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Efficacy of Potassium Silicate in Suppressing *Meloidogyne enterolobii* on Okra (*Abelmoschus esculentus* L.)

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Abstract

Potassium silicate (PSi) is widely recognized as a biostimulant that enhances plant growth by improving nutrient uptake, promoting root development, and stimulating vegetative growth. In addition, it has been reported to exhibit nematicidal activity against root-knot nematodes (RKN). However, information regarding its application for the control of *Meloidogyne enterolobii* in Thailand remains limited. Therefore, the objective of this study was to evaluate the potential of PSi in suppressing *M. enterolobii* under both controlled laboratory and greenhouse conditions. Second-stage juveniles (J2s) and eggs of the nematode were exposed to PSi at concentrations of 250, 500, 1,000, and 2,000 ppm, and nematode mortality and hatching were assessed after 2 and 7 days of incubation, respectively. The highest J2 mortality was observed at 2,000 ppm (56.0 ± 5.8%), showing an effect comparable to KCl (positive control). Inhibition of nematode hatching was most pronounced at 500 - 2,000 ppm, resulting in reductions of 58.4 ± 3.7% to 64.5 ± 2.8% relative to the distilled water control. Moreover, PSi concentrations above 500 ppm exhibited nematicidal activity by directly attracting J2 movement. Under greenhouse conditions, okra plants treated with 1,000 and 2,000 ppm prior to nematode inoculation showed the greatest suppression of *M. enterolobii*, reducing galls, egg masses, and eggs by 42.1% - 74.4%, 62.8% - 78.9%, and 54.2% - 80.6%, respectively, and lowering the nematode reproduction factor (Rf) by 3- to 4-fold compared with the RKN-inoculated control. Plant growth, particularly plant height, was also markedly enhanced. Overall, PSi application as a soil drench not only promotes plant development but also exhibits strong potential for suppressing *M. enterolobii* on okra, highlighting its value as a promising component of Integrated Pest Management (IPM) strategies for sustainable RKN control.

Keywords: Biostimulant, Nematode management, Potassium, Root-knot nematodes, Silicon, Soil-borne disease

Introduction

Over the past few decades, root-knot nematodes (RKNs) have increasingly threatened agricultural production, driven by limitations in chemical nematicide use, wider dissemination across certain cropping systems, and the emergence of novel nematode species exhibiting resistance [1]. They inflict substantial damage on crops by inducing root galls, which impair water and nutrient transport, ultimately resulting in lower yields and economic losses [2]. Recently, ten species of RKNs have been identified in Thai agricultural fields, including *M. arenaria*, *M. enterolobii*, *M. exigua*, *M. graminicola*, *M. hapla*, *M. incognita*, *M. javanica*, *M. microcephala*, *M. naasi*, and *M. thailandica* [3,4]. Among these, *M. enterolobii* is the predominant species and has been reported as a serious threat to several Thai crops, including guava, chili, mulberry, and okra [5,6], particularly okra, which is recognized as a highly susceptible host and serves as a model plant for investigating plant-nematode interactions [40]. While the impact of *M. enterolobii* on crop productivity in Thailand has not yet been quantified, its economic consequences have been documented globally, causing up to 50% yield reduction

in tomato [7] and as much as 65% loss in cucumber and tomato rootstocks [8]. The damage threshold of *M. enterolobii* has been reported to be as low as 0.25 J2/g of root tissue, a level markedly lower than those recorded for other *Meloidogyne* species. Moreover, its infection efficiency is estimated to be 30% - 50% higher compared with that of commonly occurring RKN species [9,10]. This nematode has attracted worldwide concern due to its broad host range and distinctive repertoire of effector proteins, which allow it to overcome major resistance genes and establish dense infections in diverse crops. These features highlight the exceptional pathogenic capacity of *M. enterolobii* and position it among the most damaging RKNs affecting global agriculture [11,12].

In Thailand, several studies have identified promising approaches for managing *M. enterolobii*. For instance, Puttawong *et al.* [13] demonstrated that *Bacillus thuringiensis* elicited nematode mortality and suppressed egg hatching under controlled laboratory conditions, thereby markedly diminishing gall and egg mass formation on chili plants by 80% - 95% and 86% - 98%, respectively, relative to the untreated control. Similarly, *Trichoderma harzianum* treatment on guava plants effectively suppressed *M. enterolobii* populations in both roots and soil by inducing host resistance and promoting adventitious root growth [14]. Co-inoculation of *T. asperellum* and *Streptomyces* sp. on chili plants further reduced egg mass and root gall numbers by 71% and 50%, respectively [15]. The predatory nematode *Mylonchulus hawaiiensis* also exhibited strong biocontrol potential, consuming an average of 16.1 *M. enterolobii* J2s per day under *in vitro* conditions [16]. In addition to biocontrol agents, crude extracts derived from green chiretta (*Andrographis paniculata*) and an organophosphate nematicide have demonstrated pronounced nematicidal efficacy against *M. enterolobii* [17,42]. Collectively, these findings indicate that no single method can achieve complete control of RKNs. The most effective strategy is the integration of multiple management approaches within the framework of Integrated Pest Management (IPM) to maximize control efficacy while ensuring ecological sustainability [18]. Consequently, further research is warranted to develop and refine new strategies that combine multiple control methods for practical application.

Silicon, ranking as the second most abundant element on Earth after oxygen, makes up approximately 26% of the Earth's crust. It primarily exists in silicate minerals and is essential for maintaining soil chemistry and structural integrity. Within plants, silicon strengthens cell walls, increases tolerance to both biotic and abiotic stresses, and supports overall growth and development [19]. Potassium is an essential macronutrient in plants, playing a pivotal role in root elongation, vegetative growth, and osmotic regulation. In addition, it regulates a wide array of metabolic processes, including photosynthesis, protein synthesis, stomatal activity, water balance, and carbohydrate metabolism, thereby contributing to overall plant growth and productivity [20]. Currently, several studies have indicated that the combined application of silicon and potassium, commonly delivered as potassium silicate (K_2SiO_3), provides substantial benefits to plants by acting as a biostimulant [21]. Kumar *et al.* [22] reported that foliar application of potassium silicate at 200 mg/L on green chiretta significantly increased plant height (42.86 cm), plant spread (19.68 cm^2), root length (14.87 cm), and leaf size (4.51 cm) compared with other treatments. In addition to promoting plant growth, potassium silicate exhibits nematicidal activity against *Meloidogyne* spp. [23]. For example, it caused 54% mortality of *M. incognita* J2s and significantly reduced the number of galls and egg masses on tomato plants by 59% and 63%, respectively [24]. Similarly, potassium silicate treatment of cucumber markedly decreased the final population density of *M. incognita* by 93.6%, as well as the number of galls and egg masses by 81.0% and 95.0%, respectively, compared with the RKN-treated control [25]. The available evidence suggests that potassium silicate is highly effective in controlling RKNs. However, in Thailand, although its use as a biostimulant has been documented, information regarding its specific application for RKN management remains limited. Therefore, the objective of this study was to evaluate the nematicidal activity of potassium silicate against *M. enterolobii* infecting okra under both controlled laboratory and greenhouse conditions, with the aim of providing insights into its potential application for the sustainable management of RKNs.

