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RESEARCH ARTICLE

Development of silicon-augmented resistance in rice against brown planthopper (*Nilaparvata lugens* (Stål))

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Abstract

The brown planthopper (Nilaparvata lugens (Stål)) is a major pest of rice, causing severe yield losses and overcoming many conventional resistance sources. Silicon has emerged as a promising supplementary defense factor that strengthens plant tissues and activates biochemical defense mechanisms. Exploring silicon-augmented resistance offers an eco-friendly strategy to enhance rice resilience and reduce reliance on chemical pesticides. A replicated field trial was conducted at the Research Farm, College of Agriculture, Bhawanipatna, Odisha University of Agriculture and Technology (OUAT), Odisha, to study the impact of varietal resistance and the foliar application of silicon (Si), as well as their interaction effects on brown planthopper (BPH) during the kharif crop season of 2023. Ten treatment combinations were used during the trial, including 2 rice cultivars (Lalat and TN1) and 4 Si doses: sodium silicate (2 g mL^{-1}), calcium silicate (2 g mL^{-1}), nano sodium silicate (200 m gL^{-1}) and an untreated check. When compared to the susceptible check, TN1, the resistant rice cultivar Lalat consistently showed a lower number of BPH and nano-Si formulations outperformed non-nano Si compounds in reducing the BPH population. Si-treated Lalat cultivars consistently showed lower BPH population, regardless of the Si formulations used. This suggests that Si application and host plant resistance are compatible. The additive effect of Si further increases resistance in tested rice cultivars and the 2 can be successfully combined for long-term pest management in the rice ecosystem. Plots treated with Si and the Lalat cultivar showed a favorable prey-predator ratio, indicating that the Lalat variety is less detrimental to predators and supports their abundance. Grain yields were higher in the Lalat rice cultivars treated with nano-sodium silicate (4883 kg ha^{-1}) and nano-calcium silicate (4617 kg ha^{-1}).

Keywords: brown plant hopper; calcium silicate; integrated pest management; rice; silicon-augmented resistance; sodium silicate

Introduction

The brown planthopper (BPH), *Nilaparvata lugens* (Stål), is considered one of the most destructive insect pests across India and poses a significant threat to rice production (1). The pest causes direct damage to rice plants by sucking plant sap and, indirectly, by transmitting plant viruses, resulting in yield losses.

Excessive reliance of farmers on chemical insecticides for management of BPH has led to several serious problems such as resurgence in the BPH (2), killing of natural enemies (3), secondary pest outbreak, pesticide resistance, environmental pollution and increased cost of production (4). Number of integrated strategies were developed by the entomologists in the recent past for BPH management. Use of resistant rice varieties is one of the important components of the integrated pest management (IPM) program and represents the most economical, eco-friendly and effective strategy for controlling BPH. However, only a limited number of BPH-resistant rice varieties have been developed by the rice breeders and are currently cultivated in the rice growing areas (5). Therefore, there is an urgent need to explore the manipulation of plant nutrients, which can enhance the plant's resistance to insect pests and help to maintain pest populations below the economic threshold level (ETL).

Rice is a silicon (Si)-loving crop and considered a high Si accumulating plant (6, 7). Si augmentation is considered one of the potential alternatives for enhancing plant resistance to a wide range of insect pests such as sap-feeding insects (8-10), stem-boring insects (11, 12), leaf-chewing insects (13). It plays a vital role in boosting the plant's defence mechanisms against insect pests by strengthening the cell wall (14). It leaves minimal harmful residues in food or the environment and can be easily integrated with other pest management practices (15).

Despite considerable interest in developing rice varieties with resistance to herbivores (16) and increased awareness of the role of Si in induced plant defences (4, 17), there remains a gap in research exploring the interaction effects of advanced Si treatments, particularly nano-Si formulation and host-plant resistance against insect pests and their predators in the rice ecosystem. Therefore, the present study was undertaken to study the effect of varietal resistance and Si application, as well as their interaction effect on the rice BPH and its predators. This strategy would be beneficial in reducing the dependence on chemical pesticides and would promote more sustainable rice farming practices.

