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Efficacy of amorphous silica dust for use against *Sitophilus granarius* and *Rhyzopertha dominica* as a grain protectant

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ABSTRACT

With the rise of insecticide resistance in common stored product insect species and fewer options for control due to increased regulatory oversight, it is imperative to explore other options for management. One option is the use of inert dusts such as diatomaceous earth (DE) or amorphous silica dust. In this study, we investigated the utility of an amorphous silica dust originally formulated for use against bed bugs, but applied here as a grain protectant for two stored products insects (*Sitophilus granarius* and *Rhyzopertha doninica*). A total of 200 g of wheat was conditioned with five concentrations of silica dust (ChinCheX Bed Bug Insecticide, 99 % amorphous silica), including: 0 (control), 100, 200, 500, and 1000 ppm. Insects were exposed continuously with condition evaluations at 7 and 14 days. Adults were then removed and the grain was kept for 65 d to assess progeny production. Mortality was 90 and 100 % for the 500 and 1000 ppm treatments for *R. dominica* and 100 % for both 500 and 1000 ppm treatments for *S. granarius*. Progeny production was less than 2 insects at 200 ppm and zero at 500 and 1000 ppm for *R. dominica*, while for *S. granarius*, there was less than 1 insect at 500 ppm and zero at 1000 ppm. Overall, we found that silica dust is an effective grain protectant on wheat against these bulk storage pests and provides a valuable option for use in an integrated pest management program.

1. Introduction

Bulk grain storage is an important step in the post-harvest agricultural supply chain. Grain storage is economically significant with 12.1 billion and 1.57 billion bushels of corn and wheat, respectively, stored in the US (USDA-NASS, 2025). As whole grain is stored off- and on-farm, there are a variety of internal-infesting insects that may colonize it and cause qualitative and quantitative damage (Hagstrum and Subramanyam, 2006). Losses by insects after harvest amount to over $100 billion USD globally (Wacker, 2018).

Two key internal-infesting insects in bulk storage are lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae) and granary weevil, *Sitophilus granarius* (L.) (Coleoptera: Curculionidae) (Hagstrum and Subramanyam, 2006). Both species are cosmopolitan and highly destructive internal-infesting pests, which have both been classified as major pests capable of causing rapid and significant damage (Hagstrum and Subramanyam, 2006). Infestation by both results in insect-damaged kernels in bulk storage, including exit holes where adults have emerged from grain. *Rhyzopertha dominica* is highly mobile, and can be found far from storage areas (Scheff et al., 2021), while *S. granarius* is often found associated with bulk storage facilities because it is not capable of flight. Stored product insects are economically damaging to many commodities after harvest.

Typically, fumigation has been used to remediate infestation by *R. dominica* and *S. granarius*. The most common fumigants in stored products have been methyl bromide and phosphine (Navarro, 2006). However, methyl bromide was phased out of usage as it is an ozone-depleting compound regulated by the Montreal Protocol (Fields and White, 2002). As a result, there has been a concerted effort to diversify integrated pest management (IPM) programs after harvest. This has included using a variety of other chemical control tactics, such as residual contact insecticides (Arthur, 2012), long-lasting insecticide netting (Ranabhat et al., 2025), and behaviorally-based tactics (Morrison et al. 2021). In addition, this also included extreme

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Table 1
Summary of generalized linear models examining the conditions of *R. dominica* or *S. granarius* after exposure to different concentrations of amorphous silica dust at 7 and 14 d after exposure.

Factor	df	Alive		Affected		Dead	
		Likelihood-Ratio	*P*	Likelihood-Ratio	*P*	Likelihood-Ratio	*P*
R. dominica							
concentration	4	180	0.0001	32	0.0001	250	0.0001
time	1	6.2	0.01	8.6	0.01	6.1	0.01
concentration:time	4	6	0.2	1.7	0.8	15	0.01
S. granarius							
concentration	4	590	0.0001	69	0.0001	480	0.0001
time	1	1.2	0.3	0.65	0.4	1.3	0.3
concentration:time	4	3.8	0.4	0.33	1	9.7	0.04

Table 2
Summary of generalized linear models examining progeny, frass, and damage by *R. dominica* and *S. granarius* after exposure to different concentrations of amorphous silica dust.

Response	df	*R. dominica*		*S. granarius*	
		Likelihood-Ratio	*P*	Likelihood-Ratio	*P*
Progeny	4	82	0.0001	88	0.0001
Frass	4	18	0.001	84	0.0001
Damage	4	82	0.0001	21	0.001

temperature treatments (Fields et al., 2012), hermetic storage, modified atmospheres (Navarro et al., 2012), and radiation (Hallman, 2013).