Materials and methods

Root-knot nematode (RKN) preparation

The RKN (*M. enterolobii*) used in this study was originally isolated from guava (*Psidium guajava* L.) roots, and its species identity was previously confirmed through morphological and molecular characterization by the Nematology Laboratory, Department of Plant Pathology, Faculty of Agriculture, Kasetsart University. The nematode inoculum obtained was subsequently maintained on okra plants for 2 months before being uprooted for the preparation of eggs and second-stage juveniles (J2s). The isolation of J2s and eggs followed the method outlined by Puttawong *et al.* [13]. Briefly, roots with galls containing egg masses were cut into small pieces (1 - 2 cm long), placed in a 50-mL Falcon tube containing 30 mL of 0.6% NaOCl solution, and hand-shaken for 2 min. The suspension containing nematode eggs was poured through a series of sieves with 150- and 25-µm apertures. Eggs retained on the 25-µm sieve were thoroughly rinsed with tap water and incubated in a Baermann funnel for 7 days until fresh J2s hatched. Eggs and J2s recovered from this process were used in subsequent experiments.

The tested potassium silicate formulation and its rates

The commercial potassium silicate formulation (27% K_2O, 29% SiO_2) from Bioplus (Thailand) Co., Ltd. was obtained for testing against *M. enterolobii* under laboratory and greenhouse conditions. The recommended application rate is 20 mL per 20 L of water, equivalent to 1,000 parts per million (ppm). In this study, potassium silicate was tested at concentrations of 500 (pH 7.5), 1,000 (pH 7.5), and 2,000 (pH 7.5) ppm, while distilled water (pH 7.5) and potassium chloride (8 mg/ml, pH 7.5) were used as controls.

Nematode mortality and hatching

This study aimed to evaluate the direct effect of potassium silicate (PSi) on J2s and eggs of *M. enterolobii*. Briefly, a nematode suspension containing 30 ± 5 J2s or eggs was added to PSi solutions in 96-well microplates to achieve final concentrations of 250, 500, 1,000, and 2,000 ppm. Distilled water and potassium chloride (8 mg/mL) served as controls. This experiment was arranged in a completely randomized design (CRD) with 5 replicates and was repeated once. For the nematode mortality test, inactive J2s were recorded 48 h post-incubation, and the nematodes were then rinsed 3 times with distilled water. At 24 h after rinsing, the nematodes were probed with a needle; those that did not respond were considered dead. For nematode hatching, the number of hatched nematodes was recorded 7 days post-incubation using a stereo microscope (Olympus SZ).

Repellent activity

Chemotaxis assays were conducted following the procedure described by Phanbut *et al.* [17]. Each 55-mm plastic plate was filled with 10 mL of 1.4% water agar and allowed to solidify for 1 h. The plate was then divided into 3 zones (**Figure 1**): the starting point, the treatment point, and the control point. The starting point was located at the center of the plate, while the treatment and control points were positioned on either side of the starting point, each 14 mm away. Vertical lines were drawn as boundaries on either side of the starting point, each 7 mm away. At the treatment point, 10 µL of PSi solutions (250, 500, 1,000, and 2,000 ppm) was applied, while approximately 20 J2s suspended in 10 µL of water were placed at the starting point, and 10 µL of water was added to the control point. Distilled water and potassium chloride (KCl) served as additional controls. The experiment was arranged in a CRD with 5 replications and was repeated once for validation. After 24 h of incubation, the number of J2s in each zone was recorded, and the chemotaxis index (CI) was calculated using the formula: CI = (number of nematodes in the treatment zone - number of nematodes in the control zone) / total number of nematodes in the assay. CI values were interpreted as follows: ≥ 0.2, attractant; 0.2 to 0.1, weak attractant; −0.1 to 0.1, no effect; −0.2 to −0.1, weak repellent; and ≤ −0.2, repellent.

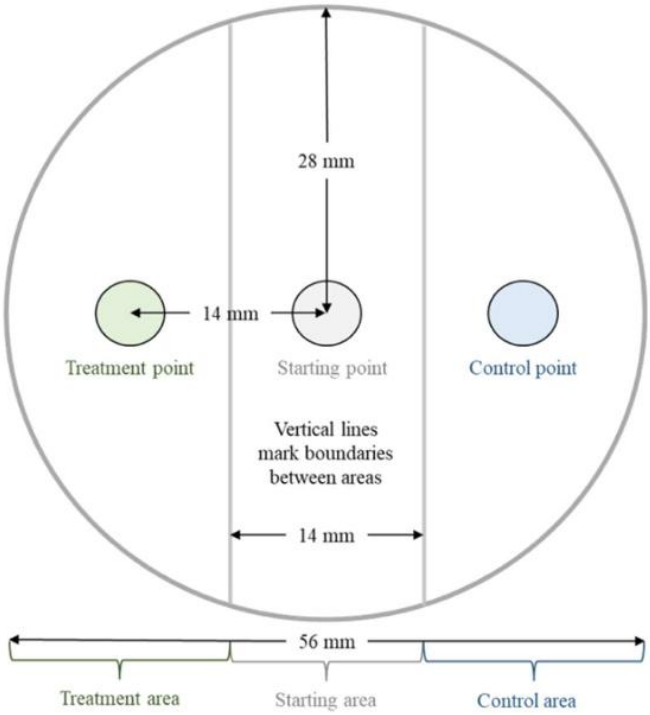

Figure 1 Schematic representation of a chemotaxis assay adapted from Phanbut *et al.* [17].

Greenhouse experiments

This experiment was conducted in the greenhouse of the Department of Plant Pathology, Faculty of Agriculture, Kasetsart University, from March to June 2025. Seven-day-old okra seedlings were transplanted into 14-cm-diameter pots filled with 500 g of sterilized soil, with one seedling per pot. At 5 days post-transplantation, the okra plants were subjected to the following treatments: 1) Distilled water only, 2) RKN only (500 J2s/pot), 3) PSi only (2,000 ppm), 4) PSi (500 ppm) + RKN (500 J2s/pot), 5) PSi (1,000 ppm) + RKN (500 J2s/pot), and 6) PSi (2,000 ppm) + RKN (500 J2s/pot). For the treatments involving both Si and RKN, 30 mL of Si solution (A total of 16.8 and 33.6 µL of active ingredient per pot for the 1,000 and 2,000 ppm treatments, respectively) was drenched around the rhizosphere of each plant 24 h prior to RKN inoculation. The current experiment was conducted in a randomized complete block design (RCBD) with 4 replicates for trial 1 and 3 replicates for trial 2. Plants were maintained in the greenhouse under long-day conditions (12 h photoperiod) at 30 ± 5 °C day/night temperatures. Watering (100 mL tap water/pot) was applied 3 times per week. N-P-K fertilizer (16-16-16) was applied at a rate of 0.2 g per pot once at 7 days after treatment. At 5 weeks post-treatment, the plants were uprooted, washed with tap water, and evaluated for the number of galls, egg masses, and eggs per gram of root. The nematode reproduction factor (RF) was calculated using the formula: final nematode density/initial nematode density [26]. In addition, plant growth parameters, including plant height, root weight, fresh shoot weight, and dry shoot weight, were recorded.

