

## Optimising potassium silicate priming for enhanced rice seed germination and resistance to golden apple snail infestation

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### ABSTRACT

Golden apple snails are a detrimental pest in rice cultivation. Despite the use of various control methods, their infestation continues to cause significant damage. While seed priming and silica (Si) are known for their agricultural benefits, their combined effectiveness against snail infestation has not been thoroughly studied. The objectives of this study were to evaluate the germination performance of Si-primed rice seeds under different immersion times and concentrations, and to assess the response of Si-primed seedlings to snail infestation. Rice seeds (cv MR297) were primed by immersion for 6, 12, or 24 h in silicate solutions of 0, 300, 600, 900, and 1200 ppm. The germination test was arranged in a completely randomised design (CRD) with two replicates. Approximately 50 seeds were placed in each Petri dish. Percentage germination, time to 50% germination ( $T_{50}$ ), mean germination time (MGT), and lengths of the plumule and radicle were recorded. Seedling vulnerability was tested using alluvial and sandy soils in a CRD with three replicates. After 24 h of fasting, the snails were released, and the seedlings were assessed after 10 days. The results showed that immersion for 6 h was sufficient to maintain a higher germination percentage of 93% ( $p < 0.05$ ).  $T_{50}$  and MGT were significantly ( $p < 0.05$ ) lower, at 2.3 and 2.8 days, respectively, for seeds immersed for 6 and 12 h. Seedling vulnerability to golden apple snails differed significantly ( $p < 0.05$ ) and was highest in sandy soil ( $34 \pm 7.01\%$ ). Nutrient uptake may have altered the biochemical defences of rice seedlings.

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## 1. INTRODUCTION

Golden apple snails (*Pomacea canaliculata*) are a major threat to rice (*Oryza sativa* L.) cultivation, which is the most widely consumed staple food for over half of the global population, particularly in Asia and Africa. Infestation is especially severe in fields where the direct-seeding method is used. In this system, improving seed germination and seedling establishment is critical for sustaining rice production (Matsushima and Sakagami, 2013). Snails feed on emerging and young rice plants by cutting stems at the base, destroying entire seedlings. In Malaysia, this pest has spread to almost all rice-growing areas (Yahaya et al., 2017), and similar outbreaks have been reported in Indonesia, Thailand, and the Philippines. A range of control methods has been attempted, including the use of pesticides, rearing ducks and fish, setting traps, transplanting, and implementing water management strategies. However, the problem remains unsolved because the snails can survive harsh environments and live without water for at least six months. Therefore, alternative approaches are urgently needed.

Seed priming is a technique that involves controlled

seed hydration to activate the preparatory processes required for germination without allowing the primary root to protrude. Different methods can be used depending on how water is supplied to the seeds. Priming can involve solid matrices, aqueous solutions, or other systems that regulate seed moisture content. Examples include nutrient solutions (Johnson et al., 2005), plant growth regulators, solid particulate systems, and controlled water levels (Pawar and Laware, 2018). Priming is an effective method for enhancing rice germination under direct seeding (Farooq et al., 2006), drought (Zhang et al., 2024), and salt stress (Zhang et al., 2025). According to Koushal et al. (2024), it is a low-risk and cost-effective solution to poor germination and weak seedling establishment. It improves the speed and uniformity of emergence, increases seedling vigour, and enhances yield under adverse environmental conditions (Paparella et al., 2015). Numerous studies on rice priming focused on germination, growth responses, and resistance to pests and diseases.

Silica (Si) is the second most abundant element in the Earth's crust (27.7%), after oxygen (46.6%). Silicon

dioxide (SiO<sub>2</sub>), or silica, is the major constituent of sand. Although Si is not an essential plant nutrient, it has been widely used in agriculture due to its ability to mitigate the effects of biotic and abiotic stress. In graminoids, Si improves growth by increasing plant height, tiller number, root volume, chlorophyll content, and biomass (Ramirez-Olvera et al., 2021). It also enhances yield components, including grain and straw production (Chatterjee et al., 2024). Moreover, Si strengthens crop resilience to drought (Jiang et al., 2023) and salinity (Jin et al., 2024) and reduces heavy metal toxicity (El-Habet, 2021). Si deposition in plant tissues forms a physical barrier against pests and can stimulate defence-related biochemical pathways. For example, Si application has suppressed planthopper populations (Yu et al., 2025) and reduced damage from whorl maggots, leaf folders, and stem borers (Chatterjee et al., 2024). Although the use of Si-primed rice seeds has been studied, little attention has been given to their role in pest resistance, particularly against golden apple snails. Therefore, the objectives of this study were to evaluate the germination of Si-primed rice seeds under different immersion times and concentrations, and to investigate the response of the Si-primed seedlings to golden apple snail infestation.