Materials and Methods

The field trials were conducted in the Research Farm, Odisha University of Agriculture and Technology (OUAT), Bhawanipatna, during kharif, 2023, in a randomized complete block design with 10 treatment combinations consisting of 2 varieties, i.e, Lalat and TN1 and 4 Si formulations, viz, nano sodium silicate (200 mg L^{-1}), nano calcium silicate (200 mg L^{-1}), sodium silicate (2 g mL^{-1}), calcium silicate (2 g mL^{-1}), along with an untreated check. Each treatment combination was replicated thrice. The foliar application of Si formulations was made at 20, 30 and 40 days after transplanting (DAT) by using a high-volume knapsack sprayer and the population of BPH and its predators was recorded 10 days after the last spray and continued at 10-day intervals, i.e, 50, 60, 70 and 80 DAT in the morning hr (8.0 - 9.00 AM).

Visual counting of nymphs and adults of BPH and their predators, such as spiders, mirid bugs, rove beetles, ground beetles and coccinellid beetles, was made from 10 randomly selected hills from each plot, leaving the 2 border rows from all 4 sides.

The plants were transplanted adopting the inter and intra row spacing of 20 and 15 cm respectively. Chemical fertilizers were applied at the rate of 100:50:50 kg ha^{-1} of nitrogen (N), phosphorus (P) and potassium (K) respectively. Field operations like fertilizer, weed and water management were taken up as and when needed as per the recommendations. Plots are separated from each other by bunds to avoid the inter-plot mixing effect of the treatments.

Statistical analysis

The field data recorded were then subjected to statistical analysis. The treatment variations were tested for significance by F-test. The standard error of means (SEm ±) and critical difference (CD) at 5 % level of significance were computed and used for comparisons of treatment means.

Results and Discussions

The study demonstrated significant effects of varietal resistance, Si application and their interaction on BPH populations. Nano-sodium and nano-calcium silicate treatments at 200 mg L^{-1} were the most effective, achieving 41-42 % population reductions over control. The resistant variety Lalat consistently exhibited lower BPH numbers than the susceptible TN1, with reductions of 58-64 %. Combined use of resistant cultivars and nano-Si formulations resulted in even greater suppression of BPH populations, supporting their compatibility in IPM. Predator observations showed no significant adverse effects of Si treatments on spider, mirid bug, or beetle populations, with prey-predator ratios indicating minimal non-target impacts. Yield data confirmed substantial gains from Si treatments, particularly in resistant varieties, with increases of 42-56 % over control. These results emphasize Si role as an additive, eco-friendly strategy alongside host plant resistance.

Brown planthopper

Foliar application of nano-sodium silicate and nano-calcium silicate at 200 mg L^{-1} was the most effective treatment and significantly reduced BPH population compared to the control. Nano-sodium silicate ranked first (1.50-1.77 hoppers per hill), followed by nano-calcium silicate (1.52-1.80 hoppers per hill), compared to the control (2.48-3.00 hoppers per hill) during different growth stages of the crop, i.e, 50-80 DAT. The present finding confirms that the nano-formulations of sodium and calcium silicate are more effective in controlling BPH populations than their non-nano counterparts, such as sodium silicate and calcium silicate. Earlier studies reported that a wide range of insect pests in agriculture were successfully controlled using surface-charged modified hydrophobic silica nanoparticles (17), as these nanoparticles can disrupt the protective barrier of insects, ultimately leading to their death (18). Nano chemicals are more effective than conventional molecules, likely due to their small size, high surface area and increased reactivity (19).

The percentage reduction of BPH was highest in plots treated with nano-sodium silicate (41.63 %), followed by nano-calcium silicate (40.56 %), calcium silicate (35.23 %) and sodium silicate (34.51 %). This indicates the superiority of the nano-formulations in reducing BPH populations compared to the conventional Si compounds. Sodium silicate (20, 21) and calcium silicate (22) were reported earlier for effective management of insect pests. Decreases in adult fecundity and nymphal survival rate of BPH in rice crop treated with Si were reported earlier (23).