Statistical analysis

Based on the *in vitro* results, data from the 2 trials were combined for statistical analysis, as no significant differences were observed according to Student's *t*-test ($p > 0.05$). In contrast, the greenhouse experiments were analyzed separately because they were conducted at different time periods. Data were analyzed using R (version 4.5.1). The normality of the data was tested using the Shapiro-Wilk test, which confirmed a normal distribution, the homogeneity of variances was tested using Levene's test. Differences among means were determined using one-way analysis of variance (ANOVA), and mean comparisons were performed using Duncan's multiple range test (DMRT) at a 95% confidence level. The Boxplots were generated and visualized with Chiplot (https://www.chiplot.online/).

Results and discussion

Nematode mortality and hatching

To evaluate the nematicidal properties of PSi, nematode J2s or eggs were mixed with the chemical at different concentrations (250, 500, 1,000, and 2,000 ppm) in 96-well microplates, and nematode mortality and hatching were recorded at 2 and 7 days post-incubation, respectively. Overall, PSi exposure led to a marked increase in nematode inactivity and mortality relative to the untreated control. The most effective concentration was 2,000 ppm, followed by 1,000 and 500 ppm, which resulted in increases over the control (mean ± SE) of 51.8 ± 5.5%, 24.3 ± 6.3%, and 24.2 ± 6.0%, respectively. In contrast, the lowest concentration (250 ppm) did not significantly differ from the untreated control (**Figure 2(A)**). Consequently, the treated nematodes were rinsed with distilled water to evaluate the effect of PSi on nematode mortality. Some nematodes recovered from their inactive state, particularly at the lower concentrations of 250 and 500 ppm. In contrast, higher concentrations (1,000 and 2,000 ppm) were associated with increased mortality. In the present study, the most effective concentration was 2,000 ppm, which resulted in 56.0 ± 5.8% mortality - comparable to the positive control (KCl, 61.1 ± 6.7%) (**Figure 2(B)**).

Regarding nematode hatching, all concentrations of PSi exhibited nematicidal activity by reducing the number of hatched juveniles compared with the untreated control. The efficacy did not increase with higher concentrations; specifically, 500, 1,000, and 2,000 ppm produced comparable effects, reducing hatching by 58.4 ± 3.7% to 64.5 ± 2.8%, which was significantly greater than the positive control (KCl, 46.1 ± 2.9%) (**Figure 3**). Based on these *in vitro* assays, PSi demonstrated toxicity against *M. enterolobii* J2s by both increasing mortality and suppressing hatching. Similar findings were reported by Bicalho *et al.* [27], although their work focused on a different RKN species (*M. paranaensis*). In contrast, Ardakani [28] found that J2 mortality and immobility were not affected by silica nanoparticles under laboratory conditions. Silicate solutions often have a high pH, which can damage nematode cuticles or interfere with their metabolism, leading to mortality. However, in this study, the pH of PSi was 7.5, similar to that of distilled water, and did not affect nematode mortality. Therefore, the observed nematode mortality was likely caused by the toxic effect of silicate ions. Despite the limited research on PSi in RKN management, our findings demonstrate that the incorporation of PSi into nematode suspensions (J2s and eggs) exerts pronounced nematicidal effects, inducing juvenile mortality and suppressing nematode hatching. To further validate its efficacy, PSi was subsequently evaluated in greenhouse experiments.

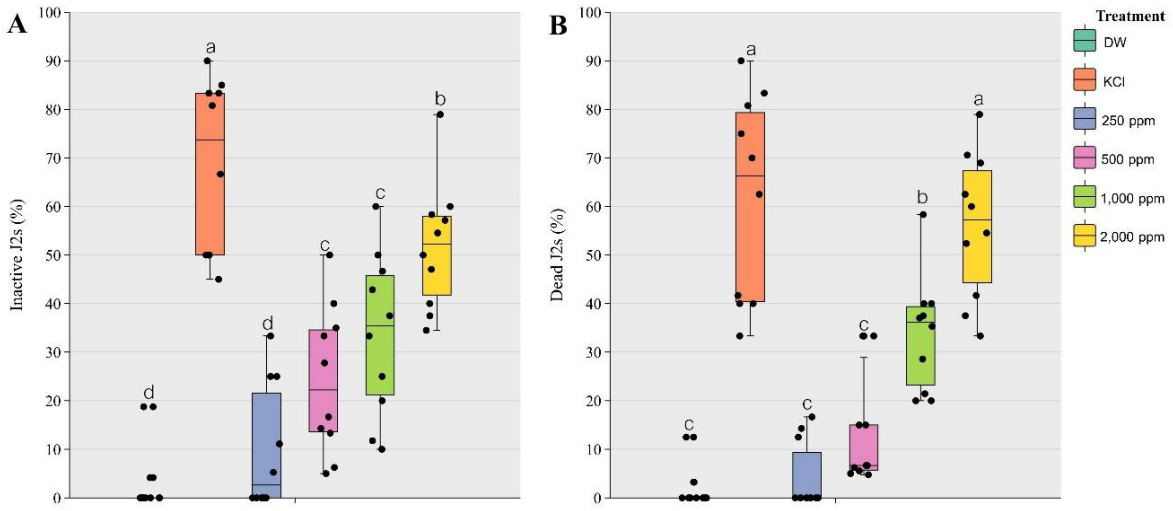

Figure 2 Box plots showed the percentage of inactive (A) and dead (B) second-stage juveniles of *Meloidogyne enterolobii* after 48 h of incubation with different concentrations of potassium silicate. Distilled water (DW) and potassium chloride (KCl) were used as controls for comparison. Mean comparisons (n = 10) were conducted using Duncan's Multiple Range Test at the 0.05 significance level. Bars sharing the same lowercase letter are not significantly different.

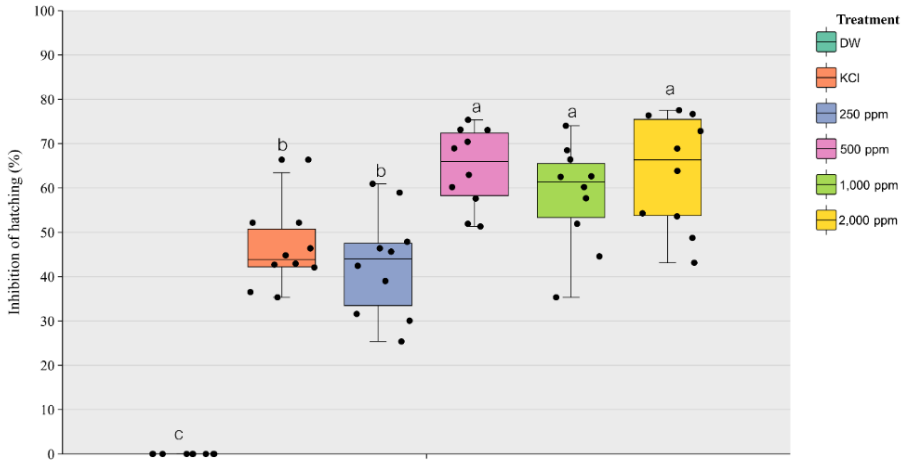

Figure 3 Box plots showed the percentage of *Meloidogyne enterolobii* hatch after 7 days of incubation with different concentrations of potassium silicate. Distilled water (DW) and potassium chloride (KCl) were used as controls for comparison. Mean comparisons (n = 10) were conducted using Duncan's Multiple Range Test at the 0.05 significance level. Bars sharing the same lowercase letter are not significantly different.