## 2. MATERIALS AND METHODS

### 2.1. Rice seeds

This study used rice seeds of cultivar MR297, a Malaysian rice variety. The certified seeds were obtained from PPK Padang Siding, Arau, Perlis (Registration No. PPK 073), a local government agency.

### 2.2. Priming treatments

Rice seed priming was carried out by soaking seeds at three immersion times (6, 12, and 24 h) with five silicate concentrations (0, 300, 600, 900, and 1200 ppm). The 0 ppm treatment used distilled water and served as the control. Approximately 500 g of rice seeds were surface-sterilised in a 3.0% (v/v) sodium hypochlorite solution (CAS No. 7681-52-9; 1:2 w/v) for 2 min. During sterilisation, floating seeds, which were infertile, were removed. The seeds were then rinsed three times with distilled water to eliminate chloride residues and subsequently drained. The silicate solution was prepared using anhydrous potassium silicate (CAS No. 1312-76-1). Fifty grams of sterilised seeds were soaked in 250 ml of silicate solution (1:5 w/v) at room temperature (25 °C) for the designated immersion times (Zhang et al., 2024). An oxygen pump supplied aeration during soaking, and the process was conducted in the dark. After soaking, the primed seeds were rinsed with distilled water for 2 min, air-dried at room temperature (Zhang et al., 2024), and sealed in polythene bags. The primed seeds were stored in a refrigerator until they were used.

### 2.3. Germination test

The germination test was conducted in two replicates of 50 seeds each, placed in Petri dishes. The Petri dishes were arranged in a completely randomised design (CRD). Filter papers lined the upper and lower parts of each petri dish. The Petri dishes were kept at room temperature for 14 days. Seeds were watered twice daily, in the morning and evening, using a water sprayer. Germination was observed and recorded daily. Seeds were considered germinated when the radicle was more than 2.0 mm in length (Ibrahim et al., 2013; Zhang et al., 2025). The lengths of the radicle and plumule were measured manually on day 14.

The number of germinated seeds was counted daily, and the percentage germination was calculated using Equation 1 (Ibrahim et al., 2013; Zhang et al., 2024).

$$\text{Seed germination (\%)} = \text{Total seed germinated} / \text{Total seed} \times 100 \quad \text{Equation 1}$$

The speed of seed germination was calculated using the time to 50% germination ( $T_{50}$ ) and mean germination time (MGT) (Ruttanaruangboworn et al., 2017; Zhang et al., 2024).  $T_{50}$  and MGT were calculated using Equations 2 and 3.

$$T_{50} = t_i + \{[(N+1) / 2 - n_i] / (n_j - n_i)\} \times (t_j - t_i) \quad \text{Equation 2}$$

Where  $N$  is the final number of germinants,  $n_i$  and  $n_j$  are the cumulative numbers of seeds germinated at adjacent times  $t_i$  and  $t_j$ , when  $n_i < N/2 < n_j$ .

$$\text{MGT} = \sum(n_i \times t_i) / \sum n_i \quad \text{Equation 3}$$

Where  $n_i$  is the number of seeds germinated at time  $t_i$ , and  $t_i$  is the number of days since the start of the test.

### 2.4. Seedling vulnerability test against golden apple snail infestation

Twenty primed rice seeds from each treatment were sown in rows in plastic boxes (21.59 × 21.59 cm). Two soil types, sandy (600 g/box) and alluvial (400 g/box), were used. Soil depth was adjusted to 1.5 cm. The boxes were arranged in a CRD with three replicates. The basic properties of the soils are presented in Table 1.

Golden apple snails (shell height = 30 mm) were collected from the nearest paddy fields near Universiti Teknologi MARA Perlis Branch, Arau Campus. Ten days after sowing, one snail was released into each box. Before release, snails were fasted for 24 h, and the water depth was increased to 5 cm to provide favourable conditions. The experiment was observed for 10 days, after which the surviving rice seedlings were counted by treatment.

This study involved golden apple snails, an invasive pest species in Malaysia. As invertebrates are not protected under national wildlife or animal welfare legislation, and according to the ethical guidelines of Universiti Teknologi MARA (UiTM), specific ethical clearance was not required. All procedures involving snails were conducted in accordance with established laboratory and field handling protocols to ensure scientific integrity and environmental responsibility.