It is clearly evident from the data presented in Table 1 that rice cultivar (Lalat) had a significantly lower number of BPH compared to the susceptible check, TN1. The percentage reduction of the BPH population in the Lalat variety ranged from 58.0-64.33 % compared to the susceptible rice variety, TN1. Present findings clearly indicate that the population increase of BPH is greatly influenced by the degree of host plant resistance and which agrees with previous research findings (24). Lower populations of BPH on resistant rice varieties, compared to those of susceptible varieties, were previously reported (25). This emphasizes the importance of selecting resistant cultivars for effective management of BPH in rice crops.

The result of this study highlighted the combined effect of varietal resistance and Si application, demonstrating a significant impact on reducing the BPH population, beyond their individual effect on the population growth of said pest. The resistant variety 'Lalat' registered a lower BPH population with nano-formulations of sodium silicate (0.99 per hill) and calcium silicate (1.04 per hill) compared to the susceptible TN1 variety, which had a BPH population of 2.30 per hill and 2.31 per hill when treated with nano-formulations of sodium silicate and calcium silicate respectively. A similar trend of the BPH population was observed in the non-nano calcium and sodium silicate treatments. This confirms that host plant resistance and Si application are compatible and can be effectively integrated into an IPM program for the management of BPH. These findings are in conformity with the earlier research work (26), which demonstrated the compatibility of host plant resistance and Si application in reducing BPH populations in rice crops. A study reported that Si reduced feeding, growth, fecundity and population increases of White backed plant hopper on susceptible rice, but not on a resistant rice line carrying the *Wbph1* and *Wbph2* genes (27).

The decrease in BPH population is regarded as one of the important criteria for assessing the resistance level of rice cultivars, as it reflects the combined effects of feeding rate, oviposition and survival rate (28). Various researchers (29, 30) had previously reported that soil Si reduces the fitness of BPH nymphs by impairing phloem sap feeding and deterring settlements on plants (29,30,31). These findings support the idea that integrating Si application with host plant resistance can be an effective strategy in managing BPH

Table1. Effect of varietal resistance and silicon on *N. lugens* during kharif rice, 2023

Silicon/Dose	50 DAT				60 DAT				70 DAT				80 DAT				Mean			
	Lalat	TN1	Mean	ROC (%)	Lalat	TN1	Mean	ROC (%)	Lalat	TN1	Mean	ROC (%)	Lalat	TN1	Mean	ROC (%)	Lalat	TN1	Mean	ROC (%)
Nano sodium silicate (200 mg L^{-1})	1.02 (1.23)	1.97 (1.57)	1.50 (1.40)	39.80	0.98 (1.22)	2.30 (1.67)	1.64 (1.44)	41.81	1.00 (1.22)	2.53 (1.74)	1.77 (1.48)	41.24	0.96 (1.21)	2.40 (1.70)	1.68 (1.46)	43.37	0.99	2.30	1.64	41.63
Sodium silicate (2 g mL^{-1})	1.17 (1.29)	2.15 (1.58)	1.66 (1.43)	33.22	1.33 (1.35)	2.38 (1.70)	1.86 (1.52)	34.18	1.31 (1.35)	2.60 (1.76)	1.96 (1.55)	34.98	1.23 (1.32)	2.60 (1.76)	1.92 (1.54)	35.39	1.26	2.43	1.84	34.51
Nano calcium silicate (200 mg L^{-1})	1.06 (1.25)	1.98 (1.57)	1.52 (1.41)	38.79	1.10 (1.26)	2.33 (1.68)	1.72 (1.47)	39.09	1.03 (1.23)	2.57 (1.75)	1.80 (1.49)	40.24	0.98 (1.21)	2.37 (1.69)	1.68 (1.45)	43.54	1.04	2.31	1.67	40.56
Calcium silicate (2 g mL^{-1})	1.19 (1.23)	2.18 (1.64)	1.69 (1.44)	32.08	1.25 (1.32)	2.37 (1.69)	1.81 (1.51)	35.84	1.25 (1.32)	2.70 (1.79)	1.98 (1.55)	34.31	1.40 (1.38)	2.30 (1.67)	1.85 (1.53)	37.64	1.27	2.38	1.82	35.23
Control	1.47 (1.40)	3.50 (2.00)	2.48 (1.70)		1.50 (1.40)	4.13 (2.15)	2.82 (1.77)		1.58 (1.43)	4.43 (2.22)	3.01 (1.83)		1.70 (1.48)	4.23 (2.18)	2.97 (1.83)		1.56	4.07	2.81	
Mean	1.18 (1.28)	2.36 (1.67)			1.23 (1.31)	2.70 (1.78)			1.23 (1.31)	2.97 (1.85)			1.26 (1.32)	2.78 (1.80)						
		SE(m) ±		CD (0.05)		SE(m) ±		CD (0.05)		SE(m) ±		CD (0.05)		SE(m) ±		CD (0.05)				
Variety		0.02		0.07		0.03		0.09		0.02		0.06		0.02		0.06				
Treatment		0.04		0.12		0.04		0.12		0.06		0.12		0.03		0.09				
Variety x Treatment		0.05		0.15		0.06		0.18		0.06		0.18		0.04		0.12				

