



Five invasive alien plant powders, Norway spruce (*Picea abies* [L.] H. Karst.) wood ash and diatomaceous earth against *Sitophilus oryzae* (L.) adults: are they closer to guns or roses?

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ABSTRACT

We tested the insecticidal efficacy of different powders as surface treatment against the rice weevil (*Sitophilus oryzae*) adults. We have applied dusts from five invasive alien plant species (*Solidago canadensis*, *Solidago gigantea*, *Amorpha fruticosa*, *Rhus typhina*, *Ailanthus altissima*) and two inert dusts, i.e. wood ash from Norway Spruce (*Picea abies*) and commercial product SilicoSec® (as diatomaceous earth). Mortality was evaluated from 1st till 7th day after exposure, at 20 and 25 °C, two values of relative humidity and two doses (20 and 40 g/m²). After Day 7, alive beetles were placed into clean Petri dishes, and mortality counts were measured from 8th till 14th day. In general, we have detected poor efficacy of plant powders against *S. oryzae*. SilicoSec® at 20 g/m² caused 100 % mortality at 25 °C and 55% RH, after seven days. Wood ash (13.46% SiO₂) was less effective in comparison to SilicoSec® (79.48% SiO₂), as approx. 60% mortality was recorded at the same conditions. We have detected that leaves of *A. altissima* and flowers of *S. gigantea* are rich with polyphenols (like catechin hydrate), on average almost 17 mg/g in *S. gigantea* flowers. Flowers and leaves of *Solidago* species are also rich with essential oil, like beta-copaene. The results of our research indicate that the powders of invasive plants are closer to fragrant roses in controlling *S. oryzae* adults, while the gun for this pest is only diatomaceous earth. To improve the effectiveness of invasive plant products, we suggest testing their independent effectiveness in liquid form as well as combinations of their essential oils with inert dusts.

1. Introduction

Storage pests represent an increasingly important group of plant pests, which can be attributed to the increase in global population (Ehrlich et al., 1993; Huang et al., 2022), intensive trade (Qin et al., 2023), climate change (Adler et al., 2022) and the fact that all continents (Europe is more or less an exception) report greater or lesser resistance of storage pests to insecticides (Agrafiotti et al., 2019). Primary storage pests cause most of the stored grain losses, including species from the genus *Sitophilus* (Liška et al., 2017). *Sitophilus* beetles are classified

among the most important primary pests distributed throughout the world, causing damage to stored grain, rice, wheat, maize and peas (Grenier et al., 1997). These pests can be found in silos, granaries and storage areas. The weevils cause damage by eating the grain from the outside, and their larvae cause damage by eating the grains from the inside. These pests, also deposit faeces in the grain. These deposited faeces increase the moisture content. Weevils also warm the cereal mass and enable the development of secondary harmful microorganisms. In this way, the development of mycotoxins, which cause allergies and other diseases in livestock and humans, is promoted. It is important to

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Table 1

Geochemical analysis of inert dusts used in our survey.

Chemical substance	Unit	Inert dust	
		SilicoSec	Wood ash
SiO ₂	%	79.48	13.46
Al ₂ O ₃	%	4.62	4.25
Fe ₂ O ₃ (T)	%	2	1.34
MnO	%	0.029	1.81
MgO	%	0.33	4.3
CaO	%	0.45	37.05
Na ₂ O	%	0.11	0.53
K ₂ O	%	0.15	7.42
TiO ₂	%	0.154	0.218
P ₂ O ₅	%	0.02	2.74
LOI	%	11.18	26.34
Total	%	98.52	99.46
Ba	ppm	264	2565
Sr	ppm	131	495
Y	ppm	4	7
Sc	ppm	11	2
Zr	ppm	26	8
He	ppm	<1	<1
V	ppm	197	20

focus on the prevention and control of mycotoxins in food systems and thus prevent the consumption of food contaminated with mycotoxins (James and Zikankuba, 2018).

The rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) consumes a small amount of grain, but with its frequent breeding cycle, it causes great economic damage (Korunić, 1990; Rojht et al., 2010). The damage caused by weevils ranges from 5 to 10% in the temperate zone and from 20 to 30% in the tropical zone and represents a major economic problem (Haque et al., 2000; Rajendran and Sriranjini, 2008). Rice weevil is generally present in various types of cereals, but it is most commonly present in wheat (Athie and Paula, 2002). Awareness of the importance of a healthy environment, not only for humans but also for all living beings, is on the rise, so this is the main reason for the importance of the use of natural resources in all areas of our lives (Radulescu and Radulescu, 2011). A major problem in crop storage, is crop loss and the crop poor quality as a result of attack by various storage pests that are difficult to control (Rajendran and Sriranjini, 2008). Effective chemical insecticides are still used, but with their harmful effects, they have a negative impact on the environment. As alternatives to the fumigant phosphine, which is the most widely used synthetic insecticide for the control of storage pests in the world (Nguyen et al., 2015), diatomaceous earth (Athanasios et al., 2008; Rojht et al., 2010), wood ashes (Bohinc et al., 2018), zeolites (Eroglu et al., 2019), powders of various plant species (Mehta and Kumar, 2020),

essential oils (Chaubey, 2013) and other materials have been studied in the last 30 years. Unfortunately, only some of them, such as diatomaceous earth has also been used in pest control for warehouses (Trematerra, 2013; Stejskal et al., 2021).

The use of suitable environmentally friendly plant powders of invasive alien plant species is certainly one of the topics that urgently needs to be evaluated and developed. Invasive alien plant species are spreading rapidly, especially in urban areas. Despite the growing (especially negative) importance of invasive plants (Stajerová et al., 2017), there is little research on their potential use in plant pest control (Laznik et al., 2020). Due to the high content of some chemical substances that can have an insecticidal effect (for example, the tree of heaven is rich in polyphenols, and Canada goldenrod is rich in essential oils, phenols and terpenoids), the powders of such plants have potential as insecticides with appropriate application (Zhang et al., 2011; Bae et al., 2020). In the chosen method of application (a mixture of grains and invasive plant powders), a recent study (Bohinc et al., 2020a) showed the unsatisfactory efficacy of the powders of selected invasive plants, so in the present research, we studied their contact action on the rice beetle. In this regard, we compared the effectiveness of powders of five invasive alien plant species that, in previous investigations, showed better activity against the *S. oryzae* than other invasive alien plant species (Bohinc et al., 2020a) and Norway spruce, *Picea abies* (L.) H. Karst. (Pinales: Pinaceae) wood ash, which was proven to be effective against maize weevil, *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae) in the research of Bohinc et al. (2018). In addition to wood ash, we also included diatomaceous earth as a second positive control in the experiment, which has been proven to be the most effective inert powder for controlling storage pests (Korunić et al., 2020). Based on the results of this research, we hypothesized that Norway spruce powder and diatomaceous earth would be more effective than the powders of invasive alien plant species.

2. Materials and methods

2.1. Test insects

In the experiment, we used 2- to 4-week-old *S. oryzae* adults that were obtained from the Laboratory of Entomology, University of Ljubljana, Biotechnical Faculty, Department of Agronomy, in Ljubljana, Slovenia and reared under ambient conditions, 22 ± 2 °C and relative humidity (R.H.) of $55 \pm 5\%$.

2.2. Experimental design

We used wheat, *Triticum aestivum* L. var. *aestivum* obtained from

Table 2

Average values of total essential oils, polyphenols and specific polyphenols in invasive alien plant species.

Plant species	Essential oils (ml/100 g)	Total polyphenols (w %)	Specific polyphenols (mg/g)							
			Catechin hydrate	Naringin	p-coumaric acid	Quercetin	Rutin hydrate	Ferulic acid	Hydroxy coumarin	Caffeic acid
<i>A. altissima</i> leaves	0.01 ± 0.0	2.81 ± 0.12	18.90 ± 0.80	2.08 ± 0.08	ND	0.52 ± 0.30	3.78 ± 0.15	0.04 ± 0.00	ND	0.26 ± 0.01
<i>R. typhina</i> leaves	0.01 ± 0.0	5.34 ± 0.21	7.83 ± 0.31	1.16 ± 0.04	ND	0.39 ± 0.23	4.90 ± 0.23	0.07 ± 0.01	ND	0.11 ± 0.01
<i>A. fruticosa</i> leaves	0.38 ± 0.02	3.02 ± 0.14	9.30 ± 0.44	0.18 ± 0.01	ND	0.42 ± 0.21	4.87 ± 0.26	0.07 ± 0.01	ND	0.36 ± 0.02
<i>S. canadensis</i> leaves	0.79 ± 0.09	3.40 ± 0.16	2.91 ± 0.14	0.17 ± 0.01	0.16 ± 0.01	0.68 ± 0.36	1.43 ± 0.01	ND	ND	ND
<i>S. canadensis</i> flowers	1.58 ± 0.06	4.75 ± 0.24	7.77 ± 0.40	0.40 ± 0.02	0.68 ± 0.03	0.94 ± 0.40	7.48 ± 0.38	0.08 ± 0.00	0.24 ± 0.01	ND
<i>S. gigantea</i> leaves	2.28 ± 0.06	4.75 ± 0.26	8.60 ± 0.48	0.23 ± 0.01	2.60 ± 0.14	7.03 ± 3.64	1.83 ± 0.10	0.16 ± 0.01	ND	ND
<i>S. gigantea</i> flowers	0.93 ± 0.00	5.39 ± 0.24	16.32 ± 0.74	0.36 ± 0.02	5.05 ± 0.23	3.31 ± 1.86	1.47 ± 0.07	0.06	ND	ND

ND-not able to detect (below the level of detection).