However, one class of chemical control alternatives for controlling storage insect pests, after harvest are diatomaceous earth (e.g., DE) and amorphous silica (AS) (Zeni et al., 2021). Unlike some other alternatives (e.g., extreme temperature, hermetic storage, modified atmospheres, and radiation), DE is not cost-prohibitive and largely accessible. Diatomaceous earth, or diatomite, is a source of silica. It contains AS along with impurities such as aluminum, iron, and potassium (Hakamada et al., 2010). For example, a commercial diatomaceous earth was obtained from a Colombian brewing company, where it was used as a filter for beer production. After analyzing the spent product, the total amount of silica in the DE was 91.86 and 43 % of that silica was amorphous silica (Mejía et al., 2016). Amorphous silica dust is comprised of pure SiO_2 and has a more uniform particle size and shape. One industrial grade diatomaceous earth used for pest control contained 80 % SiO2 plus TiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, K_2O. The DE also had a more variable structure due to the diatoms present (Oumarou et al., 2024). In one study, mean mortality after exposure to DE in the laboratory was 93–100 % in crack-and-crevice treatments for six stored product species, including *Sitophilus granarius* (Collins and Cook, 2006). Diatomaceous earth suppressed several stored product species in bagged wheat under fluctuating environmental conditions in simulated warehouses, including *Sitophilus oryzae* (Rigopoulou et al., 2023). An enhanced DE product with a botanical (plant extract bitterbarkomycin) was effective at inducing 98 % mortality in *R. dominica* at just 50 ppm, and increased in efficacy with increasing temperature (Athanassiou et al., 2008). It was also found that the efficacy of silica against *R. dominica* and *T. confusum* was enhanced when combined with nanoparticles (Ziaee and Ganji, 2016). Overall, DE is highly effective against many stored product insects in different types of commodities and storage environments. In the case of stored products insect pests, pure silica dust has not been well utilized for the control of stored products insects, however the idea of using pure silica dust against stored products insects is gaining momentum (Salem, 2020; Du, 2021; Metz, 2022; Selladurai, 2024).

DE is long-lasting in current formulations and there has been no documented cases of resistance (Arthur, 2002). However, at the current recommended doses, DE changes the bulk density of grain, resulting in a lower price point, but importantly it does not reduce grain quality (Shah and Khan, 2014; Korunic et al., 1998). Typically, DE is most effective against the most susceptible species, *Cyrtoplestes* spp. at a concentration of 300 ppm for 24 h, but the same concentration did not result in 100 % mortality of *T. castaneum* even after 21 d (Korunic and Fields, 1995; Fields and Muir, 1996). Most recommended doses of DE are applied at 500–3500 ppm (Shah and Khan, 2014).

Silica and DE have also been developed for other species, including bed bugs, *Cimex lectularis* L. (Hemiptera: Cimicidae). A new insecticide product, ChinChex® (Hong Kong, China) containing 99 % amorphous silica, has recently been developed for *C. lectularis*. An older version of the same product with 45 % amorphous silica and 55 % silica dioxide was found to inflict 100 % mortality in impregnated harborages after 21 d against *C. lectularis* (Kerdsawang et al., 2023). However, ChinChex® amorphous silica has never been assessed against stored product pests nor evaluated as a grain protectant. If successful against *R. dominica* and *S. granarius*, this could expand the use pattern for this compound that has otherwise been marketed for bed bugs and urban households. Higher efficacy from a closer to pure AS may provide a better cost profile for using as a grain protectant, and may provide an additional option to food facility managers for management of stored product insects. Thus, our aims were to evaluate ChinChex® as a grain protectant against *R. dominica* and *S. granarius* in wheat at multiple concentrations ranging from 100 to 1000 ppm and 7 or 14 d after exposure, and assessing F_1 progeny production 65 d later. Our hypothesis was that the highest mortality will occur at 500–1000 ppm AS, and that *R. dominica* would be more susceptible to AS than *S. granarius*.

2. Materials and methods

2.1. Insect colonies

Adult *S. granarius and R. dominica* were reared on whole kernels of maize and retained in incubators under constant abiotic conditions at 27 ± 0.1 °C (mean ± SE), 55 ± 1 % RH, and 14:10 (L:D) h photoperiod. Colonies were maintained at the Laboratory of Entomology and Agricultural Zoology (LEAZ), at the Department of Agriculture, Crop Production and Rural Environment, University of Thessaly, Greece.

