 c      |
| 3         |                           | 6.54 d      |
| F         |                           | 234.60      |
| \( P_{\text{value}} \) |                   | 0.00        |

| Intensity of biosilica application (T) |       |
|--------------------------------------|-------|
| 1                                    | 4.18 a|
| 2                                    | 5.28 b|
| 3                                    | 6.09 c|
| \( F \)                              | 173.45|
| \( P_{\text{value}} \)               | 0.00  |

\( \text{Interaction} \)

**Figure 3.** The interaction effect between doses and fertilization intensity of biosilica on maize yield (t/ha)

Generally, the mean value of plant height and the number of leaves indicated that increasing the application dose did not guarantee an increase in the values of the two observed growth parameters. The similar trend is seen in the study results of Sugianta et al. [40], Nurmala et al. [41], and Yuvakkumar et al. [42]. This is related to the function of Si which is only as a beneficial element that contributes to supporting plant resistance to exogenous stress conditions both biotic and abiotic while its effect on plant growth and development is not essential [43] or minimal, especially during the vegetative period [44]. Haynes [45] and Kowalska et al. [46] added that Si accumulator plants such as rice and sugarcane are generally more responsive to Si application so that their positive effect on...
growth and production is more significant. Generally, increasing the intensity of fertilization did not give a significantly different mean value of plant height and number of leaves but gave a higher mean value of both. Our findings are similar to other studies such as Pikukuh et al. [47] that have reported an increase in fertilization intensity up to 4 times on sugarcane which is a Si accumulator plant for the entire observation time resulted in the mean value of plant height and number of leaves which in general were not significantly different but higher. The success of Si mediation in increasing plant growth, yield and resistance under stress conditions is determined by the level of Si absorption into plant tissues. One of the factors that affect the Si absorption level is the fertilization method. The results of other studies stated that compared to the foliar Si application, the consistent application of Si to the roots was more effectively absorbed by plants, thereby increasing the Si content in the rice plant tissue [48] and increasing the biomass of shoots and roots of wheat [49]. To ensure an increase in Si uptake, silica deposits and their effect on plant growth and production, it is recommended that the intensity of foliar Si fertilization be more frequent and follow plant growth stages [48, 50].

4. Conclusion

Our results show that the addition of silica fertilizer to maize plants increases resistance to fall armyworms and showed a positive response to the cob yield. Applying silica fertilizer to maize plants did not show clear effect for both plant height and number of leaves. We conclude that application of doses in the range of 2 – 3 l silica fertilizer/ha applied 3 times should be recommended for maize plants protection against fall armyworm.

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