Table 3

Amount of essential oil in samples of invasive alien plant species, presented as rel. %.

	<i>S. canadensis</i> leaves	<i>S. canadensis</i> flowers	<i>S. gigantea</i> leaves	<i>S. gigantea</i> flowers	<i>A. fruticosa</i> leaves
alfa-pinene	4.19	1.11	1.01	2.30	1.09
camphene	0.23	0.04	0.12	0.52	0.09
sabinene	0.05	0.01	0.04	0.11	0.02
beta-pinene	0.77	0.14	0.19	0.78	0.15
beta-myrcene	0.19	0.19	0.05	0.18	0.12
alpha-phellandrene	0.01	0.06	0.11	0.27	ND
p-cymene	ND	0.02	0.68	0.11	0.01
limonene	0.78	0.80	0.22	0.63	0.06
trans ocimene	ND	ND	ND	ND	0.17
ocymene	0.02	0.03	ND	ND	0.93
Borneol	0.07	0.26	0.16	0.11	0.04
bornyl acetate	1.84	2.29	2.71	4.23	0.12
alpha-cubebene	0.02	0.05	0.06	0.03	0.64
alpha-copaene	0.15	0.29	0.09	0.08	1.05
beta-bourbonene	0.30	0.14	0.10	0.21	0.32
beta-elemene	0.53	0.40	0.15	0.12	0.41
cyprene	0.04	0.17	0.39	0.61	0.37
beta-caryophyllene	1.87	2.65	16.17	8.87	4.92
alpha-caryophyllene	0.55	0.74	0.46	0.44	1.37
gamma-gurjurene	ND	ND	4.72	2.01	5.56
beta-copaene	39.62	58.40	27.87	50.33	ND
bicyclogermacrene	0.37	0.61	1.23	2.18	5.56
beta-selinene	1.19	1.90	0.16	0.09	0.98
gamma-cadinene	0.18	0.12	0.14	0.25	6.34
beta-bisabolene	0.34	0.25	0.36	0.06	ND
gamma-murolene	0.16	0.12	0.18	–	24.92
isolekene	ND	ND	ND	–	6.04
alpha-bergamotene	ND	ND	ND	–	4.06
cadina-1 (10),4-diene	0.27	0.81	0.66	0.70	6.93
germacren B	0.20	0.74	0.33	0.12	0.26
spathulenol	0.49	0.83	2.96	0.94	0.19
aromadendrene	2.14	1.68	2.44	1.46	2.94

ND-not able to detect.

Table 4Repeated measures ANOVA parameters for main effects and associated interactions for mortality level of *Sitophilus oryzae* adults from the 1st to 7th day (error $df = 193$).

Source	df	F	P
Source between variables			
All between	128	411.8	<0.05
Intercept	1	312.5	<0.05
Exposure day	4	799.3	<0.05
Dose	1	4.3	<0.05
Treatment	7	2319.4	<0.05
RH	1	682.5	<0.05
Exposure day x treatment	28	390	<0.05
Exposure day x RH	4	87.2	<0.05
Dose x treatment	7	12	<0.05
Dose x RH	1	0.2	0.65
Treatment x RH	7	303.5	<0.05
Exposure day x dose x treatment	28	0.9	0.50
Exposure day x dose x RH	4	1.5	0.18
Exposure day x treatment x RH	28	42.0	<0.05
Dose x treatment x RH	7	2.01	0.05
Source within variables			
Within interactions	65	112.1	<0.05
Temperature	1	227.25	<0.05
Exposure day x temperature	4	49.86	<0.05
Dose x temperature	1	2.42	0.12
Treatment x temperature	7	95.73	<0.05
RH X temperature	1	541.08	<0.05
Exposure day x dose x temperature	4	1.96	0.09
Exposure day x treatment x temperature	28	36.97	<0.05
Exposure day x RH x temperature	4	43.82	<0.05
Dose x treatment x temperature	7	1.08	0.37
Dose x RH x temperature	1	1.50	0.22
Treatment x RH x temperature	7	207.9	<0.05

Infrastructure Centre Jable. Powders that were applied to Petri dishes can be divided into two groups: powders of invasive alien plant species and inert dusts. From the group of inert dusts, we used diatomaceous earth formulation SilicoSec®, Metrob Ltd., Začret, Slovenia and wood ash from Norway spruce, *P. abies*, which was obtained from a local household near Radovljica (46.323113, 14.186781). Wood ash was sieved through a 1 mm mesh and stored in a plastic bucket with a lid. We used powders (leaves and flowers) of five invasive alien plant species, namely, tree of heaven, *Ailanthus altissima* (Mill.) Swingle (Sapindales: Simaroubaceae), Canada goldenrod, *S. canadensis* (L.) (Asterales: Asteraceae), giant goldenrod, *S. gigantea* (Aiton) (Asterales: Asteraceae), false indigo, *Amorpha fruticosa* (L.) (Fabales: Fabaceae) and staghorn sumac, *Rhus typhina* (L.) (Sapindales: Anacardiaceae). Invasive alien plant species were air dried in the dark. Leaves and flowers of invasive alien plant species were collected on several dates in 2021 in the Municipality of Ljubljana: tree of heaven and staghorn sumac were collected on 15th September, *Amorpha* on 28th July, Canada goldenrod leaves and flowers on 10th September, Giant goldenrod leaves on 24th August and Giant goldenrod flowers on September 10, 2021. When the collected material was sufficiently dry, we separated the leaves. Separated leaves were ground with a mill (Brabender GmbH & Co. KG, Duisburg, Germany). Plant powders were stored in plastic containers in a freezer at -20°C until usage.

2.3. Bioassay

Surface treatment was conducted in plastic Petri dishes with an area of 153.5 cm^2 . We applied powders at two different rates, 20 g and 40 g per m^2 . We spread the inert dust equally all over the surface of the Petri dish. Thirty undefined sex, 2–4 weeks old *S. oryzae* adults, were placed in each Petri dish. The adult mortality was evaluated on the 1st, 2nd, 3rd, 4th and 7th day after exposure. 10 to 15 wheat kernels were added to each Petri dishes as food source. Bioassays were performed in nine

Table 5
Mean mortality (±SE) of *Sitophilus oryzae* adults exposed from the 1st to 7th day to a lower dose of powders (20 g/m²) at two temperatures within 55% RH.

		Day 1	Day 2	Day 3	Day 4	Day 7
20 °C	Wood ash	0.99 ± 0.50 A bc	1.84 ± 0.51 A c	3.72 ± 0.93 A d	8.17 ± 1.13 A d	25.29 ± 2.92 A d
	SilicoSec®	0.66 ± 0.44 A b	3.39 ± 0.59 A d	16.73 ± 1.89 A e	35.41 ± 3.55 A e	87.94 ± 2.86 A e
	<i>A. altissima</i> L*	1.32 ± 0.52 A b	1.32 ± 0.33 B c	1.32 ± 0.56 A c	1.32 ± 0.62 A bc	3.63 ± 1.08 A c
	<i>R. typhina</i> L*	0.66 ± 0.44 Ab	0.66 ± 0.28 A b	0.66 ± 0.13 A b	0.66 ± 0.12 A b	0.66 ± 0.22 A b
	<i>A. fruticosa</i> L*	0.00 ± 0.00 A a	0.00 ± 0.00 A a	0.00 ± 0.00 A a	0.00 ± 0.00 A a	0.00 ± 0.00 A a
	<i>S. canadensis</i> L*	0.33 ± 0.33 A ab	1.00 ± 0.59 A ab	1.09 ± 0.59 B bc	1.21 ± 0.80 A bc	3.59 ± 1.87 A c
	<i>S. canadensis</i> F*	0.66 ± 0.43 A b	0.66 ± 0.31 A b	0.66 ± 0.45 A b	0.66 ± 0.21 A b	0.66 ± 0.32 A b
	<i>S. gigantea</i> L*	0.33 ± 0.33 A ab	0.79 ± 0.60 A bc	1.01 ± 0.60 A bc	1.01 ± 0.28 A bc	2.42 ± 1.12 A bc
	<i>S. gigantea</i> F*	0.00 ± 0.00 A a	0.41 ± 0.26 A bc	0.63 ± 0.45 A bc	0.82 ± 0.61 A b	1.49 ± 0.60 A b
	Wood ash	0.66 ± 0.44 A ab	9.77 ± 2.32 B c	26.31 ± 3.64 B c	46.61 ± 4.35 B d	59.77 ± 4.12 A c
25 °C	SilicoSec®	6.77 ± 1.57 B c	19.62 ± 2.87 B d	86.84 ± 2.73 B d	99.25 ± 0.49 B e	100.00 ± 0.00 B d
	<i>A. altissima</i> L*	0.33 ± 0.33 A a	0.79 ± 0.60 A ab	1.75 ± 1.04 A ab	2.38 ± 0.95 A b	5.43 ± 1.61 B d
	<i>R. typhina</i> L*	0.33 ± 0.33 A a	0.33 ± 0.20 A a	0.79 ± 0.60 A a	1.00 ± 0.59 A ab	3.30 ± 1.11 B ab
	<i>A. fruticosa</i> L*	0.66 ± 0.44 B ab	0.83 ± 0.33 B ab	1.42 ± 0.57 B ab	1.42 ± 0.57 B ab	2.00 ± 0.68 B a
	<i>S. canadensis</i> L*	0.66 ± 0.44 B ab	0.66 ± 0.27 A ab	0.83 ± 0.33 A a	0.83 ± 0.33 A a	2.17 ± 0.81 A a
	<i>S. canadensis</i> F*	1.03 ± 0.74 A b	1.58 ± 0.74 A b	2.54 ± 0.88 B b	4.09 ± 1.37 B c	6.55 ± 1.79 B b
	<i>S. gigantea</i> L*	0.00 ± 0.00 A a	0.83 ± 0.33 B ab	1.79 ± 1.28 B ab	2.76 ± 1.28 B b	3.71 ± 1.37 A ab
	<i>S. gigantea</i> F*	0.66 ± 0.44 A b	0.66 ± 0.27 B ab	1.00 ± 0.59 A ab	1.21 ± 0.59 A ab	2.79 ± 0.70 B b