2.2. Grain preparation and experimental setup

Five jars of grain were filled with 200 g of soft wheat that had been frozen at −20 °C for 72 h prior to use to prevent any insect contamination during the experiment. The jars of wheat were then conditioned with five different concentrations of silica dust (ChinCheX Bed Bug Insecticide, 99 % amorphous silica dust). The five concentrations were as follows: 0 ppm (control), 100 ppm (0.02 g silica on 200 g of wheat), 200 ppm (0.04 g of silica on 200 g of wheat), 500 ppm (0.1 g of silica on 200 g of wheat), and 1000 ppm (0.2 g silica on 200 g wheat). The jars (32 oz) of wheat were shaken and rolled for 1 min in order to coat grains with the silica dust. The silica dust was very fine and nearly invisible except at higher concentrations. There were three vials (3 cm in diameter × 8 cm high) with 20 g of the treated wheat per silica dust

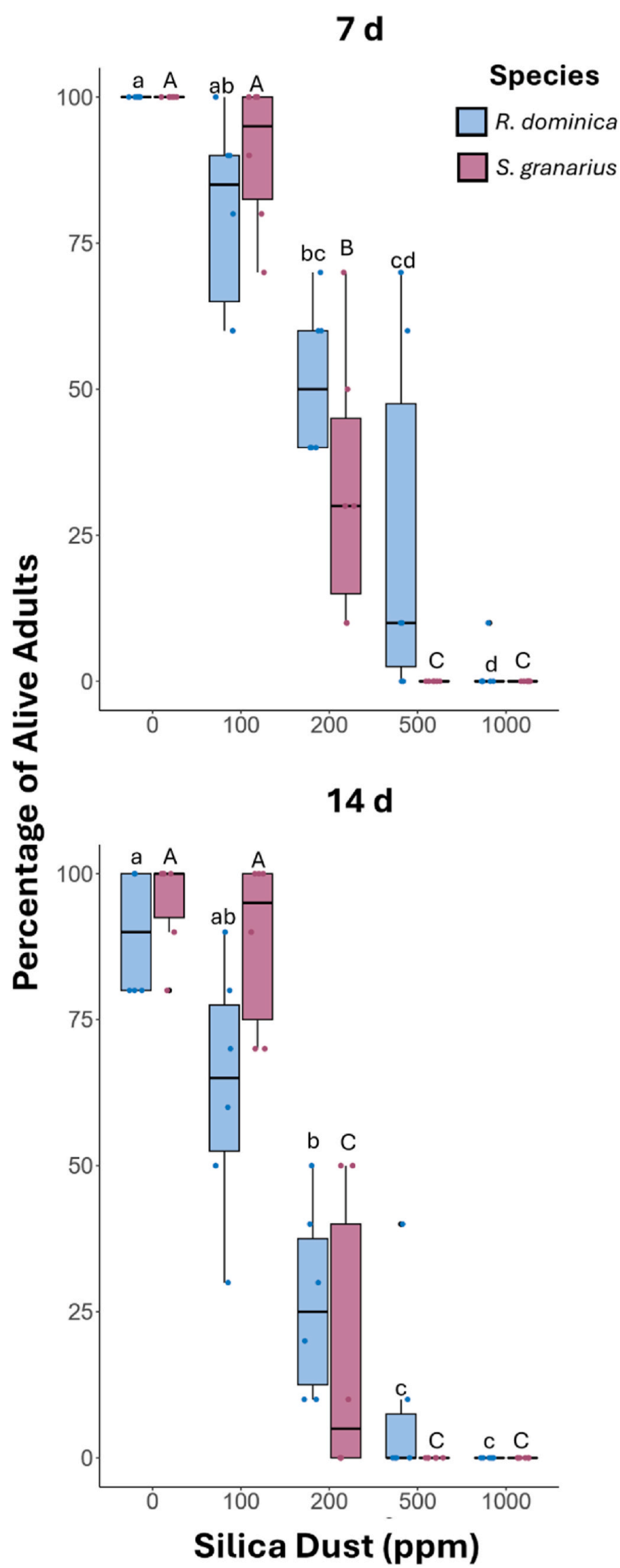

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Fig. 1. Percentage of alive adult *R. dominica* (blue) and *S. granarius* (pink) after 7- (top panel) or 14-d (bottom panel) exposure to amorphous silica dust at five different concentrations (0, 100, 200, 500, and 1000 ppm). Boxplots with shared letters are not significantly different from each other (Tukey HSD, α = 0.05). Upper case letters denote comparisons within *S. granarius* while lower case letters denote comparisons within *R. dominica*. The thick horizontal line indicates the median, while the whiskers indicate the range in the box plots. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

concentration and per insect species (*S. granarius* and *R. dominica*). Vials were sealed with a perforated lid with fine metal wire mesh adhered over the perforation for ventilation. Cohorts of ten insects were placed into each vial. The experiment was repeated two times for a total of n = 6 replicates per treatment combination. Experiments ran at 27 ± 0.1 °C (mean ± SE), 55 ± 1 % RH, and 14:10 (L:D) h photoperiod.

Adults and their conditions (alive, affected, or dead) were checked at 7 days and 14 days. Using the criteria described by Ranabhat et al. (2022): alive were those individuals moving normally and unimpaired, while those that were classified as dead were completely immobile, showing no signs of movement by limbs or antennae. Individuals classified as affected fell between these two extremes, and included those with drunken or sluggish movement, on their backs with twitching of antennae and/or legs, and those unable to right themselves after prodding with a fine brush. After 14 d, all founding adults were removed, and grains were held for 65 d. We then recorded progeny production (number of adults), weight of damaged and undamaged kernels, and the weight of the frass produced by the insects.