*Figures in the parentheses are transformed $(\sqrt{⊠} + 0.5)$ values. **DAT**- Days after transplanting, **ROC**-Reduction over control.

populations in rice ecosystems.

Spider

Plant varieties that attract more numbers of predators or natural enemies can have a significant impact on managing insect pests in the agricultural ecosystem. Using safer molecules for insect pest management allows predators to survive and play a crucial role in a sustainable pest management programme.

Data presented in Table 2 revealed that TN1 consistently recorded a higher spider population (1.14-1.30 per hill) compared to Lalat (0.36-1.10 per hill) might be due to higher prey availability for the spiders in TN1 during the crop period. The present study indicates that the application of Si compounds, whether in normal or nano form, did not have a marked impact on spider populations relative to the control. Mean data presented in Table 2 revealed that sodium silicate recorded a higher spider population (0.74 spiders per hill) followed by calcium silicate (0.65 spiders per hill), compared to nano sodium and nano-calcium silicate (0.60 spiders per hill). The presence of more spiders in plots treated with sodium silicate and calcium silicate could indicate that these treatments did not adversely affect them. Si increases predators and parasitoids' attraction to pest-infested plants and boosts biological control (32, 33).

Mirid bug

The present study revealed that the variety TN1 had a significantly higher number of mirid bugs (1.03 bugs per hill) compared to Lalat (0.90 bugs per hill). This implies the predatory bugs showed a clear preference for the TN1 variety (Table 3). Si treatments had no significant effect on the mirid bug population, indicating they did not have a notable impact on the bug population. Among the treatments, the untreated check plots had the highest bug population (1.15 bugs per hill), followed by nano-sodium silicate and calcium silicate (0.95 bugs per hill), sodium silicate (0.93 bugs per hill) and nano-calcium silicate (0.87 bugs per hill).

Predatory beetles

Population of predatory beetle, viz. coccinellid beetles, ground beetles and rove beetles were recorded from different plots. The susceptible variety TN1 recorded slightly higher predatory beetle populations (1.03 beetles per hill), whereas the resistant variety Lalat recorded 0.92 beetles per hill (Table 3). Since this difference was not statistically significant, it indicates that both varieties supported similar beetle populations.

The untreated check plots had the highest beetle population (1.07 beetles per hill), followed by nano-sodium silicate and sodium silicate (0.98 beetles per hill). No significant interaction effect was found between varietal resistance and Si treatments on the predatory beetle population.

Prey-predator ratio

The molecules with a lower prey-predator ratio compared to the untreated check are most preferred for their incorporation into an integrated pest management programm (34). Safer molecules of Si allow the predators to live in appreciable numbers, which can reduce the increasing pest population. Moreover, varieties which attract more predators will harm pest populations. The prey-predator ratio presented in Fig. 1 provides a clear indication of the comparative toxicity of the molecules to the BPH population and their predators.