L* stands for leaves, F* stands for flowers.
Within each column and treatment, means followed by the same uppercase letter do not differ significantly by Tukey HSD test at $P = 0.05$. For comparison within column between the same treatment, $df = 1,65$ (Day 1, for wood ash, $F = 7.55$, $P = 0.35$; for SilicoSec, $F = 4.55$, $P < 0.01$; for *A. altissima* leaves, $F = 7.42$, $P = 0.10$; for *R. typhina* leaves, $F = 1.77$, $P < 0.04$; for *A. fruticosa*, $F = 7.14$, $P = 0.06$; for *S. canadensis* L, $F = 3.55$, $P < 0.01$; for *S. canadensis* F, $F = 9.09$, $P = 0.09$; for *S. gigantea* L, $F = 12.01$, $P = 0.07$; for *S. gigantea* F, $F = 14.10$, $P = 0.09$; Day 2, for wood ash, $F = 44.09$, $P < 0.01$; for SilicoSec, $F = 17.93$, $P < 0.01$; for *A. altissima* leaves, $F = 12.32$, $P = 0.45$; for *R. typhina* leaves, $F = 47.75$, $P < 0.01$; for *A. fruticosa*, $F = 7.12$, $P = 0.12$; for *S. canadensis* L, $F = 9.45$, $P < 0.01$; for *S. canadensis* F, $F = 12.09$, $P = 0.07$; for *S. gigantea* L, $F = 42.01$, $P < 0.01$; for *S. gigantea* F, $F = 21.10$, $P < 0.01$; Day 3, for wood ash, $F = 22.09$, $P < 0.01$; for SilicoSec, $F = 44.33$, $P < 0.01$; for *A. altissima* leaves, $F = 12.32$, $P = 0.11$; for *R. typhina* leaves, $F = 3.15$, $P = 0.91$; for *A. fruticosa*, $F = 3.12$, $P < 0.01$; for *S. canadensis* L, $F = 9.75$, $P < 0.01$; for *S. canadensis* F, $F = 14.12$, $P < 0.01$; for *S. gigantea* L, $F = 8.01$, $P < 0.05$; for *S. gigantea* F, $F = 6.10$, $P = 0.32$; Day 4, for wood ash, $F = 13.10$, $P < 0.01$; for SilicoSec, $F = 34.33$, $P < 0.01$; for *A. altissima* leaves, $F = 10.32$, $P = 0.08$; for *R. typhina* leaves, $F = 7.15$, $P = 0.61$; for *A. fruticosa*, $F = 3.12$, $P < 0.01$; for *S. canadensis* L, $F = 1.75$, $P = 0.71$; for *S. canadensis* F, $F = 22.12$, $P < 0.01$; for *S. gigantea* L, $F = 8.01$, $P < 0.01$; for *S. gigantea* F, $F = 11.10$, $P = 0.72$; Day 7, for wood ash, $F = 44.10$, $P < 0.01$; for SilicoSec, $F = 66.33$, $P < 0.01$; for *A. altissima* leaves, $F = 10.32$, $P = 0.08$; for *R. typhina* leaves, $F = 7.15$, $P = 0.61$; for *A. fruticosa*, $F = 3.12$, $P < 0.01$; for *S. canadensis* L, $F = 1.75$, $P = 0.71$; for *S. canadensis* F, $F = 22.12$, $P < 0.01$; for *S. gigantea* L, $F = 20.01$, $P = 0.08$; for *S. gigantea* F, $F = 45.10$, $P = 0.43$.
Within each column and temperature, means followed by the same lowercase letter do not differ significantly by Tukey HSD test at $P = 0.05$. For comparison within column within the same temperature between treatments, $df = 1,16$ (Day 1, for 20 °C, $F = 45.12$, $P < 0.01$, for 25 °C, $F = 22.45$, $P < 0.01$; Day 2, for 20 °C, $F = 22.23$, $P < 0.01$, for 25 °C, $F = 11.17$, $P < 0.01$; Day 3, for 20 °C, $F = 11.11$, $P < 0.01$, for 25 °C, $F = 11.17$, $P < 0.05$; Day 4, for 20 °C, $F = 15.11$, $P < 0.01$, for 25 °C, $F = 42.17$, $P < 0.05$; Day 7, for 20 °C, $F = 42.91$, $P < 0.01$, for 25 °C, $F = 19.13$, $P < 0.05$).

replicates. The commercial formulation SilicoSec® and wood ash from Norway spruce served as positive controls., while untreated Petri dishes with food were served as negative control. After 7 days of exposure, alive adults were transferred to untreated clean Petri dishes containing only 10–15 wheat kernels. On the 8th, 9th, 10th, 11th and 14th day of exposure delayed mortality was also evaluated. Studies were performed at two different temperatures (20 and 25 °C) and two values of RH (55 and 75%). Exposure studies were carried out in a rearing chamber (Kambič Laboratory Equipment, Semič, Slovenia) for 24 h full darkness. All bioassays were repeated three times (three series of petri dishes) by preparing new treated and control petri dishes each time (3 × 3 petri dishes in each combination).

2.4. Geochemical analysis of inert dusts and chemical analysis of invasive alien plant species

Geochemical analysis was conducted at Activation Laboratories Ltd., Canada. The most aggressive ICP fusion technique employs a lithium metaborate/tetraborate fusion for whole-rock analysis. Fusions were carried out using a robotic system, which provided a fast fusion of the highest quality. The resulting molten bead was rapidly digested in a weak nitric acid solution. The fusion ensured that the entire sample was dissolved. Samples were prepared and analysed in a batch system. Each batch contained a method reagent blank, certified reference material and 6% replicates. Samples were mixed with a flux of lithium metaborate and lithium tetraborate and fused in an induction furnace. The molten melt was immediately poured into a solution of 5% nitric acid containing an internal standard and mixed continuously until completely dissolved. The samples were analysed for major oxides and selected trace elements on an ICP. Calibration was performed using 14

prepared USGS and CANMET certified reference materials. One of the 14 standards was used during the analysis for every group of ten samples.
The analysis of total polyphenols in the powder of invasive alien plant species was carried out in the Agrochemical Laboratory at the Institute of Hops and Brewing of Slovenia in Žalec, where the analysis of the polyphenols was analysed by HPLC analysis. The entire procedure of formulation of sample extracts, formulation of standard solutions and HPLC conditions is described by Bohinc et al. (2020a). Determination of the total essential oil content was carried out according to the Analytica-EBC 7.10 method with GC analysis. A detailed description can be found in Bohinc et al. (2020a).

2.5. Data analysis

The acquired mortality data were adjusted for mortality in the control treatment using Abbott's formula when it exceeded 5% and expressed as a percentage (Abbott, 1925). Mortality counts were analysed by using repeated measures MANOVA with exposure day as the repeated measures variable and treatment, temperature, and RH as the main effects. Averages for mortality counts (all bioassays) were separated using the Tukey HSD test at the 5% level (Statgraphics Centurion, 2009).

3. Results

3.1. Geochemical analysis of inert dusts used in our survey

The results obtained with geochemical analysis are presented in Table 1. In our study, we used two different inert dusts, wood ash of local origin and the diatomaceous earth formulation SilicoSec®. As presented,

Table 6Mean mortality ($\pm$ SE) of *Sitophilus oryzae* adults exposed from the 1st to 7th day to a higher dose of powders (40 g/m²) at two temperatures within 55% RH.