**Table 1:** Basic properties of sandy and alluvial soils (Mohamad et al., 2023).

Soil property	Unit	Sandy	Alluvial
pH	–	5.82	5.12
Electrical conductivity	mS/m	0.34	2.49
Total carbon	%	0.43	1.71
Total nitrogen	%	0.07	0.17
C/N ratio	–	6.14	10.06
Phosphorus	ppm	3.33	20.72
Exchangeable Ca	meq/100 g	0.02	0.07
Exchangeable Mg	meq/100 g	not detected	0.01
Exchangeable K	meq/100 g	11.05	8.63
Exchangeable Na	meq/100 g	0.01	0.01
Cation exchange capacity	meq/100 g	3.65	10.90

### 2.5. Statistical analysis

Analysis of variance (ANOVA) was used to compare treatments. Tukey’s HSD test ( $p < 0.05$ ) was applied for mean comparisons. Data distribution ( $p < 0.05$ ) and homogeneity of variance ( $p < 0.05$ ) were assessed using the Shapiro-Wilk test and Levene’s test, respectively. All analyses were performed using R software version 4.2.0.

## 3. RESULT AND DISCUSSION

### 3.1. Germination test

The ANOVA results (Table 2) showed that immersion time had a significant influence ( $p < 0.05$ ) on both the percentage and speed of germination (Figure 1). However, Si concentration and its interaction with immersion time were not significant (Figure 2). Seeds immersed for 6–12 h achieved the highest germination rates ( $\geq 90\%$ ), whereas prolonged immersion for 24 h reduced germination ( $< 80\%$ ) across all concentrations. The lowest germination rate (67%) occurred at 600 ppm Si after 24 h of immersion, while the highest rate (94%) was observed at 300 ppm Si after 6–12 h of immersion. Plumule length (mean =  $4.23 \pm 0.40$  cm) and radicle length (mean =  $3.71 \pm 0.41$  cm) did not differ significantly among treatments ( $p \geq 0.05$ ). These findings suggest that germination was more sensitive to immersion duration than to Si concentration. Prolonged soaking appeared to reduce seed viability, possibly due to excessive leaching or hypoxic conditions.

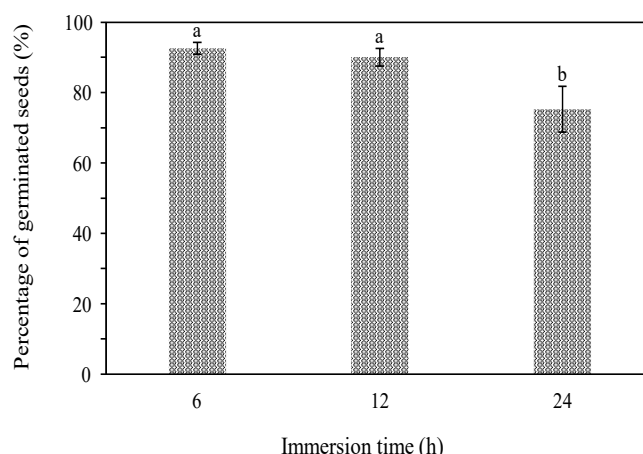
Seed germination percentages were averaged over 5 and 10 days. According to IRR (2015), high-quality seeds should have a germination rate of 85–90%. In this study, the

highest percentage was observed at 6 h of immersion. Similar results were reported for rice varieties NSIC Rc122 (‘Angelica’), Rc160 (‘Tubigan 14’), Rc300 (‘Tubigan 14’), and Rc286 (‘Sahod Ulan 9’) in the Philippines using hydropriming (Ranmeechai et al., 2022). Some studies have reported higher percentages after 12 h of immersion. For example, Ibrahim et al. (2013) found that hydro-priming for at least 12 h enhanced the germination of rice cv. NERICA 2 (upland rice) in Nigeria. In contrast, other studies reported the highest germination after 24 h. Yari and Sheidaie (2011) and Yari et al. (2012) demonstrated that a 24 h priming duration was optimal for rice cv. Fajer, Sherodi, and Taram Mahali in Iran. Immersion time, therefore, determines the period required for seeds to absorb sufficient water. For rice cv. MR297, 6 h of immersion was sufficient to activate the metabolic processes necessary for germination. Conversely, 24 h immersion may have caused over-imbibition, reflected in the lowest germination percentage (Ranmeechai et al., 2022). The lack of significant interaction between immersion time and Si concentration may indicate that the concentration range tested was physiologically ineffective for influencing germination. As a result, the measured variables were unable to detect subtle treatment effects.