Table 2. Impact of silicon and varietal interaction on spider population during kharif rice, 2023

Silicon/ Dose	50 DAT			60 DAT			70 DAT			80 DAT			Mean		
	Lalat	TN1	Mean	Lalat	TN1	Mean	Lalat	TN1	Mean	Lalat	TN1	Mean	Lalat	TN1	Mean
Nano sodium silicate (200 mg L^{-1})	0.12 (0.79)	0.64 (1.01)	0.38 (0.90)	0.22 (0.84)	0.73 (1.10)	0.47 (0.97)	1.00 (1.11)	1.03 (1.20)	1.02 (1.15)	0.27 (0.88)	0.84 (1.14)	0.56 (1.01)	0.40	0.81	0.60
Sodium silicate (2 g mL^{-1})	0.23 (0.84)	0.79 (1.11)	0.51 (0.98)	0.32 (0.90)	0.74 (1.07)	0.53 (0.98)	0.97 (1.20)	1.20 (1.29)	1.08 (1.24)	0.35 (0.92)	1.04 (1.21)	0.70 (1.07)	0.46	1.03	0.74
Nano calcium silicate (200 mg L^{-1})	0.28 (0.88)	0.53 (1.00)	0.41 (0.94)	0.27 (0.88)	0.71 (1.07)	0.49 (0.97)	1.00 (1.12)	1.05 (1.23)	1.03 (1.17)	0.29 (0.88)	0.69 (1.08)	0.49 (0.98)	0.46	0.74	0.60
Calcium silicate (2 g mL^{-1})	0.22 (0.85)	0.81 (1.13)	0.52 (0.99)	0.33 (0.91)	0.38 (0.94)	0.36 (0.92)	0.92 (1.16)	1.15 (1.30)	1.04 (1.23)	0.27 (0.87)	1.18 (1.28)	0.73 (1.08)	0.43	0.88	0.65
Control	0.73 (1.10)	1.14 (1.26)	0.94 (1.18)	0.36 (0.93)	1.22 (1.29)	0.79 (1.11)	1.10 (1.23)	1.30 (1.36)	1.20 (1.29)	0.70 (1.09)	1.30 (1.32)	1.00 (1.21)	0.72	1.24	0.98
Mean	0.32 (0.89	0.78 (1.10)			0.30 (0.89)	0.76 (1.09)	1.00 (1.16)	1.15 (1.27)		0.38 (0.93)	1.01 (1.21)				
	SE(m) ±	CD (0.05)		SE(m) ±	CD (0.05)		SE(m) ±	CD (0.05)		SE(m) ±	CD (0.05)				
Variety	0.05	0.15		0.05	0.15		0.03	0.09		0.05	0.15				
Treatment	0.07	NS		0.07	NS		0.04	NS		0.08	NS				
Variety x Treatment	0.10	NS		0.10	NS		0.06	NS		0.10	NS				

*Figures in the parentheses are transformed (√⊠ + 0. 5) values. **DAT**- Days after transplanting.

Table 3. Impact of varietal resistance and silicon on mirid bug and predatory beetle population in kharif 2023

Silicon/ Dose	Mirid bug			Beetles		
	Lalat	**TN1**	**Mean**	**Lalat**	**TN1**	**Mean**
Nano sodium silicate (200 g mL^{-1})	0.90 (1.18)	1.00 (1.22)	0.95 (1.20)	0.97 (1.21)	1.00 (1.22)	0.98 (1.22)
Sodium silicate (2 g mL^{-1})	0.90 (1.20)	0.93 (1.20)	0.93 (1.20)	0.93 (1.20)	1.02 (1.23)	0.98 (1.21)
Nano calcium silicate (200 g mL^{-1})	0.80 (1.14)	0.93 (1.20)	0.87 (1.17)	0.90 (1.14)	0.93 (1.20)	0.87 (1.17)
Calcium silicate (2 g mL^{-1})	0.90 (1.18)	1.00 (1.22)	0.95 (1.20)	0.90 (1.18)	0.92 (1.19)	0.91 (1.19)
Control	1.00 (1.22)	1.30 (1.34)	1.15 (1.28)	0.88 (1.17)	1.27 (1.23)	1.07 (1.25)
Mean	0.90 (1.19)	1.03 (1.24)		0.92 (1.18)	1.03 (1.23)	
		SE(m) ±	CD (0.05)		SE(m) ±	CD (0.05)
Variety		0.05	NS		0.04	NS
Treatment		0.08	NS		0.08	NS
Variety x Treatment		0.12	NS		0.12	NS

*Figures in the parentheses are transformed (√⊠ + 0. 5) values. **DAT**-Days after transplanting, **ROC**-Reduction over control .