		Day 1	Day 2	Day 3	Day 4	Day 7
20 °C	Wood ash	1.11 $\pm$ 0.56 Aab	1.85 $\pm$ 1.12 A c	7.47 $\pm$ 1.78 A c	8.81 $\pm$ 1.73 A e	21.54 $\pm$ 1.91 A d
	SilicoSec®	1.85 $\pm$ 1.12 Ab	6.67 $\pm$ 1.47 A d	21.80 $\pm$ 2.42 A d	46.74 $\pm$ 5.69 A f	91.54 $\pm$ 2.24 A e
	<i>A. altissima</i> L*	1.48 $\pm$ 1.12 Ab	1.85 $\pm$ 1.12 A c	2.38 $\pm$ 0.95 A b	2.68 $\pm$ 1.26 B d	5.51 $\pm$ 1.67 B c
	<i>R. typhina</i> L*	0.00 $\pm$ 0.00 Aa	0.00 $\pm$ 0.00 A a	0.83 $\pm$ 0.33 A ab	0.83 $\pm$ 0.00 A abc	0.83 $\pm$ 0.045 A ab
	<i>A. fruticosa</i> L*	0.37 $\pm$ 0.37 Aab	0.74 $\pm$ 0.49 B b	0.83 $\pm$ 0.33 A ab	0.83 $\pm$ 0.38 A abc	2.18 $\pm$ 1.23 A c
	<i>S. canadensis</i> L*	0.00 $\pm$ 0.00 Aa	0.00 $\pm$ 0.00 A a	0.21 $\pm$ 0.21 A a	0.38 $\pm$ 0.38 A a	1.07 $\pm$ 0.76 A b
	<i>S. canadensis</i> F*	0.00 $\pm$ 0.00 Aa	0.37 $\pm$ 0.37 A ab	0.42 $\pm$ 0.28 A ab	0.42 $\pm$ 0.00 A ab	0.42 $\pm$ 0.34 A a
	<i>S. gigantea</i> L*	0.00 $\pm$ 0.00 Aa	1.48 $\pm$ 0.80 B bc	1.58 $\pm$ 0.74 A b	1.58 $\pm$ 0.57 A c	3.24 $\pm$ 1.23 A c
	<i>S. gigantea</i> F*	0.00 $\pm$ 0.00 Aa	0.00 $\pm$ 0.00 A a	0.21 $\pm$ 0.21 A a	0.38 $\pm$ 0.38 A a	2.09 $\pm$ 0.75 A bc
	Wood ash	1.16 $\pm$ 0.46 Ac	7.25 $\pm$ 1.28 B c	22.90 $\pm$ 2.30 B c	47.70 $\pm$ 2.73 B c	57.63 $\pm$ 3.75 B d
	SilicoSec®	7.54 $\pm$ 2.06 B d	29.39 $\pm$ 2.92 B d	90.45 $\pm$ 2.61 B d	99.23 $\pm$ 0.76 B d	100.00 $\pm$ 0.00 B e
	<i>A. altissima</i> L*	1.24 $\pm$ 0.70 A c	1.24 $\pm$ 0.41 A b	1.24 $\pm$ 0.41 A ab	1.24 $\pm$ 0.79 A ab	2.20 $\pm$ 0.85 A ab
25 °C	<i>R. typhina</i> L*	0.58 $\pm$ 0.38 B b	0.58 $\pm$ 0.41 B a	0.59 $\pm$ 0.40 A a	0.97 $\pm$ 0.54 A a	2.54 $\pm$ 1.17 B ab
	<i>A. fruticosa</i> L*	0.29 $\pm$ 0.29 Aab	0.42 $\pm$ 0.42 A a	0.89 $\pm$ 0.80 A a	1.36 $\pm$ 0.84 A ab	3.35 $\pm$ 1.68 A b
	<i>S. canadensis</i> L*	1.16 $\pm$ 0.46 BCE	1.16 $\pm$ 0.07 B ab	1.16 $\pm$ 0.06 B ab	1.16 $\pm$ 0.06 B a	1.16 $\pm$ 0.40 A a
	<i>S. canadensis</i> F*	0.87 $\pm$ 0.43 Bbc	0.87 $\pm$ 0.06 B a	0.87 $\pm$ 0.07 Ba	0.87 $\pm$ 0.40 A a	1.39 $\pm$ 0.60 A a
	<i>S. gigantea</i> L*	0.00 $\pm$ 0.00 A a	0.13 $\pm$ 0.06 A a	1.40 $\pm$ 0.83 A ab	2.97 $\pm$ 0.98 A b	5.30 $\pm$ 1.54 A c
	<i>S. gigantea</i> F*	0.29 $\pm$ 0.29 A ab	1.02 $\pm$ 0.53 B ab	1.78 $\pm$ 0.86 B b	2.54 $\pm$ 1.02 B b	4.15 $\pm$ 0.92 B bc

L* stands for leaves, F* stands for flowers.

Within each column and treatment, means followed by the same uppercase letter do not differ significantly by Tukey HSD test at $P = 0.05$. For comparison within column between the same treatment, $df = 1,65$ (Day 1, for wood ash, $F = 7.55$, $P = 0.35$; for SilicoSec, $F = 4.55$, $P < 0.01$; for *A. altissima* leaves, $F = 7.42$, $P = 0.10$; for *R. typhina* leaves, $F = 1.77$, $P = 0.05$; for *A. fruticosa*, $F = 7.14$, $P < 0.01$; for *S. canadensis* L, $F = 3.55$, $P < 0.01$; for *S. canadensis* F, $F = 9.09$, $P < 0.01$; for *S. gigantea* L, $F = 12.01$, $P < 0.01$; for *S. gigantea* F, $F = 14.10$, $P < 0.01$; Day 2, for Wood ash, $F = 20.16$, $P < 0.01$; for SilicoSec, $F = 51.55$, $P < 0.01$; for *A. altissima* leaves, $F = 13.22$, $P < 0.05$; for *R. typhina* leaves, $F = 3.77$, $P = 0.06$; for *A. fruticosa*, $F = 12.44$, $P = 0.07$; for *S. canadensis* L, $F = 3.55$, $P < 0.01$; for *S. canadensis* F, $F = 15.09$, $P = 0.09$; for *S. gigantea* L, $F = 12.01$, $P < 0.01$; for *S. gigantea* F, $F = 32.10$, $P < 0.01$; Day 3, for wood ash, $F = 45.09$, $P < 0.01$; for SilicoSec, $F = 12.33$, $P < 0.01$; for *A. altissima* leaves, $F = 12.32$, $P = 0.09$; for *R. typhina* leaves, $F = 9.15$, $P = 0.51$; for *A. fruticosa*, $F = 3.12$, $P = 0.07$; for *S. canadensis* L, $F = 11.75$, $P < 0.01$; for *S. canadensis* F, $F = 42.12$, $P = 0.07$; for *S. gigantea* L, $F = 45.01$, $P < 0.05$, for *S. gigantea* F, $F = 45.10$, $P < 0.01$; Day 4, for wood ash, $F = 13.10$, $P < 0.01$; for SilicoSec, $F = 34.33$, $P < 0.01$; for *A. altissima* leaves, $F = 10.32$, $P = 0.08$; for *R. typhina* leaves, $F = 7.85$, $P = 0.57$; for *A. fruticosa*, $F = 12.12$, $P < 0.01$; for *S. canadensis* L, $F = 1.75$, $P = 0.71$; for *S. canadensis* F, $F = 22.12$, $P < 0.01$; for *S. gigantea* L, $F = 8.01$, $P < 0.05$, for *S. gigantea* F, $F = 11.10$, $P = 0.72$; Day 7, for wood ash, $F = 44.10$, $P < 0.01$; for SilicoSec, $F = 66.33$, $P < 0.01$; for *A. altissima* leaves, $F = 10.32$, $P = 0.08$; for *R. typhina* leaves, $F = 7.15$, $P = 0.61$; for *A. fruticosa*, $F = 3.12$, $P < 0.01$; for *S. canadensis* L, $F = 1.75$, $P = 0.71$; for *S. canadensis* F, $F = 22.12$, $P < 0.01$; for *S. gigantea* L, $F = 20.01$, $P = 0.08$, for *S. gigantea* F, $F = 3.10$, $P = 0.69$).

Within each column and temperature, means followed by the same lowercase letter do not differ significantly by Tukey HSD test at $P = 0.05$. For comparison within column within the same temperature between treatments, $df = 1,16$ (Day 1, for 20 °C, $F = 12.12$, $P < 0.01$, for 25 °C, $F = 45.20$, $P < 0.01$; Day 2, for 20 °C, $F = 12.23$, $P < 0.01$, for 25 °C, $F = 77.17$, $P < 0.01$; Day 3, for 20 °C, $F = 9.17$, $P < 0.01$, for 25 °C, $F = 45.17$, $P < 0.05$; Day 4, for 20 °C, $F = 11.11$, $P < 0.01$, for 25 °C, $F = 33.17$, $P < 0.05$; Day 7, for 20 °C, $F = 42.91$, $P < 0.01$, for 25 °C, $F = 19.13$, $P < 0.05$).

SilicoSec® had the highest amount of SiO₂, while wood ash had the highest amount of CaO.

3.2. Chemical analysis of plant powders from invasive alien plant species used in our survey

As presented in Table 2, the highest w% of total polyphenols was detected in flowers obtained from *S. gigantea*. The highest value (mg/g) of catechin hydrate was recorded in leaves from *A. altissima* and flowers of *S. gigantea*. Rutin hydrate was the most abundant polyphenol in samples obtained in flowers from *S. canadensis*, while the highest amount of quercetin was found in *S. gigantea* leaves. Hydroxy coumarin was not defined in the majority of samples. Detailed values are presented in Table 2.

As presented in Table 3, essential oils were detected only in 3 invasive alien plant species among the 5 tested. Essential oils were recorded in different plant parts of the two *Solidago* species. Beta-copaene was the most abundant essential oil substance in 4 out of 5 samples of *Solidago* species, followed by beta-caryophyllene, bornyl acetate, alfa-pinene and aromadendrin.