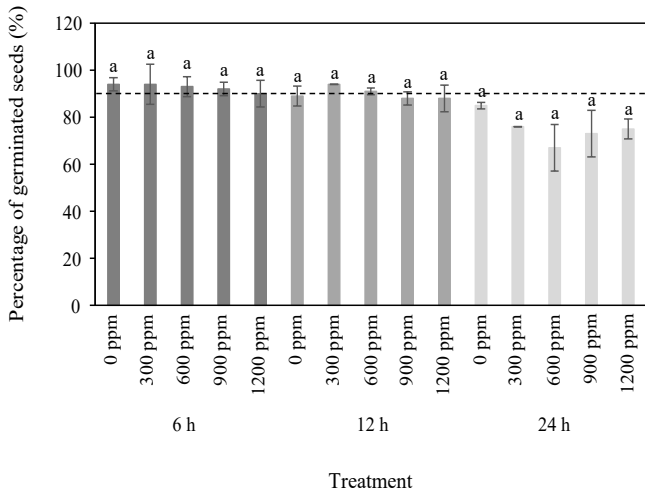
**Table 2:** Analysis of variance of percentage germination of Si-primed rice seeds and speed of seed germination (n = 30).

Variable	Immersion time (I)	Si concentration (S)	I × S
Germinated seeds (%)	3.94E-06***	0.276 <sup>ns</sup>	0.384 <sup>ns</sup>
T <sub>50</sub>	0.004**	0.062 <sup>ns</sup>	0.751 <sup>ns</sup>
MGT	4.18E-04***	0.506 <sup>ns</sup>	0.574 <sup>ns</sup>

Note: T<sub>50</sub> = time to 50% germination; MGT = mean germination time; \*\* and \*\*\* denote significant differences at  $p < 0.01$  and  $p < 0.001$ , respectively. ns = no significant difference at  $p \geq 0.05$

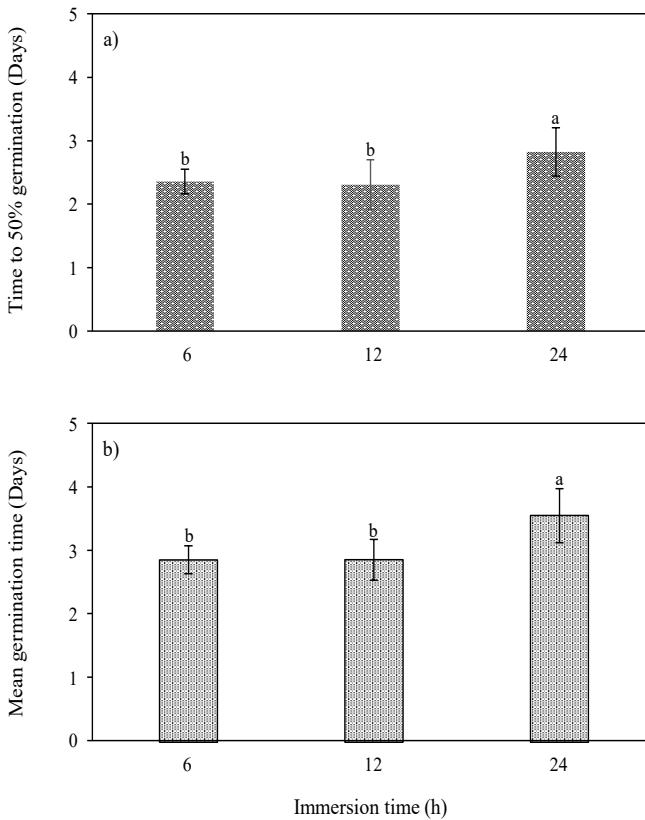


**Figure 1:** Percentage of germinated Si-primed rice seeds at different immersion times. Bars represent mean ± standard deviation. Different letters indicate significant differences by Tukey’s HSD test ( $p < 0.05$ ).



**Figure 2:** Percentage of germinated Si-primed rice seeds treated with three immersion times and five silicate concentrations. Bars represent mean ± standard deviation. Different letters indicate significant differences by Tukey's HSD test ( $p < 0.05$ ).

The speed of germination ( $T_{50}$  and MGT) at different immersion times is presented in Figure 3. No significant interaction was observed between immersion time and Si concentration (Table 2). However, immersion time alone had a significant effect on both variables. Seeds immersed for 6 and 12 h had faster  $T_{50}$  and lower MGT compared with those immersed for 24 h.