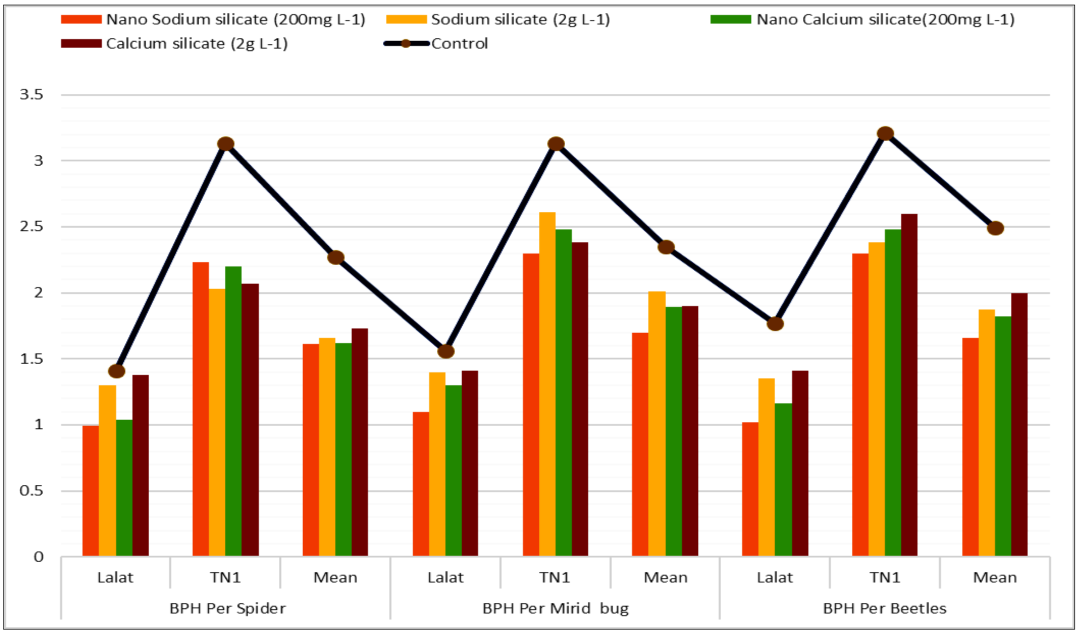

Fig. 1. Impact of varietal resistance and silicon on prey-predator ratio at peak activity of BPH.

Table 4. Effect of varietal resistance and silicon on grain yield of rice (Lalat, TN1) during kharif 2023

Treatment/ Dose	Lalat (Kg ha^{-1})	TN1 (Kg ha^{-1})	Mean	% increase over control
Nano sodium silicate (200 g mL^{-1})	4883	4433	4658	56.40
Sodium silicate (2 g L^{-1})	4450	4033	4242	42.41
Nano calcium silicate (200 g mL^{-1})	4617	4383	4500	51.09
Calcium silicate (2 g L^{-1})	4267	4250	4258	42.98
Control	3100	2857	2978	
Mean	4263	3991		
		SE (m) ±	**CD (0.05)**	
Variety		0.44	1.30	
Treatment		0.69	2.06	
Variety x Treatment		0.98	2.91	

The ratios of BPH per spider, BPH per mirid bug and BPH per predatory beetles were lower in all the Si-treated plots, irrespective of nano and non-nano Si, compared to the control, indicating their safety to all the predators. The present study revealed that nano sodium silicate was the safest compound for the predators, i.e, spider, mirid bug and the predatory beetles like coccinellid beetle, rove beetle, ground beetle, followed by nano calcium silicate, sodium silicate and calcium silicate.