Repellent activity

The repellent activity of PSi against RKN was evaluated by assessing their movement and distribution. At 24 h post-treatment, the results indicated that J2s were attracted to PSi at 500 ppm and above, whereas 250 ppm had no effect on nematode movement, similar to the responses observed in the controls treated with distilled water and KCl (**Table 1**). This study demonstrates that higher concentrations (≥ 500 ppm) of PSi attract the movement of *M. enterolobii* J2s, similar to other chemicals with comparable properties, such as potassium nitrate [29] and raffinose and maltose released from the root exudates of tomato and *Medicago* spp. [30]. In contrast, some chemicals exhibit a repellent effect on RKN, such as sesquiterpene acid from vetiver [31] and andrographolide from green chiretta [17]. The presence of soluble silicon in plant tissues has been shown to attract natural predators and parasitoids during pest infestations, thereby enhancing biological control [43]. According to Connick [44], silicon fertilization can modify or increase the emission of herbivore-induced plant volatiles in *E. postvittana*-infested grapevines, making the plants more appealing to the generalist predator *Dicranolaius bellulus*. To date, the effect of PSi on nematode movement has not been reported. This study provides the first evidence that PSi can influence nematode attraction.

Table 1 Repellent activity of potassium silicate at concentrations of 250, 500, 1,000, and 2,000 ppm on the movement of *M. enterolobii* second-stage juveniles at 24 h after incubation, compared with controls (distilled water and KCl). The chemotaxis index (CI) is presented as mean ± standard error.

Treatment	CI value
Distilled water	0.03 ± 0.02b
KCl	0.07 ± 0.0b
250 ppm	0.09 ± 0.06b
500 ppm	0.20 ±0.06ab
1,000 ppm	0.35 ± 0.10a
2,000 ppm	0.30 ± 0.07a

Mean (n = 10) comparisons were performed using Duncan's Multiple Range Test at the 0.05 significance level. Values within a column followed by the same lowercase letter are not significantly different. Chemotaxis index (CI): ≥ 0.2 indicated an attractant; between 0.2 and 0.1, a weak attractant; 0.1 to −0.1, without effect; between −0.1 and −0.2, a weak repellent; and ≤ −0.2, a repellent.

Greenhouse experiments

The efficacy of PSi application for nematicidal activity against *M. enterolobii* and its effects on okra growth are presented in **Table 2** and **Figures 4** and **5**. At 5 weeks post-treatment, results were consistent across both trials, with PSi-treated plants exhibiting fewer root galls, egg masses, and nematode eggs per gram of root compared to the RKN-inoculated controls. In Trial 1, the highest efficacy of PSi against *M. enterolobii* infection was observed at 1,000 and 2,000 ppm, reducing galls, egg masses, and eggs by 70.7% - 74.4%, 69.7% - 78.9%, and 73.5% - 80.6%, respectively. In contrast, in Trial 2, the highest efficacy was observed at different concentrations: 500 - 2,000 ppm for root galls (42.1% - 54.6% reduction), 2,000 ppm for egg masses (62.8% reduction), and 1,000 - 2,000 ppm for nematode eggs (54.2% - 69.0% reduction). Additionally, the nematode Rf value was significantly reduced in plants treated with 2,000 ppm PSi, by 4.0-fold in Trial 1 and 3.2-fold in Trial 2, compared to the RKN-inoculated control (**Figure 4**). In this study, Trials 1 and 2 yielded differing results regarding the concentration of PSi most effective in reducing egg masses and eggs. This variability may be attributed to environmental fluctuations between the trial periods, highlighting the need for additional experiments to confirm the findings and ensure reproducibility. Nevertheless, the results of this study demonstrated that PSi treatment significantly reduced *M. enterolobii* infection in okra roots, consistent with [24], who reported that PSi application in tomato plants decreased *M. incognita* population density and nematode Rf values. Several studies have further shown that silicon-treated plants are effective in suppressing RKN populations. In coffee, silicon application enhances biochemical responses that strengthen resistance to *M. exigua* by suppressing its reproductive capacity [32]. A similar result was observed in cowpea, where silicon treatment reduced *M. javanica* infection and lowered the Rf value in roots [33]. Moreover, PSi application achieved a level of *M. enterolobii* suppression comparable to that of *Bacillus thuringiensis* used in chili plants (80% - 95% gall reduction and 86% - 98% egg mass reduction) [13]. Therefore, this study highlights that applying PSi as a root drench in okra is an effective *M. enterolobii* management strategy that could be integrated into an IPM program.

There are several possible mechanisms by which PSi controls RKNs. Firstly, PSi exhibits nematicidal properties by killing nematode juveniles and reducing hatching. This assertion is substantiated not only by the present results but also by the findings of Bicalho *et al.* [27]; El-Saedy *et al.* [34], who demonstrated its nematicidal efficacy against *M. incognita* and *M. paranaensis* under *in vitro* conditions. Secondly, [38, 41] highlight that an important role of silicon application against phytopathogens (i.e., bacteria, fungi, and nematodes) is the activation of plant resistance, as it functions as an elicitor that induces systemic acquired resistance (SAR) through the upregulation of defense-related genes in the salicylic acid (SA) pathway. [35] reported that sugarcane treated with silicon exhibited higher peroxidase activity, which resulted in a reduction of *M. incognita* in the roots. Peroxidase (POD) enzymes are pivotal components of plant defense, being implicated in multiple processes such as pathogen resistance and stress adaptation through their involvement in antioxidant protection and the biosynthesis of antimicrobial metabolites [36,37]. Another experiment conducted by [38] demonstrated that root-applied silicon reduced the population density and delayed the development of *M. graminicola* in rice roots, which was correlated with elevated transcript levels of defense-related genes (*OsERF1*, *OsEIN2*, and *OsACS1*) in the ethylene (ET) pathway. Thus, the decreased incidence of *M. enterolobii* infection in okra roots observed in this study is likely attributable to the mechanisms outlined above, with the primary mechanism already validated. Future investigations should prioritize elucidating the extent to which PSi induces plant resistance, including measurements of enzymes associated with plant defense responses and the expression levels of defense-related genes, thereby providing deeper insights into its mode of action against *M. enterolobii*.