2.3. Statistics

The percentage of alive, affected, and dead *R. dominica* and *S. granarius* were analyzed with a generalized linear model based on a Poisson or Quasipoisson distribution using separate models for each species and condition. Quasipoisson distribution was only used when needed (>2 dispersion factor) to account for overdispersion (Aho, 2016). Fixed, explanatory variables included concentration of amorphous silica (0, 100, 200, 500, and 1000 ppm), exposure time (7 or 14 d), and their interaction. A log-likelihood ratio was calculated based on a Chi-squared distribution to test for significance. Upon a significant result from the model, Tukey HSD at α = 0.05 was used for multiple comparisons. R Software was used for all analyses (R Core Team, 2025). Tables were created using the packages gt (Iannone et al., 2025) and gtExtras (Mock, 2024). The package *ggplot2* package was used to generate the figures (Wickham, 2016). For this and all other analyses, α = 0.05 except otherwise noted.

In addition, the progeny, frass, and percentage of damaged kernels produced were analyzed separately for *R. dominica* and *S. granarius* using a generalized linear model based on a Poisson or Quasipoisson distribution. Concentration of amorphous silica (0, 100, 200, 500, and 1000 ppm) was included as a fixed, explanatory variable. A log-likelihood ratio was calculated based on a Chi-squared distribution to test for significance. Upon a significant result from the model, Tukey HSD was used for multiple comparisons.

3. Results

3.1. Insect condition and mortality

There was a significant effect of the silica dust concentration on the percentage of alive, affected, and dead adult *R. dominica* and *S. granarius* (Table 1; Fig. 1). After 7 d exposure at 0 and 100 ppm silica dust, the percentage of alive *R. dominica* and *S. granarius* was 100 % and greater than 75 %, respectively. This was compared to individuals of both species exposed at 200 ppm silica dust, where the percentage remaining alive was 30–50 %. At 500 and 1000 ppm, the percentage alive fell