Among the test varieties, TN1 showed a higher number of BPH (2.33 per spider) compared to Lalat, which had 1.20 and 1.23 per spider respectively. It was also found that TN1 noticed higher numbers of BPH (2.58 per mirid bug) and (2.60 per predatory beetles) compared to Lalat, i.e, 1.35 per mirid bug and 1.34 per predatory beetle respectively. The resistant variety, Lalat, exhibited a more favorable prey-predator ratio compared to the susceptible variety TN1. This suggests that Lalat can better support the predator populations and keep the pest population in check. This finding is in conformity with a previous research work (35) where the combined effect of predation by a mirid bug, *Cryptorhinus lividipenis* and resistant cultivars significantly reduces BPH population more than either the predators or cultivars resistant alone. Earlier research at International Rice Research Institute (IRRI) on BPH population in relation to predators and plant resistance revealed that the predation rate was highest on resistant cultivars (36). This was attributed to the greater movement of BPH in search of suitable feeding sites. Resistant rice varieties noticed a lower prey-predator ratio compared to susceptible varieties, indicating that the resistant varieties have lower numbers of prey compared to predators and confirms the compatibility of Host Plant Resistance (HPR) and natural enemies for effective management of BPH population in rice (34).

The lower hoppers/predator ratios observed in Si-treated plots suggest that Si is less harmful to predators, allowing them to thrive and maintain better control over the hopper populations. The favorable prey-predator ratio will provide a combined action of the host plant resistance and predation, which can effectively contain the hopper population in the natural ecosystem. A combination of varietal resistance and predation by mirid bug has a cumulative effect on green leafhopper control (35, 37)

Yield

The grain yield obtained from different treated plots as mentioned in Table 4 revealed that the resistant rice variety Lalat recorded a higher grain yield (4883 kg ha^{-1}) compared to the susceptible variety TN1 (3100 q ha^{-1}). Among the Si treatments, the highest yield was recorded with nano-sodium silicate (4658 kg ha^{-1}), followed closely by nano-calcium silicate (4500 kg ha^{-1}). Nano sodium silicate-treated Lalat cultivars recorded the highest grain yield (4883 kg ha^{-1}), followed by nano-calcium silicate (4617 kg ha^{-1}), sodium silicate (4450 kg ha^{-1}) and calcium silicate (4267 kg ha^{-1}). The application of Si treatments increased crop yield by approximately 42.41-56.40 % compared to the untreated control, highlighting the impact of Si treatments in enhancing rice productivity in resistant rice cultivars like Lalat. The higher grain yield of rice from Si application was reported at Central Rice Research Institute (CRRI), Cuttack, may be due to vertical positioning of the leaves, which exposed a greater surface area to sunlight, thereby enhancing the rate of photosynthesis and ultimately increasing the grain yield (38, 39).

Conclusion

This study confirms the compatibility of host plant resistance and Si application for sustainable BPH management in rice. Si treatments, especially nano-formulations, enhance resistance levels while maintaining natural enemy populations. Integrated use of resistant varieties and Si can reduce reliance on chemical insecticides, mitigate pest resurgence and resistance and improve rice yield sustainably. The most successful treatments were 200 mg L^{-1} of nano -calcium silicate and nano-sodium silicate, which reduced the population by 41-42 % compared to the control. Utilizing Si and resistant cultivars together could reduce the need for chemical pesticides, prevent pest resistance and resurgence and sustainably increase rice yield. Integrated use of resistant varieties and Si can reduce reliance on chemical insecticides, mitigate pest resurgence and resistance and improve rice yield sustainably. This approach offers a viable, eco-friendly component for rice IPM programs.

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Authors' contributions

MD carried out the field studies, collected and compiled data and drafted the preliminary manuscript. SKN identified and conceptualised the research problem and guided MD in carrying out the research work. BM finalised the manuscript and performed the statistical analysis. CB, SB and SD coordinated during the research work and participated in improvisation and final preparation of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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