Table 2 Influence of potassium silicate (PSi) treatments at different concentrations on *Meloidogyne enterolobii* (RKN) in okra plants under greenhouse pot assays.

Treatment	No. of galls/g root	Reduction (%)	No. of egg masses/g root	Reduction (%)	No. of eggs/g root	Reduction (%)
Trial 1						
Distilled water	0b	-	0c	-	0b	-
PSi (2,000 ppm)	0b	-	0c	-	0b	-
RKN	44.4 ± 3.7a	-	37.9 ± 2.3a	-	8,453.7 ± 1,259.4a	-
500 ppm PSi + RKN	46.9 ± 9.9a	-	31.9 ± 5.3a	-	6,505.0 ± 1,519.1a	-
1,000 ppm PSi + RKN	11.4 ± 3.1b	74.4 ± 6.9	8.0 ± 2.1bc	78.9 ± 5.4	2,241.0 ± 335.9b	73.5 ± 4.0
2,000 ppm PSi + RKN	13.0 ± 2.6b	70.7 ± 6.0	11.5 ± 2.2b	69.7 ± 5.9	1,637.5 ± 176.3b	80.6 ± 4.0
Trial 2						
Distilled water	0c	-	0b	-	0c	-
PSi (2,000 ppm)	0c	-	0b	-	0c	-
RKN	31.1 ± 9.5a	-	20.6 ± 7.5a	-	5,149.2 ± 1,434.4a	-
500 ppm PSi + RKN	14.1 ± 2.6b	54.6 ± 8.4	10.7 ± 0.7ab	-	2,856.2 ± 1,069.8ab	-
1,000 ppm PSi + RKN	18.0 ± 1.2b	42.1 ± 3.7	10.3 ± 2.7ab	-	2,357.3 ± 726.3bc	54.2 ± 14.1
2,000 ppm PSi + RKN	15.8 ± 3.0b	49.1 ± 9.7	7.7 ± 1.5b	62.8	1,595.0 ± 348.8bc	69.0 ± 6.8

Data are presented as means ± standard error (n = 4 for trial 1; n = 3 for trial 2). Mean comparisons were performed using Duncan's Multiple Range Test at the 0.05 significance level. Values within a column followed by the same lowercase letter are not significantly different.

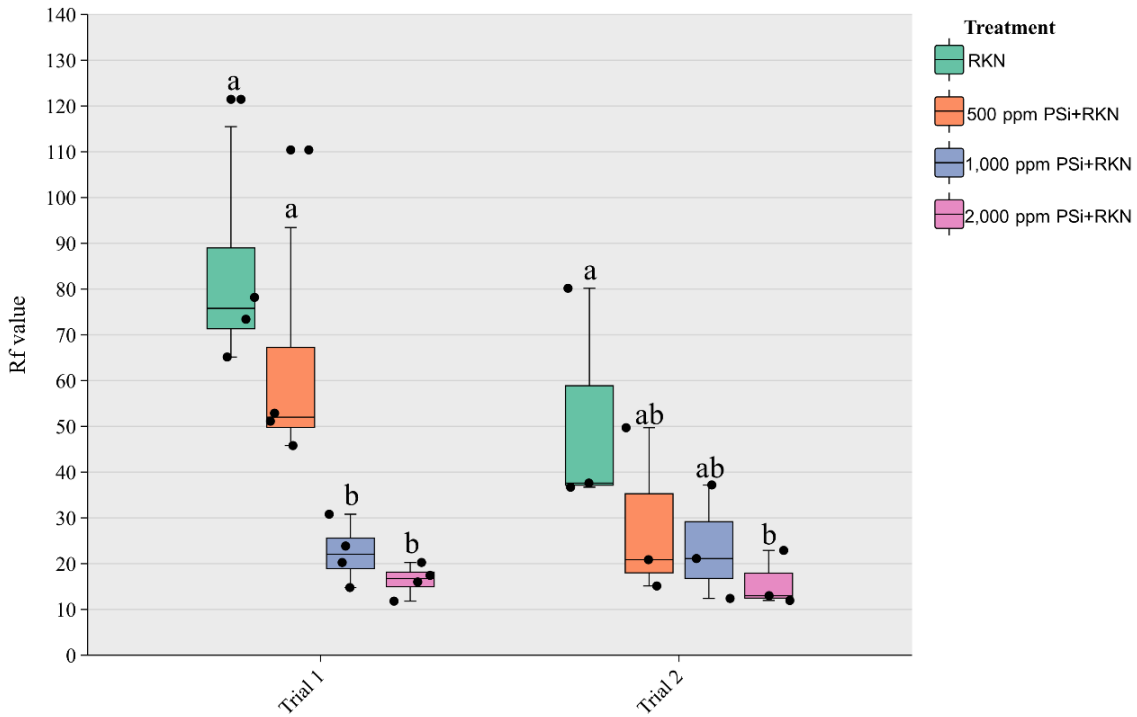

Figure 4 Nematode reproduction factor (Rf) of *Meloidogyne enterolobii* (RKN) on okra plants treated with different concentrations of potassium silicate (PSi). Mean comparisons (n = 4 for trial 1; n = 3 for trial 2) were conducted using Duncan's Multiple Range Test at the 0.05 significance level. Bars sharing the same lowercase letter within each trial do not differ significantly.