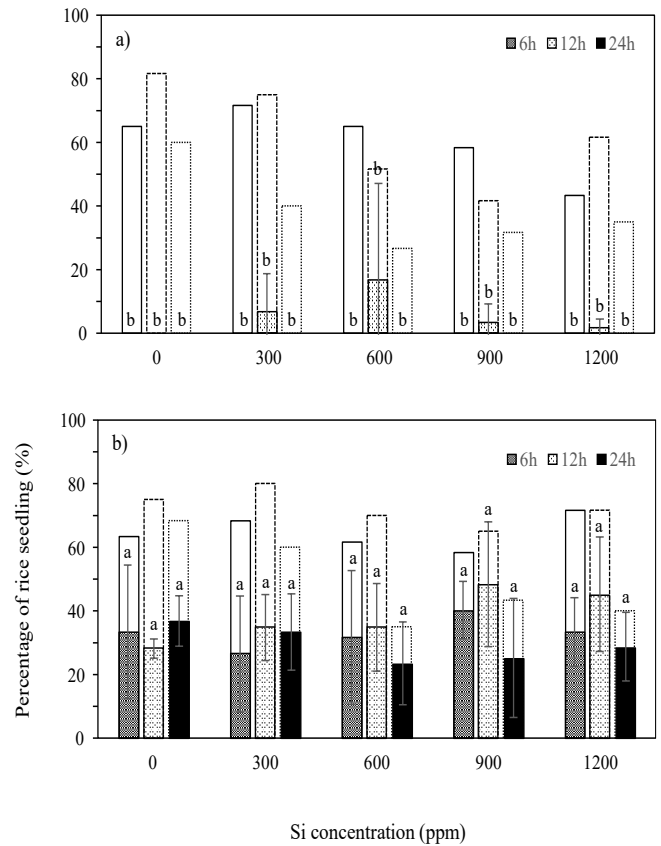


**Figure 3:** Speed of Si-primed rice seed germination at different immersion times: a)  $T_{50}$  and b) MGT. Bars represent mean ± standard deviation. Different letters indicate significant differences by Tukey's HSD test ( $p < 0.05$ ).

Immersion for 6 and 12 h accelerated germination, as shown by lower  $T_{50}$  and MGT values. This may be attributed to enhanced  $\alpha$ -amylase activity and increased sugar content during optimal soaking (Farooq et al. 2006; Ibrahim et al., 2013). MGT responded similarly to  $T_{50}$ , with lower values representing faster germination (Ruttanaruangboworn et al., 2017). Seed germination speed is a critical indicator of crop establishment (Zhang et al., 2024). Rapid germination ensures uniform seedling emergence, which is essential for achieving optimum plant density and yield under variable field conditions. Furthermore, rapid germination reflects seed vigour and the ability to withstand stress, which is vital for sustainable rice production (Yamane et al., 2018).

### 3.2. Seedling vulnerability test against golden apple snail infestation

The percentages of surviving seedlings in sandy and alluvial soils are shown in Figure 4. Statistical analysis revealed a significant effect of soil type ( $p < 0.001$ ). Survival was highest in sandy soil ( $34 \pm 7.01\%$ ) and lowest in alluvial soil ( $2 \pm 4.5\%$ ). Although no significant effects were observed for immersion time, Si concentration, or their interaction, the highest survival rate ( $38 \pm 8.16\%$ ) was recorded in sandy soil after 12 h of immersion.



**Figure 4:** Percentage of surviving primed rice seedlings grown in a) alluvial and b) sandy soils after 10 days of snail exposure. The dashed bar-line graph indicates percentage germination, while the patterned bar graph shows surviving seedlings. Bars represent mean ± standard deviation. Different letters indicate significant differences by Tukey's HSD test ( $p < 0.05$ ) (modified from Mohamad et al., 2023).

The difference between sandy and alluvial soils can be attributed to their varying nutrient content, which is higher in alluvial soils (Table 1). Liao et al. (2020) reported that Si can enhance the utilisation of essential nutrients, such as nitrogen and phosphorus. Similarly, Greger et al. (2018) found that Si increases the availability of calcium, phosphorus, sulfur, manganese, zinc, copper, and molybdenum, thereby influencing nutrient uptake and accumulation in plants. Seedlings grown in alluvial soil may therefore have taken up more nutrients than those in sandy soil. This suggests that nutrient uptake by primed seedlings influences plant defence systems (Altieri et al., 2014).

Si enhances plant defences against golden apple snails through both physical and biochemical mechanisms (Reynolds et al., 2016; Rizwan et al., 2021). Physical resistance involves the deposition of Si in plant tissues, which hardens cell walls and increases resistance to snail feeding (Horgan et al., 2017; Luyckx et al., 2017). Biochemically, Si can stimulate the production of secondary metabolites and defence-related enzymes that reduce palatability. Secondary metabolites, such as phytoalexins and phenolic compounds, exhibit anti-herbivore effects, while enzymes like peroxidase and polyphenol oxidase are involved in defence responses (Singh et al., 2021; Osibe et al., 2024). In addition, Si may influence herbivore behaviour by altering plant chemistry. Si complexes with organic compounds in tissues (Sheng and Chen, 2020), which can affect digestibility and palatability. In sandy soil, nitrogen deficiency may have triggered the production of secondary metabolites or defence enzymes, reducing snail feeding. Zheng et al. (2021) reported that nitrogen deficiency alters rice metabolism, particularly phenylpropanoid pathways, leading to differential defence responses.