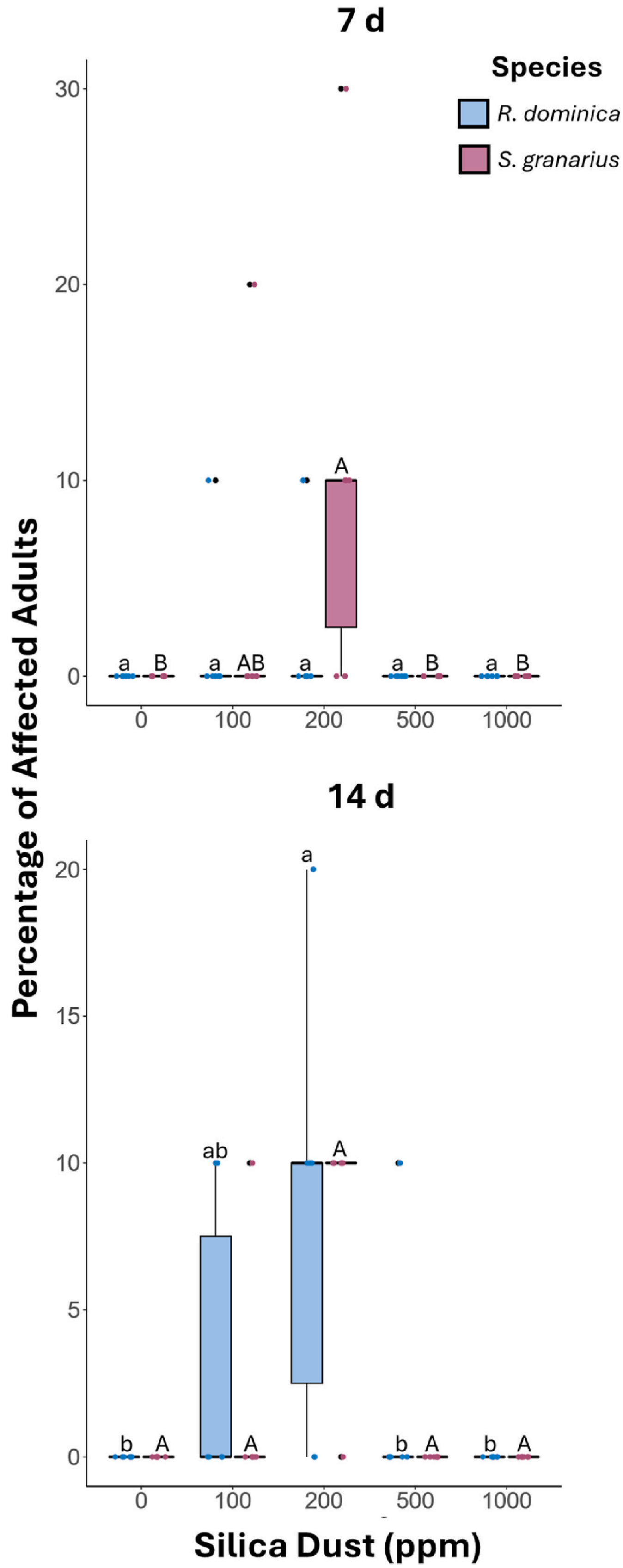

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Fig. 2. Percentage of affected adult *R. dominica* (blue) and *S. granarius* (pink) after 7- (top panel) or 14-d (bottom panel) exposure to amorphous silica dust at five different concentrations (0, 100, 200, 500, and 1000 ppm). Boxplots with shared letters are not significantly different from each other (Tukey HSD, $\alpha = 0.05$). Upper case letters denote comparisons within *S. granarius* while lower case letters denote comparisons within *R. dominica*. The thick horizontal line indicates the median, while the whiskers indicate the range in the box plots. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

sharply to zero for both species except for *R. dominica* where less than 15 % remained alive at 500 ppm. After 7-d exposure, the percentage alive was greater than 50 % at 0 and 200 ppm for both species. The percentage alive fell to 26 % for *R. dominica* and less than 20 % for *S. granarius* at 200 ppm after 14-d exposures. There were no adults left alive at 500 and 1000 ppm after 14 d (Fig. 1). There were few if any affected individuals, ten percent or less, across all treatments, with most treatments yielding no affected individuals at 7 and 14 d (Fig. 2). The percentage of dead adults of both species was zero at 0 ppm, less than 20 % at 100 ppm treatment and 7 d, and well below 50 % at 100 ppm and 14 d exposure (Fig. 3). After 7 d at 200 ppm, adults exhibited 50–60 % mortality and 60–80 % mortality after 14 d exposure. Mortality was nearly 100 % for both species at 500 and 1000 ppm at 7 and 14 d exposure (see Table 1).

3.2. Progeny production

There was a significant effect of concentration on the progeny production of adult *R. dominica* and *S. granarius* (Fig. 4; Table 2). Progeny production in the control (0 ppm) averaged 107 and 56 individuals for *R. dominica* and *S. granarius*, respectively, after 65 d incubation and the removal of founding adults at day 14. By contrast, progeny production was only 14 and 62 adults at 100 ppm for *R. dominica* and *S. granarius*, respectively (Fig. 4). At 200, 500, and 1000 ppm exposure, progeny was nearly zero or zero for *R. dominica* after 65 d. For *S. granarius* at 200, 500, and 1000 ppm, progeny production was nearly 0–20 adults after 65 d.

3.3. Frass and damaged kernels

Concentration of silica significantly affected the frass production by adult of *R. dominica* and *S. granarius* (Fig. 5; Table 2). Frass produced was just over 1 g for *R. dominica* and less than 0.2 g for *S. granarius* in the control treatment. In contrast, frass production was less than 0.2 g at 100 ppm for *R. dominica*, while it was lowered to zero at 200, 500, and 1000 ppm. Frass production was less than 0.2 g at 100 and 200 ppm and zero at 500 and 1000 ppm for *S. granarius* (Fig. 5). Moreover, concentration of silica significantly affected the percentage of damaged kernels produced by adult *R. dominica* and *S. granarius* (Fig. 6; Table 2). In the control, the percentage of damaged kernels was about 15 % for *R. dominica* and nearly 8 % for *S. granarius*. Conversely, damage was less than 3 % of kernels at 100 ppm for *R. dominica* and almost 24 % for *S. granarius*. The percentage of damaged kernels was zero for all remaining treatments except the 200 ppm treatment for *S. granarius* which was just under 3 % of kernels (Fig. 6).

4. Discussion

The use of inert dusts such as diatomaceous earth (DE) and amorphous silica dust for stored product protection is not a new concept (Losic and Korunic, 2017; Zeni et al., 2021). DE has been evaluated against many of the main stored product insect species, including the red flour beetle, *Tribolium confusum* Jacquelin DuVal (Coleoptera: Tenebrionidae), the rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae), the saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.) (Coleoptera: Silvanidae), the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Laemophloeidae), the Indian meal moth, *Plodia*