3.3. Initial mortality (from the 1st to 7th day after exposure)

Using a general statistical analysis, we noted a significantly higher mortality at 25 °C (7.46 $\pm$ 0.49%) and 55% relative humidity (8.40 $\pm$ 0.53%), using the SilicoSec® formulation (36.35 $\pm$ 1.93%), and on the 7th day after treatment (13.98 $\pm$ 1.09), while no significant differences were found between the two concentrations tested. All main effects and some interactions were significant (Table 4). With the use of a relatively low concentration of powder, at 7-day post-application, less than 1%

mortality was highlighted in Petri dishes treated with the lowest dose of *R. typhina* leaves, *A. fruticosa* leaves and *S. canadensis* flowers when exposed to 20 °C and 55% RH. A total of 88% mortality was detected under the same conditions when exposed to SilicoSec®, and 25% mortality was reported with the use of wood ash. When exposed to 25 °C and 55% RH, 60% mortality was noted in the treatment with wood ash, and 100% mortality was detected when the beetles were exposed to SilicoSec®. Details are presented in Table 5. When *S. oryzae* adults were exposed to 40 g/m² at 20 °C and 55% RH, more than 91% mortality was detected in the SilicoSec® treatment after 7 days. On the other hand, 21% mortality was found under the same temperature conditions when adults in Petri dishes were exposed to wood ash. At 25 °C, 100% mortality was detected when adults were exposed to SilicoSec®, while in the wood ash treatment, the mortality of the beetles did not exceed 58%. When using dust from invasive plants, the mortality of beetles did not exceed 6% in any case. Details are presented in Table 6.

As presented in Table 7, less than 2% mortality was achieved at 20 °C and 75% RH when *S. oryzae* adults were exposed to crushed leaves of *R. typhina*, *A. fruticosa*, *S. gigantea* and crushed leaves and flowers of *S. canadensis* at lower doses. When exposed to 25 °C, the mortality of *S. oryzae* adults in the treatments outlined above was higher than 5% only in Petri dishes treated with leaves from *R. typhina*. When diatomaceous earth was used, the beetle mortality on the 7th day was 52% at 25 °C and 87% at 20 °C. Wood ash affected 9% of beetle mortality at 20 °C but did not exceed 2% at 25 °C.

As presented in Table 8, at both temperatures within 75% RH, less than 2% adult mortality was detected in treatments with crushed leaves of *A. altissima*, *R. typhina*, *A. fruticosa* and crushed leaves/flowers of *S. canadensis*. Wood ash and diatomaceous earth showed better insecticidal activity on beetles at 20 °C, as the mortality of beetles was 16% in

Table 7Mean mortality ($\pm$ SE) of *Sitophilus oryzae* adults exposed from the 1st to 7th day to a lower dose of powders (20 g/m²) at two temperatures within 75% RH.

		Day 1	Day 2	Day 3	Day 4	Day 7
20 °C	Wood ash	0.66 $\pm$ 0.44 Ab	0.87 $\pm$ 0.43 Ab	1.16 $\pm$ 0.46 Aa	2.86 $\pm$ 0.86 Bb	8.99 $\pm$ 2.67 Bd
	SilicoSec®	1.65 $\pm$ 0.52 Ac	3.52 $\pm$ 1.28 Ac	13.44 $\pm$ 2.15 Ab	28.73 $\pm$ 2.49 BCE	87.22 $\pm$ 1.57 Be
	<i>A. altissima</i> L*	0.33 $\pm$ 0.33 Aab	0.33 $\pm$ 0.29 Ab	0.58 $\pm$ 0.38 Aa	1.24 $\pm$ 0.70 Aa	1.80 $\pm$ 0.91 Abc
	<i>R. typhina</i> L*	0.33 $\pm$ 0.33 Aab	0.33 $\pm$ 0.29 Ab	0.33 $\pm$ 0.29 Aa	0.58 $\pm$ 0.39 Aa	0.58 $\pm$ 0.28 Aa
	<i>A. fruticosa</i> L*	0.33 $\pm$ 0.33 Aab	0.58 $\pm$ 0.38 Ab	1.16 $\pm$ 0.46 Aa	1.16 $\pm$ 0.46 Aa	1.42 $\pm$ 0.57 Ab
	<i>S. canadensis</i> L*	0.33 $\pm$ 0.33 Aab	0.58 $\pm$ 0.38 Ab	0.87 $\pm$ 0.43 Aa	0.87 $\pm$ 0.43 Aa	1.21 $\pm$ 0.60 Aab
	<i>S. canadensis</i> F*	0.00 $\pm$ 0.00 Aa	0.29 $\pm$ 0.29 Aab	0.58 $\pm$ 0.38 Ab	0.87 $\pm$ 0.43 Aa	1.21 $\pm$ 0.60 Aab
	<i>S. gigantea</i> L*	0.00 $\pm$ 0.00 Aa	0.00 $\pm$ 0.00 Aa	0.29 $\pm$ 0.29 Aa	0.58 $\pm$ 0.38 Aa	1.42 $\pm$ 0.57 Aab
	<i>S. gigantea</i> F*	0.33 $\pm$ 0.33 Aab	1.24 $\pm$ 0.70 Bb	1.53 $\pm$ 0.69 Ba	1.54 $\pm$ 0.69 Bab	3.13 $\pm$ 1.03 Ac
	Wood ash	0.37 $\pm$ 0.37 Aab	0.66 $\pm$ 0.44 Aa	0.99 $\pm$ 0.49 Aa	0.99 $\pm$ 0.49 Aa	1.98 $\pm$ 0.49 Aab
	SilicoSec®	1.48 $\pm$ 0.58 Ab	4.58 $\pm$ 1.54 Ab	13.01 $\pm$ 2.36 Ab	20.07 $\pm$ 2.70 Ac	51.67 $\pm$ 3.57 Ad
	<i>A. altissima</i> L	0.37 $\pm$ 0.37 Aab	0.66 $\pm$ 0.43 Aa	1.32 $\pm$ 0.52 Aa	1.65 $\pm$ 0.52 Aa	1.98 $\pm$ 0.49 Aab
25 °C	<i>R. typhina</i> L*	0.74 $\pm$ 0.74 Aab	1.03 $\pm$ 0.74 Aa	2.51 $\pm$ 1.86 Bb	3.26 $\pm$ 2.57 Bb	6.81 $\pm$ 2.60 BCE
	<i>A. fruticosa</i> L*	0.37 $\pm$ 0.37 Aab	0.37 $\pm$ 0.33 Aa	0.37 $\pm$ 0.33 Aa	0.37 $\pm$ 0.33 Aa	1.32 $\pm$ 0.52 Aa
	<i>S. canadensis</i> L*	0.74 $\pm$ 0.49 Ab	0.74 $\pm$ 0.44 Aa	0.74 $\pm$ 0.44 Aa	0.99 $\pm$ 0.50 Aab	2.40 $\pm$ 1.03 Ab
	<i>S. canadensis</i> F*	0.37 $\pm$ 0.37 Aab	0.66 $\pm$ 0.43 Aa	0.66 $\pm$ 0.43 Aa	0.99 $\pm$ 0.43 Aab	2.02 $\pm$ 0.73 Aab
	<i>S. gigantea</i> L*	0.00 $\pm$ 0.00 Aa	1.32 $\pm$ 0.52 Ba	2.35 $\pm$ 0.68 Bb	2.35 $\pm$ 0.69 Aab	2.35 $\pm$ 0.69 Aab
	<i>S. gigantea</i> F*	0.37 $\pm$ 0.37 Aab	0.37 $\pm$ 0.33 Aa	0.37 $\pm$ 0.33 Aa	0.99 $\pm$ 0.49 Ab	2.02 $\pm$ 0.73 Aab

Within each column and treatment, means followed by the same uppercase letter do not differ significantly by Tukey HSD test at $P = 0.05$. For comparison within column between the same treatment, $df = 1,65$ (Day 1, for wood ash, $F = 13.55$, $P = 0.35$; for SilicoSec, $F = 4.55$, $P = 0.07$; for *A. altissima* leaves, $F = 7.42$, $P = 0.07$; for *R. typhina* leaves, $F = 19.47$, $P = 0.07$; for *A. fruticosa*, $F = 7.14$, $P = 0.07$; for *S. canadensis* L, $F = 42.55$, $P = 0.11$; for *S. canadensis* F, $F = 9.09$, $P < 0.01$; for *S. gigantea* L, $F = 12.01$, $P < 0.01$, for *S. gigantea* F, $F = 14.10$, $P = 0.11$; Day 2, for Norway Spruce, $F = 14.16$, $P = 0.06$, SilicoSec, $F = 12.55$, $P = 0.09$; for *A. altissima* leaves, $F = 14.22$, $P = 0.09$; for *R. typhina* leaves, $F = 12.77$, $P = 0.06$; for *A. fruticosa*, $F = 17.44$, $P = 0.09$; for *S. canadensis* L, $F = 3.55$, $P < 0.01$; for *S. canadensis* F, $F = 15.09$, $P = 0.09$; for *S. gigantea* L, $F = 12.01$, $P < 0.01$, for *S. gigantea* F, $F = 32.10$, $P < 0.01$; Day 3, for Wood ash, $F = 12.09$, $P = 0.05$; for SilicoSec, $F = 12.45$, $P = 0.06$; for *A. altissima* leaves, $F = 12.32$, $P = 0.09$; for *R. typhina* leaves, $F = 12.15$, $P = 0.05$; for *A. fruticosa*, $F = 3.12$, $P = 0.07$; for *S. canadensis* L, $F = 11.75$, $P < 0.01$; for *S. canadensis* F, $F = 42.12$, $P = 0.07$; for *S. gigantea* L, $F = 45.01$, $P < 0.05$, for *S. gigantea* F, $F = 45.10$, $P < 0.01$; Day 4, for wood ash, $F = 13.10$, $P < 0.01$; for SilicoSec, $F = 34.33$, $P < 0.01$; for *A. altissima* leaves, $F = 12.32$, $P < 0.08$; for *R. typhina* leaves, $F = 7.85$, $P = 0.57$; for *A. fruticosa*, $F = 17.12$, $P = 0.06$; for *S. canadensis* L, $F = 12.75$, $P = 0.81$; for *S. canadensis* F, $F = 45.12$, $P < 0.01$; for *S. gigantea* L, $F = 8.01$, $P < 0.05$, for *S. gigantea* F, $F = 11.10$, $P = 0.72$; Day 7, for wood ash, $F = 30.01$, $P < 0.01$; for SilicoSec, $F = 99.33$, $P < 0.01$; for *A. altissima* leaves, $F = 44.32$, $P = 0.25$; for *R. typhina* leaves, $F = 7.15$, $P = 0.61$; for *A. fruticosa*, $F = 17.12$, $P = 0.15$; for *S. canadensis* L, $F = 1.95$, $P = 0.31$; for *S. canadensis* F, $F = 22.12$, $P < 0.01$; for *S. gigantea* L, $F = 20.01$, $P = 0.08$, for *S. gigantea* F, $F = 12.10$, $P = 0.17$).