The synergistic effect of Si on nutrient uptake may also modify herbivore-induced plant volatile (HIPV) profiles. HIPVs are volatile compounds released during herbivore attack that function in plant defence and attract natural enemies (Leroy et al., 2019). For example, Si-treated rice plants released higher amounts of (E)- $\beta$ -farnesene, (Z)-3-hexenyl acetate, and methyl salicylate when attacked by *Cnaphalocrocis medinalis*, attracting parasitoid wasps (*Trathala flavour-orbitalis* and *Microplitis mediator*) (Liu et al., 2017). Nutrient status, particularly nitrogen availability, may influence this defence mechanism (Li et al., 2021), which could explain the patterns observed in seedlings grown in alluvial soil. To date, no field studies have directly assessed the vulnerability of Si-primed rice seedlings to golden apple snails. However, Horgan et al. (2017) showed that direct application of silica to soil (4 g/m<sup>2</sup> of ground SiO<sub>4</sub> applied 14 days before transplanting) did not significantly reduce snail damage in rice cv. IR50.

#### 4. CONCLUSION

Seed immersion for 6 h was sufficient to achieve a higher germination percentage of 93% ( $p < 0.05$ ). Immersion for 6 and 12 h resulted in significantly accelerated germination, as shown by lower values of T<sub>50</sub> (2.3 days) and MGT (2.8 days). No significant effect was observed for Si concentration. Seedling vulnerability to golden apple snails differed significantly between soil types. Although seedlings grown in sandy soil showed better survival, the synergistic effect of Si on nutrient uptake may have influenced the biochemical defences of rice seedlings.

Therefore, further studies are necessary to confirm the effectiveness of silicates in preventing golden apple snail infestations and to enhance their application for sustainable rice production.

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#### REFERENCES

- Altieri, M.A., Nicholls, C.I., & Fritz, M.A. (2014). Handbook Series Book 7 – Manage Insects on Your Farm: A guide to Ecological Strategies. Sustainable Agriculture Research and Education (SARE) College Park, MD.
- Chatterjee, S., Guchait, S., & Halder, P. (2024). Critical role of exogenously applied silicon on insect pests and yield in Kharif rice. *Journal of Advances in Biology & Biotechnology*, 27(2), 794–808. <https://doi.org/10.9734/jabb/2024/v27i121827>
- El-Habet, H.B.I. (2021). Role of silica in mitigation of Cd, Pb and Cr toxicities in rice under irrigation with drainage water in the Egypt Nile delta. *Irrigation and Drainage*, 70(1), 52–69. <https://doi.org/10.1002/ird.2525>
- Farooq, M., Barsa, S.M.A., & Wahid, A. (2006). Priming of field-sown rice seed enhances germination, seedling establishment, allometry and yield. *Plant Growth Regulation*, 49, 285–294. <https://doi.org/10.1007/s10725-006-9138-y>
- Greger, M., Landberg, T., & Vaculik, M. (2018). Silicon influences soil availability and accumulation of mineral nutrients in various plant species. *Plants*, 7(2), 41. <https://doi.org/10.3390/plants7020041>
- Horgan, F.G., Palenzuela, A.N., Stuart, A.M., Naredo, A.I., Ramal, A.F., Bernal, C.C., & Almazan, M.L.P. (2017). Effects of silicon soil amendments and nitrogen fertilizer on apple snail (Ampullariidae) damage to rice seedlings. *Crop Protection*, 91, 123–131. <https://doi.org/10.1016/j.cropro.2016.10.006>
- Ibrahim, N.D., Bhadmus, Z., & Singh, A. (2013). Hydro-priming and re-drying effects on germination, emergence and growth of upland rice (*Oryza sativa* L.). *Nigerian Journal of Basic and Applied Science*, 21(2), 157–164. doi: <http://dx.doi.org/10.4314/njbas.v21i2.11>
- IRRI (2015) Rice Production Manual – Plant Establishment. International Rice Research Institute (IRRI).
- Jiang, H., Xu, X., Sun, A., Bai, C., Li, Y., Nuo, M., Shen, X., Li, W., Wang, D., Tian, P., Wei, X., Wang, G., Yang, M., & Wu, Z. (2023). Silicon nutrition improves the quality and yield of rice under dry cultivation. *Journal of Science of Food and Agriculture*, 104(4), 1897–1908. <http://doi.org/10.1002/jsfa.13098>
- Jin, W., Li, L., He, W., & Wei, Z. (2024). Application of silica nanoparticles improved the growth, yield, and grain quality of two salt-tolerant rice varieties under saline irrigation. *Plants*, 13(17), 2452. <https://doi.org/10.3390/plants13172452>
- Johnson, S.E., Lauren, J.G., Welch, R.M., & Duxburi, J.M.A. (2005). Comparison of the effects of micronutrient seed priming and soil fertilization on the mineral