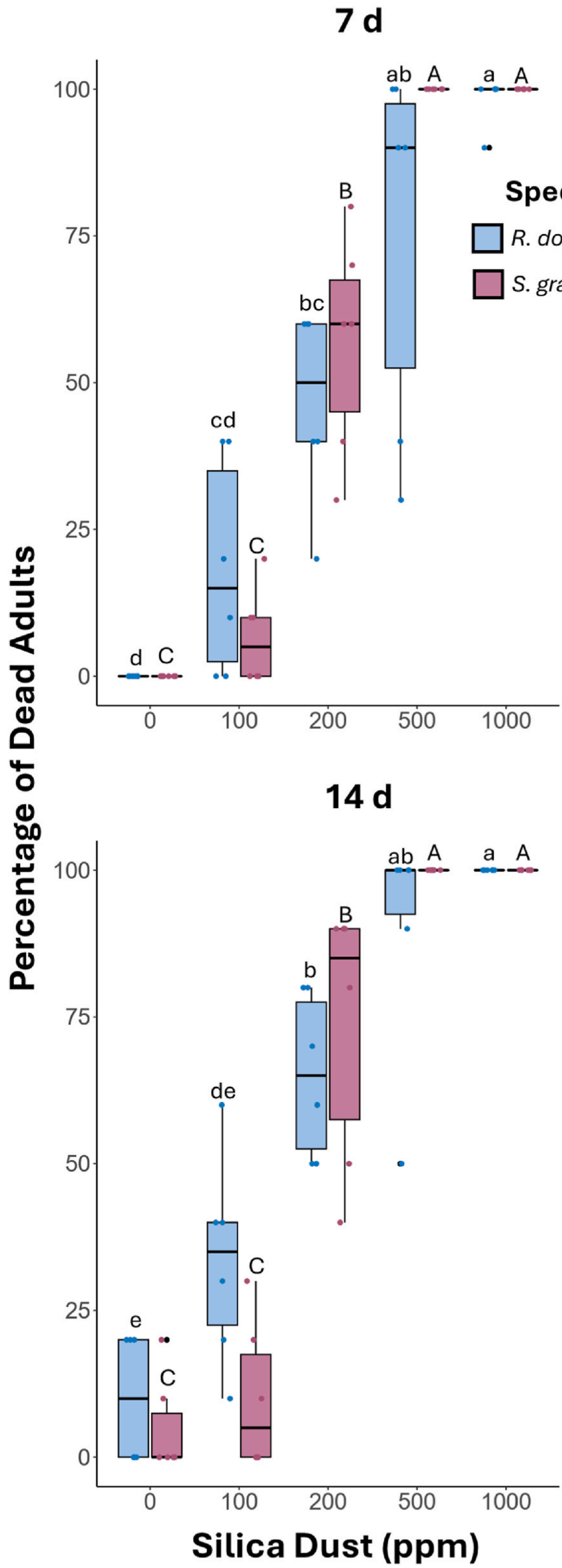

Fig. 3. Percentage of dead adult *R. dominica* (blue) and *S. granarius* (pink) after 7- (top panel) or 14-d (bottom panel) exposure to amorphous silica dust at five different concentrations (0, 100, 200, 500, and 1000 ppm). Boxplots with shared letters are not significantly different from each other (Tukey HSD, α = 0.05). Upper case letters denote comparisons within *S. granarius* while lower case letters denote comparisons within *R. dominica*. The thick horizontal line indicates the median, while the whiskers indicate the range in the box plots. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

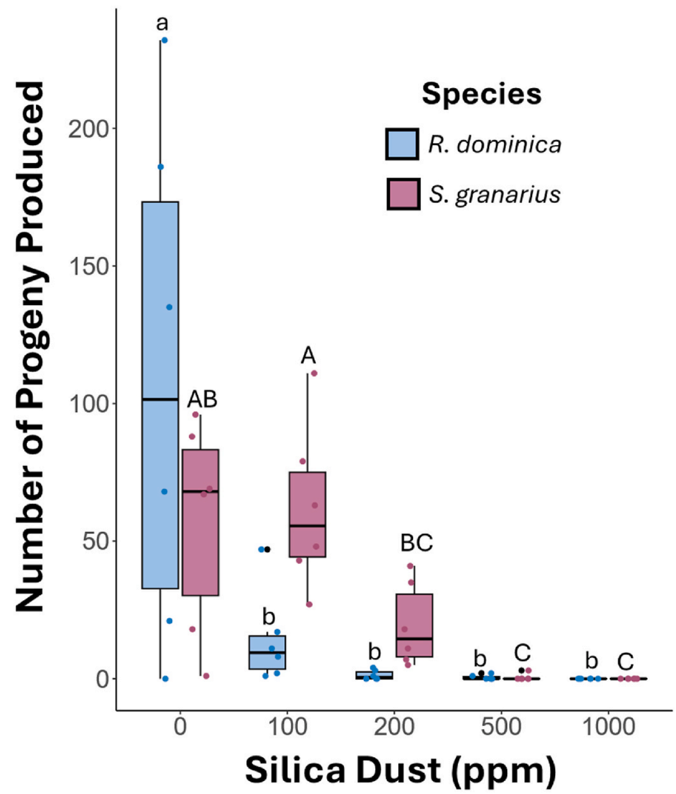

Fig. 4. Progeny produced by *R. dominica* (blue) and *S. granarius* (pink) after exposure to amorphous silica dust at five different concentrations (0, 100, 200, 500, and 1000 ppm) for 14 d and incubation under constant conditions for 65 d. Boxplots with shared letters are not significantly different from each other (Tukey HSD, α = 0.05). Upper case letters denote comparisons within *S. granarius* while lower case letters denote comparisons within *R. dominica*. The thick horizontal line indicates the median, while the whiskers indicate the range in the box plots. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