Within column and temperature, means followed by the same lowercase letter do not differ significantly by Tukey HSD test at $P = 0.05$. For comparison within column within the same temperature between treatments, $df = 1,16$ (Day 1, for 20 °C, $F = 42.12$, $P < 0.01$, for 25 °C, $F = 32.20$, $P < 0.01$; Day 2, for 20 °C, $F = 27.23$, $P < 0.01$, for 25 °C, $F = 30.17$, $P < 0.01$; Day 3, for 20 °C, $F = 16.17$, $P < 0.01$, for 25 °C, $F = 16.17$, $P < 0.05$; Day 4, for 20 °C, $F = 30.11$, $P < 0.01$, for 25 °C, $F = 25.17$, $P < 0.05$; Day 7, for 20 °C, $F = 42.91$, $P < 0.01$, for 25 °C, $F = 19.13$, $P < 0.01$).

the first case and 93% in the second.

3.4. Delayed mortality

According to general statistical analysis. The highest mortality was recorded at 55 % RH. With a general statistical analysis, we found significantly highest mortality of the beetles at 55% relative humidity (20.53 $\pm$ 0.82%), using the SilicoSec® formulation (93.88 $\pm$ 0.64%), and on the 10th, 11th, and 14th day after treatment (17.52 $\pm$ 1.20, 18.72 $\pm$ 1.22, and 19.64 $\pm$ 1.23), while no significant differences were found between the temperatures and concentrations of the formulations. All main effects and some interactions were significant (Table 9).

At a lower dose of dust, 8 days after treatment, 100% mortality was recorded in SilicoSec® treatment at 20 and 25 °C and 55% RH. When wood ash was used, beetle mortality was over 60% at both temperatures 14 days after treatment. Among dusts of invasive plants, the dusts of *S. canadensis* flowers and leaf dusts of *S. gigantea* had the greatest effect (9%, 14 days after treatment) on beetle mortality (Table 10). At a higher dose of dust, 8 days after treatment, 100% mortality of the adults was detected when they were exposed to SilicoSec® at both temperatures within 55% RH. Among the other powders, wood ash performed satisfactorily, affecting 61% (25 °C) or 80% (20 °C) of beetle mortality 14 days after treatment. Among the dusts of invasive plants, the dust of *S. gigantea* and *A. altissima* leaves showed the highest insecticidal activity at a lower temperature, but it did not exceed 16% efficiency (Table 11).

At a lower dose of dust and 75% RH, 100% mortality of adults was observed only when using SilicoSec® at 20 °C 14 days after treatment. At 25 °C, after 14 days when using the same formulation, the mortality of beetles was only 77%. Wood ash proved to be much less effective, affecting only 16% mortality of beetles at 20 °C after 14 days and not

even exceeding 6% mortality of beetles at 25 °C. Among dusts of invasive plants, the dust of *R. typhina* leaves showed the highest effectiveness, which at 25 °C affected beetle mortality by 14%. Details are presented in Table 12.

At 75% relative air humidity 8 days after treatment, the SilicoSec® formulation also did not affect the mortality of beetles, which would be higher than 97% (this was the case at 20 °C). Even 14 days after treatment, this formulation at 25 °C affected only 87% of the mortality of beetles. Wood ash did not exceed 38% efficacy in controlling beetles 14 days after exposure. Among the invasive plants, the highest insecticidal activity 14 days after exposure was proven for the crushed leaves of *A. fruticosa* and *S. gigantea* but did not exceed 8% efficiency (Table 13).

4. Discussion

S. oryzae is spread all over the world and is one of the most destructive pests of stored grains worldwide (Nasr et al., 2022). The prevalence of this species represents a major economic problem because they cause damage in silos, granaries and storage areas where mainly wheat, maize and pea grains are stored (Grenier et al., 1997). *S. oryzae* causes yield loss and poor crop quality (Rajendran and Sriranjini, 2008).

Today, chemical insecticides are still predominantly used for controlling stored-product pests, but they also have a negative impact on the environment (Daglish, 2004; Aulicky and Stejskal, 2015; Baltaci and Borchmann, 2022). The advantages of plant powders over synthetic insecticides are that they are a rich source of bioactive organic substances and are easily biodegradable, less toxic and harmful to the environment (Duke et al., 2003; Mario et al., 2023). Therefore, we decided to conduct a study, in which the influence of the contact action of natural powders on the mortality of *S. oryzae* adults have been evaluated. Based on our previous research experiences (Bohinc et al., 2018,

Table 8

Mean mortality (±SE) of *Sitophilus oryzae* adults exposed from the 1st to 7th day to higher doses of powders (40 g/m²) at two temperatures within 75% RH.

		Day 1	Day 2	Day 3	Day 4	Day 7
20 °C	Wood ash	1.54 ± 0.69 Bb	2.49 ± 0.95 Abc	3.44 ± 0.89 BCE	5.30 ± 1.30 BCE	16.47 ± 3.22 Bb
	SilicoSec®	3.15 ± 0.97 Ac	4.93 ± 1.07 Ac	14.17 ± 1.38 Ad	35.45 ± 2.36 Ad	93.26 ± 1.77 BCE
	<i>A. altissima</i> L*	0.29 ± 0.29 Aa	0.58 ± 0.39 Aab	0.58 ± 0.39 Aa	0.87 ± 0.43 Aa	1.99 ± 0.77 Aa
	<i>R. typhina</i> L*	0.29 ± 0.29 Aa	0.58 ± 0.39 Aab	1.16 ± 0.46 Aab	1.16 ± 0.46 Aab	1.62 ± 0.62 Aa
	<i>A. fruticosa</i> L*	0.29 ± 0.29 Aa	1.24 ± 0.70 Ab	1.24 ± 0.70 Aab	1.53 ± 0.69 Aab	1.99 ± 0.76 Aa
	<i>S. canadensis</i> L*	0.29 ± 0.29 Aa	0.29 ± 0.29 Aa	0.95 ± 0.70 Aa	1.24 ± 0.70 Aab	1.62 ± 0.62 Aa
	<i>S. canadensis</i> F*	0.58 ± 0.38 Aab	1.24 ± 0.70 Ab	1.53 ± 0.60 Aab	1.53 ± 0.60 Aab	1.87 ± 0.60 Aa
	<i>S. gigantea</i> L*	0.58 ± 0.38 Aab	1.24 ± 0.70 Ab	1.62 ± 0.87 Aab	2.74 ± 1.61 Ab	3.24 ± 1.84 Aa
	<i>S. gigantea</i> F*	0.29 ± 0.29 Aa	0.58 ± 0.38 Bab	1.45 ± 0.45 Ab	1.45 ± 0.45 Aab	2.12 ± 0.54 Aa
	Wood ash	0.00 ± 0.00 Aa	0.66 ± 0.44 Ab	0.87 ± 0.64 Aa	1.04 ± 0.54 Aa	1.42 ± 0.89 Aa
25 °C	SilicoSec®	2.72 ± 0.81 Ac	6.77 ± 1.57 Ac	19.85 ± 2.43 Bb	32.83 ± 2.43 Ab	64.15 ± 1.40 Ab
	<i>A. altissima</i> L*	0.00 ± 0.00 Aa	0.70 ± 0.70 Aab	0.70 ± 0.62 Aa	0.92 ± 0.92 Aa	1.63 ± 0.99 Aa
	<i>R. typhina</i> L*	0.66 ± 0.44 Ab	1.32 ± 0.52 Ab	1.32 ± 0.39 Aa	1.32 ± 0.54 Aa	1.76 ± 0.64 Aa
	<i>A. fruticosa</i> L*	0.00 ± 0.00 Aa	1.03 ± 0.74 Ab	1.03 ± 0.64 Aa	1.09 ± 0.72 Aa	1.63 ± 0.82 Aa
	<i>S. canadensis</i> L*	0.00 ± 0.00 Aa	0.66 ± 0.44 Aab	0.66 ± 0.33 Aa	0.66 ± 0.22 Aa	1.22 ± 0.52 Aa
	<i>S. canadensis</i> F*	0.33 ± 0.33 Aab	0.66 ± 0.44 Aab	0.66 ± 0.33 Aa	0.66 ± 0.22 Aa	1.38 ± 0.50 Aa
	<i>S. gigantea</i> L*	0.66 ± 0.43 Ab	0.66 ± 0.44 Aab	0.66 ± 0.33 Aa	0.66 ± 0.25 Aa	0.66 ± 0.25 Aa
	<i>S. gigantea</i> F*	0.00 ± 0.00 Aa	0.00 ± 0.00 Aa	1.12 ± 0.64 Aa	1.21 ± 0.52 Aa	1.38 ± 0.50 Aa