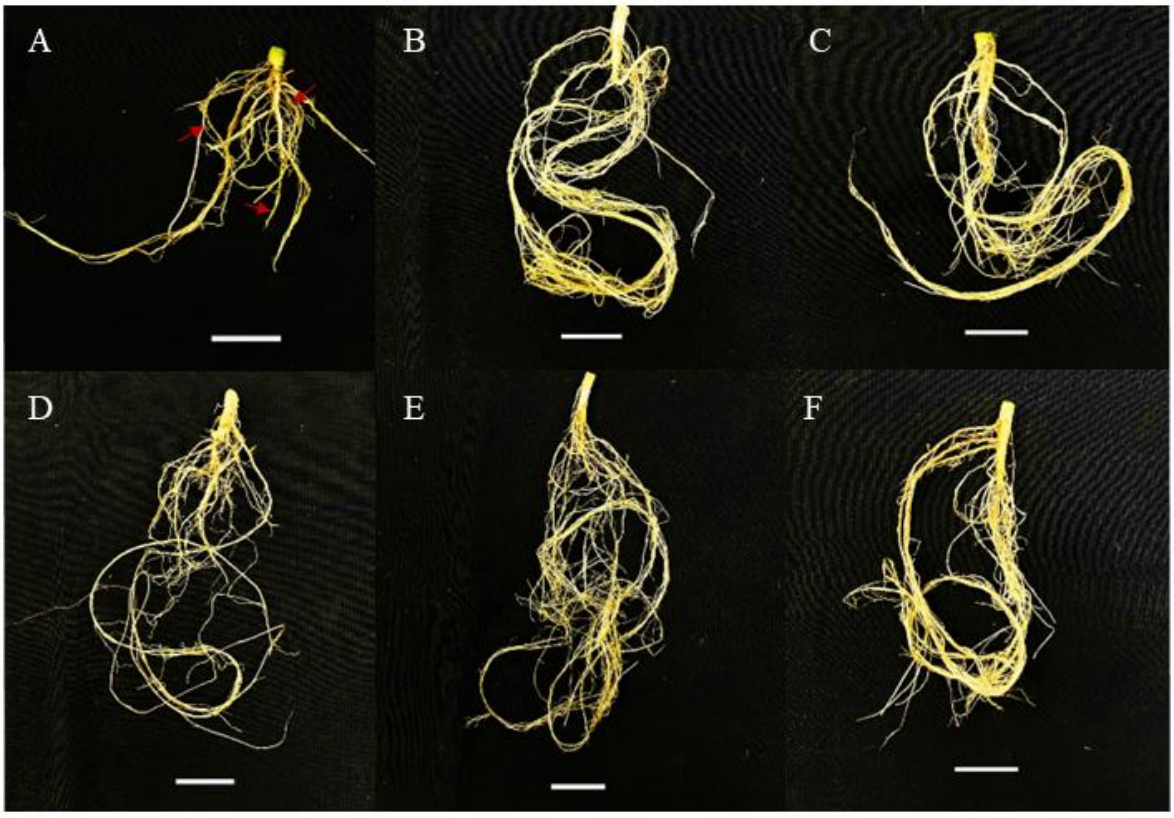

Figure 5 Okra plants treated with potassium silicate (PSi) at concentrations of 500 (D), 1,000 (E), and 2,000 ppm (F) prior to *Meloidogyne enterolobii* (RKN) inoculation. RKN (A), distilled water (B), and PSi (C) served as controls. Root gall symptoms are indicated by red arrows. The scale bar represents 2 cm.

The application of PSi into roots not only reduce the nematode population but also promote the growth of okra (**Figure 6**). The results showed that okra treated with all concentrations of PSi (500 - 2,000 ppm) prior to RKN inoculation exhibited a significant increase in plant height compared with the RKN-inoculated control, ranging from 16.3% to 25% in trial 1 and 50.6% to 53.8% in trial 2, respectively. Although other parameters, such as root weight, fresh shoot weight, and dry shoot weight, did not differ significantly from the RKN-inoculated control, there was a tendency for an increase in the plants treated with PSi. Since the experiment was conducted under greenhouse conditions and data were collected only 5 weeks post-inoculation, prolonged monitoring may highlight more pronounced growth-enhancing effects of PSi. These results are consistent with previous studies. For instance, [24] reported that PSi application enhances tomato growth under RKN stress, while Santos *et al.* [39] reported that silicon effectively suppressed *M. incognita* and promoted growth in nematode-infected cotton plants compared to the control. Silicon supplied via fertigation increased its accumulation in the plants, reduced *M. incognita* infestation, and enhanced shoot dry matter development at 69 and 185 days after inoculation. To date, the use of PSi for managing RKN has not been investigated in Thailand. This study is the first to demonstrate the efficacy of PSi in suppressing *M. enterolobii* in okra plants, providing a promising approach for improving crop health and productivity.

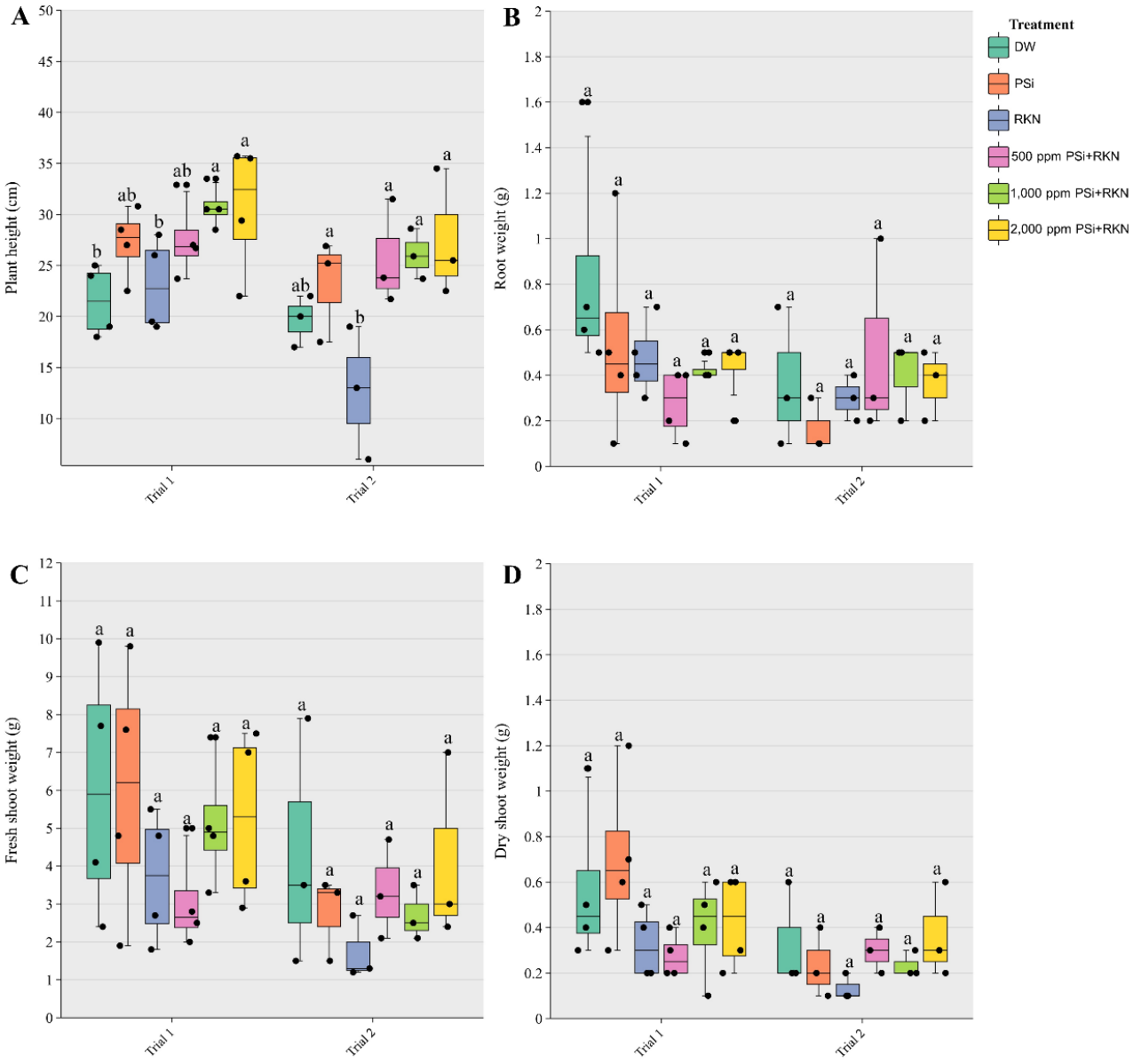

Figure 6 Influence of potassium silicate (PSi) treatments at different concentrations and *Meloidogyne enterolobii* (RKN) inoculation on okra growth: plant height (A), root weight (B), fresh shoot weight (C), and dry shoot weight (D). Mean comparisons (n = 4 for trial 1; n = 3 for trial 2) were conducted using Duncan's Multiple Range Test at the 0.05 significance level. Bars sharing the same lowercase letter within each trial do not differ significantly.