interpunctella (Hübner) (Lepidoptera: Pyralidae) and *R. dominica* (Baliota and Athanassiou, 2020; Metz, 2022; Selladurai, 2024). In this study, we evaluated a silica dust product that has already been tested extensively for use against bed bugs and proved highly effective (Kerdsawang et al., 2023). However, this off-the-shelf, registered insecticide had not been evaluated against stored product insects as a grain protectant. In our study, we found that by 200 ppm, silica dust in this formulation was highly effective against *R. dominica* and by 500 ppm, it was equally as effective for *S. granarius*, based on progeny production after 65 d. Thus, we observed *R. dominica* was slightly more susceptible to amorphous dust compared to *S. granarius*. We observed that adult mortality after exposure was nearly 100 % for both species at 500 and 1000 ppm, suggesting our initial hypothesis on effective concentrations was supported. Other work has found 750–1000 ppm of natively sourced DEs and Silico-Sec were most effective against *S. granarius* and *R. dominica*, with ~85 % and 60 % mortality after 14 d, respectively (Ogreten et al., 2025). This is in agreement with most studies on inert dusts, as they often require 1000 ppm concentration or greater to obtain effective control (Zeni et al., 2021). By contrast, another study with two amorphous silica dusts found there was complete mortality of *R. dominica* by 200 ppm (e.g., 0.2 g/kg) for one of the dusts, but not the other when applied to soft red winter wheat (Manivannan et al., 2024). In a 97 % amorphous silica formulation (e.g., Advasan®), there was ≈90 % mortality after a 7 d exposure at 8000 ppm (e.g., 8 g/kg) (Mucha-Pelzer et al., 2008).

Interestingly, we observed significant reductions in the frass produced and damage to grain well before 1000 ppm concentrations where

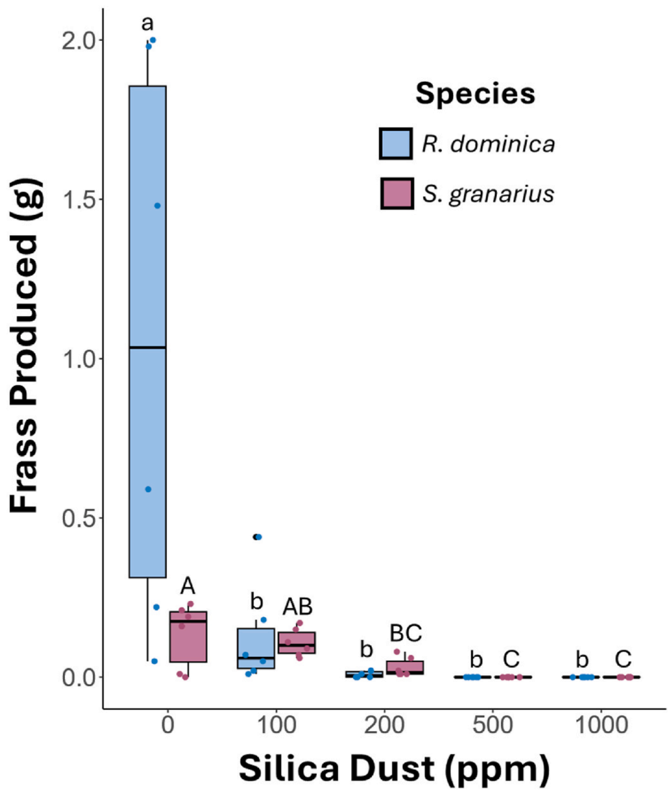

Fig. 5. Frass produced by *R. dominica* (blue) and *S. granarius* (pink) after exposure to amorphous silica dust at five different concentrations (0, 100, 200, 500, and 1000 ppm) for 14 d and incubation under constant conditions for 65 d. Boxplots with shared letters are not significantly different from each other (Tukey HSD, α = 0.05). Upper case letters denote comparisons within *S. granarius* while lower case letters denote comparisons within *R. dominica*. The thick horizontal line indicates the median, while the whiskers indicate the range in the box plots. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