Within each column and treatment, means followed by the same uppercase letter do not differ significantly by Tukey HSD test at $P = 0.05$. For comparison within column between the same treatment, $df = 1,65$ (Day 1, for wood ash, $F = 20.55, P < 0.01$; for SilicoSec®, $F = 4.55, P < 0.05$; for *A. altissima* leaves, $F = 7.42, P = 0.07$; for *R. typhina* leaves, $F = 19.47, P = 0.07$; for *A. fruticosa*, $F = 7.14, P = 0.07$; for *S. canadensis* L, $F = 42.55, P = 0.11$; for *S. canadensis* F, $F = 9.09, P < 0.01$; for *S. gigantea* L, $F = 12.01, P < 0.01$, for *S. gigantea* F, $F = 14.10, P = 0.11$; Day 2, for wood ash, $F = 14.16, P = 0.09$, SilicoSec®, $F = 17.55, P = 0.13$; for *A. altissima* leaves, $F = 14.22, P < 0.01$; for *R. typhina* leaves, $F = 12.77, P = 0.09$; for *A. fruticosa*, $F = 17.44, P = 0.23$; for *S. canadensis* L, $F = 9.55, P = 0.13$; for *S. canadensis* F, $F = 25.09, P = 0.33$; for *S. gigantea* L, $F = 12.01, P < 0.01$, for *S. gigantea* F, $F = 33.10, P < 0.01$; Day 3, for Wood ash, $F = 44.09, P < 0.01$; for SilicoSec®, $F = 23.45, P < 0.01$; for *A. altissima* leaves, $F = 44.32, P = 0.09$; for *R. typhina* leaves, $F = 12.15, P = 0.05$; for *A. fruticosa*, $F = 9.12, P = 0.07$; for *S. canadensis* L, $F = 15.75, P = 0.07$; for *S. canadensis* F, $F = 20.12, P = 0.09$; for *S. gigantea* L, $F = 20.01, P = 0.06$, for *S. gigantea* F, $F = 45.10, P < 0.01$; Day 4, for wood ash, $F = 44.10, P < 0.01$; for SilicoSec®, $F = 34.33, P = 0.07$; for *A. altissima* leaves, $F = 12.32, P = 0.18$; for *R. typhina* leaves, $F = 12.85, P = 0.27$; for *A. fruticosa*, $F = 17.12, P = 0.09$; for *S. canadensis* L, $F = 12.75, P = 0.81$; for *S. canadensis* F, $F = 45.12, P = 0.12$; for *S. gigantea* L, $F = 8.01, P = 0.66$, for *S. gigantea* F, $F = 14.10, P = 0.72$; Day 7, for wood ash, $F = 30.01, P < 0.01$; for SilicoSec®, $F = 66.33, P < 0.01$; for *A. altissima* leaves, $F = 77.32, P = 0.35$; for *R. typhina* leaves, $F = 7.15, P = 0.61$; for *A. fruticosa*, $F = 17.12, P = 0.15$; for *S. canadensis* L, $F = 1.95, P = 0.31$; for *S. canadensis* F, $F = 22.12, P = 0.51$; for *S. gigantea* L, $F = 20.01, P = 0.08$, for *S. gigantea* F, $F = 12.10, P = 0.17$). Within each column and temperature, means followed by the same lowercase letter do not differ significantly by Tukey HSD test at $P = 0.05$. For comparison within column within the same temperature between treatments, $df = 1,16$ (Day 1, for 20 °C, $F = 11.12, P < 0.01$, for 25 °C, $F = 13.20, P < 0.01$; Day 2, for 20 °C, $F = 11.23, P < 0.01$, for 25 °C, $F = 11.17, P < 0.01$; Day 3, for 20 °C, $F = 20.21, P < 0.01$, for 25 °C, $F = 17.17, P < 0.05$; Day 4, for 20 °C, $F = 25.11, P < 0.01$, for 25 °C, $F = 44.17, P < 0.05$; Day 7, for 20 °C, $F = 11.91, P < 0.01$, for 25 °C, $F = 19.13, P < 0.01$).

2020a), we hypothesized that diatomaceous earth and wood ash of Norway spruce would be more effective than the powders of invasive alien plants.

With the results of our research, we confirmed the findings of previous research that important factors in the mortality of storage beetles are exposure time, humidity and temperature (Bohinc et al., 2018), as well as the concentration of formulations (Bohinc et al., 2020b) and the type of inert dust or formulation (Liška et al., 2017; Bohinc et al., 2020a, 2020b). The reason for the general insignificance of the differences in some factors (concentration of formulations, temperature in the period between the 8th and 14th day of exposure) is attributed to the very low insecticidal efficiency of the dusts of invasive plants, since in the case of the two more effective formulations (diatomaceous earth and wood ash), even in the abovementioned factors, we found significant differences.

We also noted that different species of beetles from the same genus are differently sensitive to diatomaceous earth (Korunić and Fields, 2006; Rojht et al., 2010), which in our research, where we used the *S. oryzae*, is reflected in lower percentages of mortality compared to our previous research, where we used the *S. zeamais* (Bohinc et al., 2018). Some past research indicates a high (Tiroeselea et al., 2019) or insufficient (Songa and Rono, 1998) insecticidal efficacy of wood ash, however in our experiment, wood ash showed less insecticidal activity than diatomaceous earth but higher activity than dust from invasive plants. The SiO₂ content in wood ash was low, but the low content cannot be one of the reasons for the lower efficacy on *S. oryzae* adults than the wood ash used in the study by Bohinc et al. (2018) against *S. zeamais*, where the ash studied also had a low SiO₂ content. Therefore, we associated the insecticidal efficacy of wood ash with its hydrophilicity rather than the SiO₂ content, with which the ash deprives the beetle of the moisture necessary for its life (Batistić et al., 2023a, b). To confirm

Table 9

Repeated measures ANOVA parameters for main effects and associated interactions for mortality level of *Sitophilus oryzae* adults from the 8th to 14th day (error $df = 197$).

Source	df	F	P
Source between variables			
All between	132	44.33	<0.05
Intercept	1	44.22	<0.05
Exposure day	4	67.46	<0.05
Dose	1	44.14	<0.05
Treatment	7	13,123.4	<0.05
RH	1	990.1	<0.05
Exposure day x dose	4	4.81	<0.05
Exposure day x treatment	28	8.77	<0.05
Exposure day x RH	4	1.31	0.2624
Dose x treatment	7	16.08	<0.05
Dose x RH	1	7.92	0.004
Treatment x RH	7	731.67	<0.05
Exposure day x dose x treatment	28	1.26	0.16
Exposure day x dose x RH	4	0.69	0.60
Exposure day x treatment x RH	28	6.01	<0.05
Dose x treatment x RH	7	8.76	<0.05
Source within variables			
Within interactions	65	33.11	<0.05
Temperature	1	40.19	<0.05
Exposure day x temperature	4	4.32	<0.05
Dose x temperature	1	123.52	<0.05
Treatment x temperature	7	60.77	<0.05
RH x temperature	1	134.62	<0.05
Exposure day x dose x temperature	4	2.08	0.08
Exposure day x treatment x temperature	28	9.08	<0.05
Exposure day x RH x temperature	4	14.36	<0.05
Dose x treatment x temperature	7	24.36	<0.05
Dose x RH x temperature	1	39.90	<0.05
Treatment x RH x temperature	7	15.06	<0.05

Table 10Mean mortality ($\pm$ SE) of *Sitophilus oryzae* exposed from the 8th to 14th day to a lower dose of powders (20 g/m²) at two temperatures within 55% RH.