Conclusions

In summary, our investigation highlights the efficacy of PSi in suppressing the eggs and second-stage juveniles (J2s) of *M. enterolobii*. The highest nematode mortality was observed in J2s treated with 2,000 ppm, while hatching inhibition was noted at 500 ppm. Additionally, PSi concentrations above 500 ppm exhibited an attractant effect on *M. enterolobii*. Likewise, the results were consistent with greenhouse experiments, where plants treated with 2,000 ppm showed significant reductions in the numbers of galls, egg masses, eggs, and the Rf value, while plant growth, particularly plant height, was enhanced. Overall, these findings highlight the potential of PSi as a dual-function agent that both promotes plant growth and suppresses *M. enterolobii*. Therefore, the application of PSi as a soil drench at transplanting, in combination with other compatible agents, could serve as a promising

component of sustainable Integrated Pest Management (IPM) strategies.

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Declaration of generative AI in scientific writing

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Supansa Pluembumler: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Software, Project administration, Writing - Original draft preparation; **Natthidech Beesa**: Data curation, Investigation, Software, Writing - Original draft preparation, Visualization; **Anongnuch Sasnarukkit**: Supervision, Validation, Data Curation, Resources, Writing - Review & Editing, Resources; **Buncha Chinnasri**: Conceptualization, Validation, Investigation, Resources, Supervision, Funding acquisition, Writing - Reviewing and Editing.

References

[1] F Forghani and A Hajihassani. Recent advances in the development of environmentally benign treatments to control root-knot nematodes. *Frontiers in Plant Science* 2020; **11**, 1125.

[2] A Afzal and T Mukhtar. Revolutionizing nematode management to achieve global food security goals: An overview. *Heliyon* 2024; **10(3)**, e25325.

[3] K Jindapunnapat, B Chinnasri, N Beesa and N Chomphuphuang. Molecular phylogeny and morphological studies reveal a 30-year-oldrain tree (*Samanea saman*) maintains populations of *Meloidogyne enterolobii*, a new host plant in Thailand. *Journal of Phytopathology* 2023; **171(9)**, 409-420.

[4] N Beesa, N Kuncharoen, T Dethoup, K Jindapunnapat, A Sasnarukkit and B Chinnasri. Prevalence and characterization of plant-parasitic nematodes existing in RD41 rice fields in Pathum Thani Province, Thailand, with emphasis on *Hirschmanniella mucronata* and *Meloidogyne graminicola*. *Trends in Sciences* 2024; **21(12)**, 8952.

[5] C Boonrin, N Beesa, K Jindapunnapat, A Sasnarukkit, PJ Chen and B Chinnasri. Morphological and molecular identification of *Meloidogyne enterolobii* populations from different chili-cultivated areas in Ubon Ratchathani province, Thailand. *Trends in Science* 2024; **21(8)**, 7816.

[6] J Tangkam, N Beesa, A Suwanngam, K Puttawong, P Phanbut, T Korsrisakul, A Sasnarukkit and B Chinnasri. First report of *Meloidogyne enterolobii* infecting mulberry cv. Chiang Mai 80 (*Morus alba*) in Thailand. *New Disease Reports* 2024; **50(1)**, e12296.

[7] R Cetintas, J Brito and D Dickson. Virulence of four Florida isolates of *Meloidogyne mayaguensis* to selected soybean genotypes. *Nematropica* 2008; **38(2)**, 127-136.

[8] S Kiewnick, G Karssen, J Brito, M Oggenfuss and JE Frey. First report of root-knot nematode *Meloidogyne enterolobii* on tomato and cucumber in Switzerland. *Plant Disease* 2008; **92(9)**, 1370.

[9] JA Velloso, MAD Maquilan, VP Campos, JA Brito and DW Dickson. Temperature effects on development of *Meloidogyne enterolobii* and *M. floridensis*. *Journal of Nematology* 2022; **54(1)**, e20220013.

[10] M Shi, R Liu, DUN Madhusanka, Y Liu, N Luo, W Guo, J Zhao, H Li and Z Mao. Emerging threat of *Meloidogyne enterolobii*: Pathogenicity mechanisms and sustainable management strategies in the context of global change. *Microbiological Research* 2025; **16(8)**, 165.

[11] JB Pinheiro, LS Boiteux, MRA Almeida, RB Pereira, LCS Galhardo and RMDG Carneiro. First report of *Meloidogyne enterolobii* in capsicum rootstocks carrying the *Me1* and *Me3*/*Me7* genes

in central Brazil. *Nematropica* 2015; **45(2)**, 184-188.

[12] WB Rutter, PA Wadl, JD Mueller and P Agudelo. Identification of sweet potato germplasm resistant to pathotypically distinct isolates of *Meloidogyne enterolobii* from the Carolinas. *Plant Disease* 2021; **105(10)**, 3147-3153.

[13] K Puttawong, N Beesa, S Kasem, K Jindapunnapat, B Chinnasri and A Sasnarukkit. Potential of *Bacillus* spp. against root-knot nematode, *Meloidogyne enterolobii*, parasitizing chili (*Capsicum annuum* L.). *Crop Protection* 2024; **184**, 106780.

[14] K Jindapunnapat, B Chinnasri and S Kwankuae. Biological control of root-knot nematodes (*Meloidogyne enterolobii*) in guava by the fungus *Trichoderma harzianum*. *Journal of Developments in Sustainable Agriculture* 2013; **8(2)**, 110-118.

[15] P Sakorn and P Ruanpanun. Potential of combination of *Trichoderma asperellum* strain Cb-pin01 and *Streptomyces* sp. strain KPS-E004 in controlling *M. enterolobii* of chili. *Journal of Agricultural Science and Management* 2023; **6**, 15-22.

[16] M Phonginsee, N Beesa, A Suwanngam, K Jindapunnapat, S Chowpongpang, B Chinnasri and A Sasnarukkit. Characterization and biocontrol potential of predatory nematodes (Mononchida and Dorylaimida) against *Meloidogyne enterolobii* in Thailand. *International Journal of Agriculture and Biosciences* 2025; **14(5)**, 862-871.

[17] P Phanbut, K Puttawong, A Suwanngam, N Beesa, K Jindapunnapat, A Sasnarukkit and B Chinnasri. Nematicidal potential of green chiretta extracts against *Meloidogyne enterolobii* and *M. incognita*: *In vitro* assessment for agricultural application. *Trends in Sciences* 2024; **21(10)**, 8151.

[18] TS Devi, HS Behera, A Madhu, Samreen, S Chaudhary, S Koushal and P Reddypriya. A comprehensive review on integrated pest management in nematode. *International Journal of Research in Agronomy* 2024; **7(12)**, 760-765.