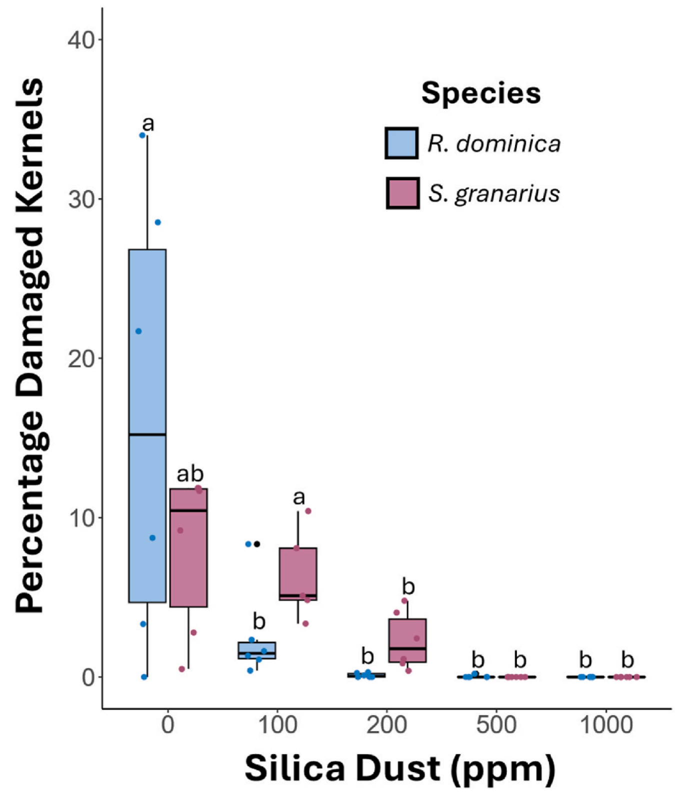

Fig. 6. Percentage of damaged kernels produced by *R. dominica* (blue) and *S. granarius* (pink) after exposure to amorphous silica dust at five different concentrations (0, 100, 200, 500, and 1000 ppm) for 14 d and incubation under constant conditions for 65 d. Boxplots with shared letters are not significantly different from each other (Tukey HSD, α = 0.05). Upper case letters denote comparisons within *S. granarius* while lower case letters denote comparisons within *R. dominica*. The thick horizontal line indicates the median, while the whiskers indicate the range in the box plots. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

mortality is typically expected for other DEs by using the amorphous silica formulation in our study. Both damage and frass were reduced significantly from 100 ppm onward, suggesting there may be a benefit to even using low concentrations of amorphous silica dust. Manivannan and Subramanyam (2023) found that a silica dust with smaller particle size was more effective at inducing mortality and halting progeny production by *T. castaneum* at lower concentrations. Materials with smaller particle size means the same volume of material has a much greater combined surface area, thus may be more efficient at disrupting cuticular hydrocarbons externally. It is likely that the fine, almost undetectable particulates for our amorphous silica dust, as observed during application, may have contributed to increased efficacy of this amorphous silica powder at lower concentrations.

It is interesting to note that the number of affected individuals was less than 10 percent or zero for most treatments. This could have been because symptoms of silica dust desiccation are harder to visually detect or may happen just shortly before death. Insects that were noted as affected displayed similar behaviors as those insects which have encountered an insecticide (e.g., the insects were slower moving or may be attempting to compulsively groom their body) in other experiments (Morrison et al. 2018; Ranabhat et al., 2022). This may be an important point for further exploration and documentation to better understand the mechanism for the mode of action behind silica dust.

We saw that progeny production after 65 d at 200, 500, and 1000 ppm was nearly zero or zero for *R. dominica*. This showed that despite adults having 14 d to oviposit in the grain, they were prevented at these concentrations of silica dust. For *S. granarius* at 200 ppm, progeny production was nearly 20 individuals, but after 500 and 1000 ppm, progeny production was absent after 65 d. Ovipositors contain fragile sensory organs used for assessing host quality and are usually kept sheathed (e.g., Seada and Hamza, 2018; Ahmed et al., 2013), but these may become disrupted when exposed to an environment with an abundance of silica dust. Going forward, it may be important to investigate the oviposition behavior of *R. dominica* and *S. granarius* after exposure to silica dust to determine the main factors responsible for the low progeny production, especially for *R. dominica*.

In conclusion, amorphous silica dust has utility in integrated pest management of stored product insects and may be a key tool especially in the case of insecticide resistant stored grain pests. In this study, silica was highly effective against two species of grain pest, *S. granarius* and *R. dominica*, at 500 and 1000 ppm which agrees with other studies on inert dusts. Finally, it also prevented progeny production and damage to grain.

CRediT authorship contribution statement

Hannah E. Quellhorst: Writing – review & editing, Validation, Investigation, Visualization, Methodology, Conceptualization, Writing – original draft, Supervision, Formal analysis. **Maria K. Sakka:** Supervision, Methodology, Resources, Conceptualization, Writing – review & editing, Project administration. **Georgia V. Baliota:** Resources, Project administration, Data curation, Writing – review & editing, Investigation. **Christos G. Athanassiou:** Writing – review & editing, Resources, Funding acquisition, Supervision, Project administration, Conceptualization, Methodology. **Kun Yan Zhu:** Resources, Funding acquisition, Writing – review & editing, Project administration, Supervision, Investigation. **William R. Morrison:** Resources, Formal analysis, Writing – review & editing, Visualization, Supervision, Investigation, Writing – original draft, Validation, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Hannah E. Quellhorst reports financial support was provided by National Institute of Food and Agriculture. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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