- nutrition of chickpea, lentil, rice and wheat in Nepal. *Experimental Agriculture*, 41(4), 427–448. <https://doi.org/10.1017/S0014479705002851>
- Koushal, S., Mankar, A.A., Anbarasan, S., Kumar, V., Kumari, J., Nagarjuna, S., Jahan, R., Kishan, K.R., & Satapathy, S.N. (2024). Mechanism and methodologies of seed priming: enhancing germination and crop resilience. *Plant Cell Biotechnology and Molecular Biology*, 25(11-12), 185–194.
- Leroy, N., de Tombeur, F., Walgraffe, Y., Cornélis, J.-T., & Verheggen, F.J. (2019). Silicon and plant natural defenses against insect pests: impact on plant volatile organic compounds and cascade effects on multitrophic interactions. *Plants*, 8(11), 444. <https://doi.org/10.3390/plants8110444>
- Liao, M., Fang, Z.-P., Liang, Y.-Q., Huang, X.-H., Xu, Y., Chen, S.-S., Xie, X.-M., Xu, C.-X., & Guo, J.-W. (2020). Effects of supplying silicon nutrient on utilization rate of nitrogen and phosphorus nutrients by rice and its soil ecological mechanism in a hybrid rice double-cropping system. *Journal of Zhejiang University Science B*, 21(6), 474–484. <https://doi.org/10.1631/jzus.b1900516>
- Li, Z., Xu, B., Du, T., Ma, Y., Tian, X., Wang, F. & Wang, W. (2021). Excessive nitrogen fertilization favors the colonization, survival, and development of *Sogatella furcifera* via bottom-up effects. *Plants*, 10, 875. <https://doi.org/10.3390/plants10050875>
- Liu, J., Zhu, J., Zhang, P., Han, L., Reynolds, O. L., Zeng, R., Wu, J., Shao, Y., You, M., & Gurr, G. M. (2017). Silicon supplementation alters the composition of herbivore induced plant volatiles and enhances attraction of parasitoids to infested rice plants. *Frontiers in Plant Science*, 8, 1265. <https://doi.org/10.3389/fpls.2017.01265>
- Luyckx, M., Hausman, J.-F., Lutts, S., & Guerriero, G. (2017). Silicon and plants: current knowledge and technological perspectives. *Frontiers in Plant Science*, 8, 411. <https://doi.org/10.3389/fpls.2017.00411>
- Matsushima, K., & Sakagami, J. (2013). Effects of seed hydropriming on germination and seedling vigor during emergence of rice under different soil moisture conditions. *American Journal of Plant Sciences*, 4(8), 1584–1593. <https://doi.org/10.4236/ajps.2013.48191>.
- Mohamad, M., Mohamad, M., Bustam, S., & Kamarudin, K.N. (2023). Preliminary study of the infestation by golden apple snails on si primed rice seedlings cultivated on difference soil types. In *Proceeding of the International Soil Science Conference: Sustainable soil management towards food security and climate change* (p. 291-294). Perlis, Malaysia 9-11 May. Malaysian Society of Soil Science: Malaysia.
- Osibe, D.A., Hojo, Y., Shinya, T., Mitani-Ueno, N., & Gális, I. (2024). Comprehensive analysis of silicon impact on defense and metabolic responses in rice exposed to herbivory stress. *Frontiers in Plant Science*, 15, 1399562. <https://doi.org/10.3389/fpls.2024.1399562>
- Paparella, S., Araújo, S.S., & Rossi, G. (2015) Seed priming: state of the art and new perspectives. *Plant Cell Reports*, 34(8), 1281–1293. <https://doi.org/10.1007/s00299-015-1784-y>
- Pawar, V.A., & Laware, S.L. (2018). Seed priming: a critical review. *International Journal of Scientific Research in Biological Sciences*, 5(5), 94–101.
- Ramirez-Olvera, S.M., Trejo-Tellez, L.I., Gomez-Merino, F.C., Ruiz-Posadas, L.D.M., Alcantar-Gonzalez, E.G., & Saucedo-Veloz, C. (2021). Silicon stimulates plant growth and metabolism in rice plants under conventional and osmotic stress conditions. *Plants*, 10, 777. <https://doi.org/10.3390/plants10040777>
- Ranmeechai, N., Lacap, A.T., Tac-an, M.I.A., & Bayogan, E.R.V. (2022). Seed germination and vigor of four Philippine rice varieties as influenced by hydropriming and storage at various durations. *Philippine Journal of Science*, 151(2), 755–765.
