Silicon Based Fertilizer: An Eco-Friendly Approach for Managing Sucking Insect pests

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ABSTRACT

Silicon (Si) fertilizers offer a sustainable strategy for enhancing plant resistance to sucking insect pests. Si is absorbed as monosilicic acid and deposited as amorphous silica, strengthening plant tissues, increasing hardness, reducing digestibility, and limiting stylet penetration by sap-feeding insects. In addition to these physical barriers, Si stimulates biochemical defenses by increasing activities of defense enzymes, phenolics, and lignin, which collectively reduce insect feeding and disease susceptibility. Studies across cropping systems show that Si supplementation decreases the performance, preference, and reproductive capacity of major pests such as aphids, whiteflies, planthoppers, and mealybugs, while also disrupting their development. Multiple Si sources (including calcium, potassium, and sodium silicates) are effective, with soil application providing greater systemic uptake than foliar spraying. Si fertilization also reduces pesticide use, production costs, and enhances yield, supporting environmentally friendly agriculture. When combined with biological control, Si fits well within integrated pest management programs, though optimized strategies for dicots are still needed.

Keywords: Eco-friendly, Physical barriers, Silicon fertilizer, Sustainable, sucking insects

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Introduction

Silico (Si)-based fertilizers constitute a sustainable and economically reliable strategy for improving plant resistance against sucking insect pests through both biochemical and physical defense mechanisms. The impact of silicon has been tested on multiple crop systems while decreasing reliance on synthetic pesticides and enhancing cop yield as well as quality.

Silicon Uptake and Accumulation in Plants

Plant-Specific Silicon Absorption Capacity

Plants showed significant dynamics in absorption of silicon specific amount mostly depends on plant species, genotypes, soil composition, concentration of Si in soil, and environmental conditions. Graminaceous plants like rice absorb and accumulate Si amount approximately 150 to 300 kg Si ha^{-1}, similarly, sugarcane (300 to 700 kg Si ha^{-1}) and Wheat (50-150kg Si ha^{-1}) significantly higher than dicotyledon plants such as cucumbers and soybeans [1]. Silicon present in soil solution in the form of monosilicic acid (H_4SiO_4) at the rate of 01. To 0.6 mM. The plants absorb silicon and transport via xylem to all parts of the plants and its deposits in the form of amorphous form $SiO_2.nH_2O$ in cell walls, bracts and intercellular spaces [2].

Silicon Deposition and Plant Structure

After uptake, silicon is deposited in plant tissues as in form of silica gel or biogenetic opal, forming a physical barrier [2]. This deposition maintains leaves in an erect position, reduces transpiration, decreases digestibility, and increases tissue hardness and abrasiveness, providing protection against insect and fungal attacks [3]. The amorphous silica deposited in epidermal tissues creates a mechanical barrier that directly impacts insect feeding behavior and performance [4]. For example, in resistant variety of sugarcane the silica bodies were recorded in scattered form throughout the pseudostem rather than arranged in distinct rows as seen in susceptible verities, exhibiting greater defense against stalk borers [3]. Similarly, sugarcane scale infestation was lower in clones with more silica cells in the internode wax band, demonstrating the direct relationship between silicon deposition patterns and pest resistance [5].

Mechanisms of Silicon-Enhanced Resistance Against Insect Pests

Physical Defense Mechanisms

Silica deposition based physical defense remains the most widely accepted mechanism by which silicon enhances plant resistance to sucking insect pests. This mechanism operates through two primary pathways: increased tissue hardness and abrasiveness that causes wear on insect mouthparts, and reduced digestibility of plant tissues [3]. Silicon deposition in epidermal tissues creates a mechanical barrier in leaf epidermis cells that increases hardness, causing wear to insect mandibles and reducing digestibility [2]. For instance, De-Oliveira *et al*. (2020) suggested that supplementation of silicon on canola limited the population of aphids at the same time as it attracts its predators [6]. In sugarcane, Kvedaras and Keeping (2007) demonstrated that silicon impedes stalk penetration by the borer Eldana saccharina, with small increases in plant silicon fertilization significantly reducing larval numbers. The physical barrier created by silicon deposition is particularly effective against chewing insects but also impacts piercing-sucking insects by making stylet penetration more difficult [7].