[19] M Luyckx, JF Hausman, S Lutts and G Guerriero. Silicon and plants: Current knowledge and technological perspectives. *Frontiers in Plant Science* 2017; **8**, 411.

[20] J Zhang, J Ding, M Ibrahim, X Jiao, X Song, P Bai and J Li. Effects of the interaction between vapor-pressure deficit and potassium on the photosynthesis system of tomato seedlings under low temperature. *Scientia Horticulturae* 2021; **283**, 110089.

[21] A Oraee and A Tehranifar. Relationship between silicon through potassium silicate and salinity tolerance in *Bellis perennis* L. *Silicon* 2023; **15**, 93-107.

[22] SR Kumar, AC Jnanesha, S Bharathkumar, K Sravya, S Venugopal and RK Lal. Unveiling the effect of foliar applied siliceous compounds on reducing seed shattering for the conservation of endangered kalmegh (*Andrographis paniculata* (Burm. f.) wall. ex nees). *Biocatalysis and Agricultural Biotechnology* 2025; **68**, 103700.

[23] S Saher. Potassium silicate: A better approach to flight root-knot nematode (*Meloidogyne incognita*). *Asian Journal of Emerging Research* 2020; **2**, 3-4.

[24] D Khairy. Nematicidal activity of jojoba oil, potassium silicate and bio-nematon singly or integrated against *Meloidogyne incognita, in vitro*, and *in vivo*. *Journal of Plant Protection and Pathology* 2025; **16(1**), 7-12.

[25] AG El-Sherif, SB Gad and SM Saadoon. Impact of potassium silicate application on *Meloidogyne incognita* infecting cucumber plants under greenhouse conditions. *Asian Journal of Nematology* 2016; **5(1)**, 1-7.

[26] O Filialuna, C Wram and I Zasada. What is the optimal way to assess *Meloidogyne* spp. reproduction in greenhouse pot experiments? *Journal of Nematology* 2022; **54(1)**, e20220012.

[27] ACG Bicalho, SA da Silva and ZAC Machado. Control of *Meloidogyne paranaensis* mediated by silicon. *Scientia Agricola* 2021; **78(3)**, e20190039.

[28] AS Ardakani. Toxicity of silver, titanium, and silicon nanoparticles on the root-knot nematode, *Meloidogyne incognita*, and growth parameters of tomato. *Nematology* 2013; **15(6)**, 671-677.

[29] H Hida, H Nishiyama, S Sawa, T Higashiyama and H Arata. Chemotaxis assay of plant-parasitic nematodes on a gel-filled microchannel device.

Sensors and Actuators B: Chemical 2015; **221**, 1483-1491.

[30] R Čepulytė, WB Danquah, G Bruening and VM Williamson. Potent attractant for root-knot nematodes in exudates from seedling root tips of two host species. *Scientific Reports* 2018; **8**, 10847.

[31] K Jindapunnapat, ND Reetz, MH MacDonald, G Bhagavathy, B Chinnasri, N Soonthornchareonnon, A Sasnarukkit, KR Chauhan, DJ Chitwood and SLF Meyer. Activity of vetiver extracts and essential oil against *Meloidogyne incognita*. *Journal of Nematology* 2018; **50(2)**, 147-162.

[32] RV Silva, RDL Oliveira, KJT Nascimento and FA Rodrigues. Biochemical responses of coffee resistance against *Meloidogyne exigua* mediated by silicon. *Plant Pathology* 2010; **59**, 586-593.

[33] EG Sampaio, FA Almeida, AM Oliveira, WL Fonseca, MLT Leite and LMS Xavier. Control of *Meloidogyne javanica* in cowpea with silicon application. *Revista Brasileira de Ciências Agrárias - Brazilian Journal of Agricultural Sciences* 2022; **17(3)**, 1-7.

[34] MAM El-Saedy, MEA El-Sayed and SE Hammad. Efficacy of boron, silicon, jojoba and four bio-products on controlling *Meloidogyne incognita* infecting Thompson seedless grapevines. *American-Eurasian Journal of Agricultural & Environmental Sciences* 2015; **15(9)**, 1710-1720.

[35] LMP Guimaraes, EMR Pedrosa, RSB Coelho, EF Couto, SRVL Maranhao and A Chaves. Efficiency and enzymatic activity elicited by methyl jasmonate and potassium silicate on sugarcane under *Meloidogyne incognita* parasitism. *Summa Phytopathologica* 2010; **36**, 11-15.

[36] A Soffan, SS Alghamdi and AS Aldawood. Peroxidase and polyphenol oxidase activity in moderate resistant and susceptible *Vicia faba* induced by *Aphis craccivora* (Hemiptera: Aphididae) infestation. *Journal of Insect Science* 2014; **14**, 285.

[37] SF Afzali, H Sadeghi and A Taban. A comprehensive model for predicting the development of defense system of *Capparis spinosa* L.: A novel approach to assess the physiological indices. *Scientific Reports* 2023; **13(1)**, 12413.

[38] LP Zhan, DL Peng, XL Wang, LA Kong, H Peng, SM Liu, Y Liu and WK Huang. Priming effect of root-applied silicon on the enhancement of induced resistance to the root-knot nematode *Meloidogyne graminicola* in rice. *BMC Plant Biology* 2018; **18(1)**, 50.

[39] LB Santos, JPS Júnior, RM Prado, RF Júnior, VF Souza, MMS Sarah and PLM Soares. Silicon allows halving cadusafos dose to control *Meloidogyne incognita* and increase cotton development. *Silicon* 2022; **14**, 3809-3816.

[40] EHC Silva, RS Soares, HO Borges, CA Franco, LT Braz and PLM Soares. Quantification of the damage caused by *Meloidogyne enterolobii* in okra. *Pesquisa Agropecuária Brasileira* 2019; **54**, e00050.

[41] M Wang, L Gao, S Dong, Y Sun, Q Shen and S Guo. Role of silicon on plant-pathogen interactions. *Frontiers in Plant Science* 2017; **8**, 701.

[42] B Chinnasri, N Beesa, A Suwanngam, K Puttawong, T Korsrisakul, P Phanbut, K Jindapunnapat and A Sasnarukkit. Efficacy of fosthiazate (Nemathorin 10% GR) in managing *Meloidogyne enterolobii* in chili crop in Thailand. *Crop Protection* 2026; **199**, 107425.

[43] KK Verma, XP Song, DD Tian, DJ Guo, ZL Chen, CS Zhong, A Nikpay, M Singh, VD Rajput, RK Singh, T Minika and YR Li. Influence of silicon on biocontrol strategies to manage biotic stress for crop protection, performance, and improvement. *Plants* 2021; **10**, 2163.

[44] VJ Connick. 2011, The impact of silicon fertilisation on the chemical ecology of grapevine, Vitis vinifera; constitutive and induced chemical defences against arthropod pests and their natural enemies. Master's Thesis. Charles Sturt University, New South Wales, Australia.