- Reynolds, O.L., Padula, M.P., Zeng, R., & Gurr, G.M. (2016). Silicon: potential to promote direct and indirect effects on plant defense against arthropod pests in agriculture. *Frontiers in Plant Science*, 7, 744. <https://doi.org/10.3389/fpls.2016.00744>
- Rizwan, M., Atta, B., Rizwan, M., Sabir, A.M., Tahir, M., Sabar, M., Ali, M., & Ali, M.Y. (2021). Silicon plays an effective role in integrated pest management against rice leafhopper *Cnaphalocrocis medinalis* Guenée (Lepidoptera: Pyralidae). *Pakistan Journal of Zoology*, 54(2), 1–7. <https://doi.org/10.17582/journal.pjz/20200330090344>
- Ruttanaruangboworn, A., Chanprasert, W., Tobunluepop, P., & Onwimol, D. (2017). Effect of seed priming with different concentrations of potassium nitrate on the pattern of seed imbibition and germination of rice (*Oryza sativa* L.). *Journal of Integrative Agriculture*, 16(3), 605–613. [https://doi.org/10.1016/S2095-3119\(16\)61441-7](https://doi.org/10.1016/S2095-3119(16)61441-7)
- Sheng, H., & Chen, S. (2020). Plant silicon-cell wall complexes: Identification, model of covalent bond formation and biofunction. *Plant Physiology and Biochemistry*, 155, 13–19. <https://doi.org/10.1016/j.plaphy.2020.07.020>
- Singh, S., Kaur, I., & Kariyat, R. (2021). The multifunctional roles of polyphenols in plant-herbivore interactions. *International Journal of Molecular Sciences*, 22(3), 1442. <https://doi.org/10.3390/ijms22031442>
- Yahaya, H., Nordin, M., Hisham, M.N.M., Sivapragasam, A., Joshi, R.C., Cowie, R.H., & Sebastian, L.S. (2017). Invasive apple snails in Malaysia. In: Joshi, R.C., Cowie, R.H., & Sebastian L.S. (Eds.) *Biology and management of invasive apple snails*, 2nd edition. Philippine Rice Research Institute (PhilRice), Los Banos. Pp. 169-195.
- Yamane, K., Garcia, R., Imayoshi, K., Mabesa-Telosa, R., Banayo, N., Vergara, G., Yamauchi, A., Cruz, P.S., & Kato, Y. (2018). Seed vigour contributes to yield improvement in dry direct-seeded rainfed lowland rice. *Annals of Applied Biology*, 172, 100–110. <https://doi.org/10.1111/aab.12405>
- Yari, L., & Sheidaie, S. (2011). Effect of seed priming on seed germination's behaviour of rice (*Oryza sativa* L.). *International Journal of AgriScience*, 1(1), 45–51 ref. 30.
- Yari, L., Sheidaie, S., Sadehgi, H., & Khazaei, F. (2012). Evaluation of temperature and seed priming duration on seed germination behavior of rice (*Oryza sativa* L.). *International Journal of Agriculture: Research and Review*, 2(1), 7–11 ref. 32.
- Yu, J., Zhong, Y., Dai, C., Cheng, Y., Gong, Y., & Hou, M. (2025). Field application of silicate suppresses rice insect pest populations and damage in association with defense-related chemicals. *Pest Management Science*. <https://doi.org/10.1002/ps.8898>
- Zhang, K., Khan, M.N., Luo, T., Bi, J., Hu, L., & Luo, L. (2024). Seed priming with gibberellic acid and ethephon improved rice germination under drought stress via reducing oxidative and cellular damage. *Journal of Soil Science and Plant Nutrition* 24, 2679–2693. <https://doi.org/10.1007/s42729-024-01691-3>
- Zhang, Y., Sultan, H., Shah, A., Mu, Y., Li, Y., Li, L., Huang, Z., Song, S., Toa, Y., Zhou, Z., & Nie, L. (2025). Regulation effect of seed priming on sowing rate of direct seeding of rice under salt stress. *Frontiers in Plant Science*, 16, 1541736. <https://doi.org/10.3389/fpls.2025.1541736>
- Zheng, Y., Zhang, X., Liu, X., Qin, N., Xu, K., Zeng, R., Liu, J. & Song, Y. (2021). Nitrogen supply alters rice defense against the striped stem borer *Chilo suppressalis*. *Frontiers in Plant Science*, 12, 691292. <https://doi.org/10.3389/fpls.2021.691292>