Biochemical Defense Mechanisms

Silicon also enhances plant resistance through biochemical defense mechanisms involving induced production of defensive enzymes and phenolic compounds. When plants are treated with silicon, they exhibit enhanced production and accumulation of chitinases, peroxidases, lignin, and phenolics, which collectively strengthen plant defense responses [2]. Treatment of silicon to melon plants significantly increases the concentration of antioxidants enzymes like superoxide dismutase, chitinase, β-1,3-glucanase, peroxidase and lignin, subsequently decreases the intensity of powder mildew [8]. Studies reported that the potassium silicate decreases the growth of citrus blackfly due to silicon induced activity of polyphenoloxidase and peroxidase in mandarin orange seedlings [6]. For sucking pests specifically, silicon induces different chemical reactions that facilitate activation of defense-related enzymes such as polyphenol oxidase, phenylalanine ammonia-lyase, and trypsin protease inhibitor, making plants less suitable for herbivore feeding and digestion [9].

Impact on Sucking Insect Pests

Reduction in Sucking Pest Performance

Numerous studies have documented that silicon application significantly reduces the performance of sap-feeding pest insects across various crop systems. Silicon treatments have been shown to reduce the population of green bug (*Schizaphis graminum*) on sorghum [10], whitefly (*Bemisia tabaci*) on cucumber and soybean [9], green peach aphid (*Myzus persicae*) on potato [1], spittlebug (*Mahanarva fimbriolata*) onb sugarcane, silvering thrips on peanut, brown plant-hopper (*Nilaparvata lugens*) on rice, leaf aphid (*Rhopalosiphum maidis*) on maize, and citrus black-fly (Aleurocanthus woglumi) on mandarin orange [11]. Positive effects of silicon treatment on wheat were evident as reduced preference, longevity, and fecundity rates, as well as decreased nymph production and feeding times by green bug aphids [1]. In rice, silicon treatments have been shown to inhibit feeding by planthoppers including *Sogatella furcifera* and *Nilaparvata lugens*, with studies correlating increased silicon content in rice with enhanced resistance to these piercing-sucking insects [12]. Silicon polymers in phloem elements may disrupt insect feeding recognition behaviors, with their presence in plant tissues increasing resistance to stylet penetration and eliciting non-preference feeding responses [5].

Physiological and Developmental Effects

Silicon application affects sucking pests through multiple physiological and developmental pathways. Increased silicon plant content via silicate fertilization decreases insect pest growth and performance rates by reducing consumption, decreasing the efficiency of food utilization, lowering digestive efficiency, altering feeding behavior, and counteracting the effects of high plant nitrogen rates that typically promote insect pest performance [3]. For citrus mealybug feeding on green coleus, silicon-based fertilizer applications impacted life history parameters including adult female egg load, size, and developmental time [9]. In greenhouse whitefly feeding on poinsettia, silicon-based fertilizer applications affected development time and adult emergence [5]. Silicon amendment to rice plants impairs sucking behavior of pests like the brown plant-hopper, with studies showing reduced feeding efficiency and increased mortality 10. The tunnel length for larvae of *Diatraea saccharalis* decreased 27% in a susceptible sugarcane variety following fertilization with silicon, demonstrating the physical barrier effect against both chewing and sucking pests [13]. Silicon also influences tritrophic interactions by altering herbivore-induced plant volatile emissions, which can attract more parasitoids to plants treated with silicon, enhancing biological control of sucking pests [7].

Application Methods and Sources of Silicon Fertilizers

Types of Silicon Fertilizers

Two main types of silicon sauces have been used to provide silicone to plant in silicon-poor soil; the treatment of silicon has been done in soil-by drenching and foliar methods [4]. There are two source types of silicon including solid and liquid. The solid source consists of Calcium silicate (Ca2SiO4) and Silicon dioxide (SiO2) fertilizer, and the liquid form of Si includes sodium silicate (Na2SiO3) and potassium silicate (K2SiO3) [1]. In the production of phosphorous and steel the calcium silicate obtains in the form of by product and widely used as silicon fertilizer source having approximately 24 percent silica that is readily available for plant uptake [14]. The ideal features of a silica source include high solubility that makes it readily available to plants in high concentrations and absence of heavy metal contamination, the ability to localize easily within cell spaces, and low const [4]. For effective disease and insect pest management, a suitable silicate fertilizer should supply a high level of soluble silicon [13].

Application Techniques and Timing

The effectiveness of silicon application depends significantly on the method and timing of application. For groundnut, field experiments demonstrated that foliar application of calcium silicate at 2.0%, 3.5%, and 5.0% (25, 30, and 35 days after sowing), soil drenching of calcium silicate at 10.0%, 15.0%, and 20.0% (20 days after sowing), and combined foliage and soil applications all impacted sucking pest populations [14]. In sugarcane, calcium silicate application at 800 kg/ha significantly increased resistance to stalk borers across multiple varieties, with the highest rate providing the greatest reduction in stalk damage [15]. For optimal pest control, silicon should be applied to the soil for root absorption rather than as foliar sprays, as this increases the plant's defense responses to both foliar and root infections. This is primarily due to silicon transporters not being expressed in leaves, making root-absorbed silicon more effective for systemic resistance. However, foliar sprays can still provide some protection, likely due to silicon deposition on the leaf surface creating a physical barrier and having osmotic or pH effects [1, 13].

Economic and Environmental Benefits

Reduction in Pesticide Use and Costs

Si application exhibited significant economic advantages by decreasing the need for pesticides applications. For example, in rice field Si has the ability to decrease numerous important insect pest for economically reliable production of rice by lowing pesticides demand [16].

Eco-friendly approach

The minimum use of chemicals due to silicon not only decreases cost of production, nonetheless, also reduced the environmental contamination. It also reduced the risk of insecticide-resistance development in insect population [1]. Silicon-based approaches offer an alternative that avoids these limitations while providing comparable or superior pest management.

Improved Crop Quality and Yield

In addition to controlling insect pest Si application improved crop quality and yield, offering various advantages economically. For example, the application of silicon in rice crop can improve appearance of grains, enhanced white color leading to better quality for milling with advantages in export in countries with strict SOP and grading standards [16]. The penalty for moving from U.S. No. 2 to U.S. No. 3 rice due to grain discoloration is $0.011/kg, so quality improvement from No. 3 to No. 2 due to silicon application generates an added annual net income of $61.60/ha. In sugarcane, 800 kg/ha of calcium silicate increased percentages of polarity, brix, refined sugar, purity, and mean weight of stalks for certain varieties [1]. Silicon also eliminates or reduces the need for liming in acid soils, with potential annual savings of $101.81/ha. These quality improvements combined with reduced pest damage result in higher marketable yields and better returns for farmers, making silicon application economically viable even when considering the cost of the fertilizer itself [16].

Integrated Pest Management Approaches

The use of silicon in integrated pest management (IPM) techniques shows potential especially when used with biological control agents. Studies showed that silicon fertilization in combination with parasitoid increased stalk borer control upto harvesting and enhanced juice quality in susceptible sugarcane variety. The average parasitism percentage of *T. busseolae* on stalk borer was considerably greater in treated plots where calcium silicate was applied in combination, exhibiting synergistic impact among silicon fertilization and biological control [11]. It also increases tritrophic interactions by changing herbivore-induced plant volatile emissions, which can appeal more parasitoids to plants treated with silicon. In cotton systems, silicon-induced host plant resistance combined with biological control using *Chrysoperla carnea* showed potential for enhanced control of whitefly (*Bemisia tabaci*) with minimal environmental harm [9]. These integrated approaches demonstrate how silicon applications can complement other IPM tactics to provide more sustainable and effective pest management solutions [11].

Conclusion

Silicon based fertilizer offers an eco-friendly and scientifically supported approach for the management of sucking insect pests by dual process of chemical and physical barrier formation. The study evidence showed consistent decrease in pest performance across various types of crop systems, with particular efficacy against sucking insect pests like white fly, mealybugs and aphids etc. For most effective results, the growers should prioritize drenching applications of sodium, potassium and calcium silicate over foliar applications to ensure root absorption and development of systematic resistance. The application of silicon mostly depends on soil conditions, soil composition and crop requirements. Economic analysis confirms that silicon application not only reduces pesticide costs but also enhances crop quality and yield, providing a positive return on investment. Future research should focus on optimizing application protocols for different cropping systems, particularly for dicot plants which have been less extensively studied than graminaceous crops.

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