		Day 8	Day 9	Day 10	Day 11	Day 14
20 °C	Wood ash	26.95 $\pm$ 2.80 Ae	35.74 $\pm$ 3.44 Ae	41.17 $\pm$ 3.70 Ae	51.27 $\pm$ 4.11 Ae	60.08 $\pm$ 4.97 Ad
	SilicoSec®	99.61 $\pm$ 0.39 Af	100.00 $\pm$ 0.00 Af	100.00 $\pm$ 0.00 Af	100.00 $\pm$ 0.00 Af	100.00 $\pm$ 0.00 Ae
	<i>A. altissima</i> L*	3.63 $\pm$ 0.70 Acd	3.63 $\pm$ 1.05 Ad	3.63 $\pm$ 1.11 Acd	3.95 $\pm$ 1.91 Ad	6.19 $\pm$ 2.59 Ad
	<i>R. typhina</i> L*	0.66 $\pm$ 0.17 Ab	0.66 $\pm$ 0.35 Ab	1.21 $\pm$ 1.02 Abc	1.64 $\pm$ 0.98 Abc	2.00 $\pm$ 1.25 Ab
	<i>A. fruticosa</i> L*	0.00 $\pm$ 0.00 Aa	0.00 $\pm$ 0.00 Aa	0.00 $\pm$ 0.00 Aa	0.00 $\pm$ 0.00 Aa	0.38 $\pm$ 0.38 Aa
	<i>S. canadensis</i> L*	4.16 $\pm$ 1.74 Ad	4.16 $\pm$ 1.40 Ad	4.16 $\pm$ 1.14 Bd	4.16 $\pm$ 1.03 Ad	4.17 $\pm$ 1.00 Ac
	<i>S. canadensis</i> F*	0.66 $\pm$ 0.26 Ab	0.66 $\pm$ 0.00 Ab	0.66 $\pm$ 0.00 Ab	0.66 $\pm$ 0.00 Ab	0.66 $\pm$ 0.00 Aa
	<i>S. gigantea</i> L*	2.43 $\pm$ 1.03 Ac	2.43 $\pm$ 1.32 Acd	2.43 $\pm$ 1.14 Ac	2.59 $\pm$ 1.21 Acd	3.62 $\pm$ 1.37 Abc
	<i>S. gigantea</i> F*	1.47 $\pm$ 0.54 Abc	1.46 $\pm$ 0.40 Ac	1.46 $\pm$ 0.00 Ab	1.46 $\pm$ 0.51 Ab	1.46 $\pm$ 0.38 Ab
	Wood ash	64.34 $\pm$ 4.26 Bd	64.34 $\pm$ 4.38 BCE	64.40 $\pm$ 4.74 BCE	64.40 $\pm$ 4.74 BCE	64.65 $\pm$ 4.77 Ad
	SilicoSec®	100.00 $\pm$ 0.00 Ae	100.00 $\pm$ 0.00 Ad	100.00 $\pm$ 0.00 Ad	100.00 $\pm$ 0.00 Ad	100.00 $\pm$ 0.00 Ae
	<i>A. altissima</i> L*	5.43 $\pm$ 1.81 Ac	5.43 $\pm$ 2.03 Ab	5.77 $\pm$ 1.80 Ab	5.77 $\pm$ 1.80 Ab	6.15 $\pm$ 1.94 Ab
25 °C	<i>R. typhina</i> L*	3.49 $\pm$ 1.11 Bab	3.80 $\pm$ 1.97 Bab	5.38 $\pm$ 2.19 Bb	6.57 $\pm$ 2.26 Bb	7.89 $\pm$ 2.45 Bbc
	<i>A. fruticosa</i> L*	2.01 $\pm$ 1.01 Ba	2.00 $\pm$ 0.99 Ba	2.04 $\pm$ 0.91 Ba	2.44 $\pm$ 1.19 Ba	2.44 $\pm$ 1.14 Ba
	<i>S. canadensis</i> L*	2.17 $\pm$ 0.82 Aa	2.17 $\pm$ 1.54 Aa	2.17 $\pm$ 1.49 Aa	4.36 $\pm$ 2.23 Aab	4.82 $\pm$ 2.14 Aab
	<i>S. canadensis</i> F*	6.56 $\pm$ 1.62 BCE	6.56 $\pm$ 1.91 Bb	6.98 $\pm$ 2.32 Bb	7.77 $\pm$ 2.32 Bb	8.70 $\pm$ 2.71 Abc
	<i>S. gigantea</i> L*	3.87 $\pm$ 1.51 Ab	3.87 $\pm$ 1.33 Aab	4.75 $\pm$ 1.79 Aab	7.55 $\pm$ 2.74 Bb	8.70 $\pm$ 2.56 BCE
	<i>S. gigantea</i> F*	2.80 $\pm$ 0.90 Aa	2.80 $\pm$ 0.80 Aa	2.80 $\pm$ 1.15 Ba	2.79 $\pm$ 1.16 Ba	2.94 $\pm$ 1.32 Aa

Within each column and treatment, means followed by the same uppercase letter do not differ significantly by Tukey HSD test at $P = 0.05$. For comparison within column between the same treatment, $df = 1,65$ (Day 8, for wood ash, $F = 14.55$, $P < 0.01$; for SilicoSec, $F = 12.55$, $P = 0.06$; for *A. altissima* leaves, $F = 7.42$, $P = 0.07$; for *R. typhina* leaves, $F = 21.47$, $P < 0.01$; for *A. fruticosa*, $F = 12.14$, $P < 0.01$; for *S. canadensis* L, $F = 11.55$, $P = 0.11$; for *S. canadensis* F, $F = 17.09$, $P < 0.01$; for *S. gigantea* L, $F = 9.01$, $P = 0.08$, for *S. gigantea* F, $F = 9.10$, $P = 0.06$; Day 9, for wood ash, $F = 25.16$, $P < 0.01$, SilicoSec, $F = 22.55$, $P = 0.19$; for *A. altissima* leaves, $F = 19.22$, $P = 0.09$; for *R. typhina* leaves, $F = 12.77$, $P = 0.09$; for *A. fruticosa*, $F = 17.44$, $P < 0.01$; for *S. canadensis* L, $F = 4.55$, $P = 0.19$; for *S. canadensis* F, $F = 11.09$, $P < 0.01$; for *S. gigantea* L, $F = 11.01$, $P < 0.01$, for *S. gigantea* F, $F = 17.10$, $P < 0.01$; Day 10, for wood ash, $F = 88.09$, $P < 0.01$; for SilicoSec, $F = 23.45$, $P < 0.01$; for *A. altissima* leaves, $F = 33.32$, $P = 0.09$; for *R. typhina* leaves, $F = 33.15$, $P < 0.01$; for *A. fruticosa*, $F = 15.12$, $P < 0.01$; for *S. canadensis* L, $F = 12.75$, $P < 0.01$; for *S. canadensis* F, $F = 14.12$, $P < 0.01$; for *S. gigantea* L, $F = 11.01$, $P = 0.06$, for *S. gigantea* F, $F = 23.10$, $P < 0.01$; Day 11, for wood ash, $F = 77.10$, $P < 0.01$; for SilicoSec, $F = 40.33$, $P = 0.07$; for *A. altissima* leaves, $F = 12.32$, $P = 0.18$; for *R. typhina* leaves, $F = 12.85$, $P < 0.01$; for *A. fruticosa*, $F = 24.12$, $P < 0.01$; for *S. canadensis* L, $F = 12.75$, $P = 0.81$; for *S. canadensis* F, $F = 30.12$, $P = 0.17$; for *S. gigantea* L, $F = 10.01$, $P < 0.01$, for *S. gigantea* F, $F = 7.10$, $P = 0.42$; Day 14, for wood ash, $F = 29.01$, $P = 0.07$; for SilicoSec, $F = 17.33$, $P = 0.06$; for *A. altissima* leaves, $F = 77.32$, $P = 0.35$; for *R. typhina* leaves, $F = 15.15$, $P < 0.05$; for *A. fruticosa*, $F = 27.12$, $P < 0.05$; for *S. canadensis* L, $F = 17.95$, $P < 0.05$; for *S. canadensis* F, $F = 27.12$, $P = 0.51$; for *S. gigantea* L, $F = 20.01$, $P = 0.08$, for *S. gigantea* F, $F = 33.10$, $P = 0.19$).

Within each column and temperature, means followed by the same lowercase letter do not differ significantly by Tukey HSD test at $P = 0.05$. $Df = 1,16$ (Day 8, for 20 °C, $F = 11.12$, $P < 0.01$, for 25 °C, $F = 13.20$, $P < 0.01$; Day 9, for 20 °C, $F = 31.23$, $P < 0.01$, for 25 °C, $F = 33.17$, $P < 0.01$; Day 10, for 20 °C, $F = 43.21$, $P < 0.01$, for 25 °C, $F = 21.17$, $P < 0.05$; Day 11, for 20 °C, $F = 25.11$, $P < 0.01$, for 25 °C, $F = 66.17$, $P < 0.05$; Day 14, for 20 °C, $F = 11.91$, $P < 0.01$, for 25 °C, $F = 44.13$, $P < 0.01$).

Table 11Mean mortality ($\pm$ SE) of *Sitophilus oryzae* exposed from the 8th to 14th day to a higher dose of powders (40 g/m²) at two temperatures within 55% RH.

		Day 8	Day 9	Day 10	Day 11	Day 14
20 °C	Wood ash	27.91 $\pm$ 1.74 Ad	34.63 $\pm$ 3.14 Ae	56.30 $\pm$ 4.83 Ae	69.44 $\pm$ 5.55 Ad	80.00 $\pm$ 0.00 Bd
	SilicoSec®	99.61 $\pm$ 0.39 Ae	100.00 $\pm$ 0.00 Af	100.00 $\pm$ 0.00 Af	100.00 $\pm$ 0.00 Ae	100.00 $\pm$ 0.00 Ae
	<i>A. altissima</i> L*	5.81 $\pm$ 1.30 BCE	8.95 $\pm$ 1.42 Ad	10.62 $\pm$ 1.41 Bd	12.69 $\pm$ 1.59 BCE	15.20 $\pm$ 2.00 BCE
	<i>R. typhina</i> L*	1.03 $\pm$ 0.41 Aab	2.85 $\pm$ 1.03 Ab	2.97 $\pm$ 1.36 Bb	4.36 $\pm$ 1.95 Bb	6.18 $\pm$ 2.13 Bab
	<i>A. fruticosa</i> L*	2.84 $\pm$ 1.40 Ab	5.79 $\pm$ 1.88 Ac	6.60 $\pm$ 2.16 BCE	6.74 $\pm$ 2.09 Bcb	7.68 $\pm$ 1.84 Bb
	<i>S. canadensis</i> L*	1.42 $\pm$ 0.66 Aab	2.07 $\pm$ 0.70 BCE	2.07 $\pm$ 0.87 Bab	3.17 $\pm$ 1.62 Bab	6.18 $\pm$ 2.37 Bab
	<i>S. canadensis</i> F*	0.52 $\pm$ 0.34 Aa	0.64 $\pm$ 0.32 Aa	0.83 $\pm$ 0.46 Aa	1.98 $\pm$ 1.20 Aa	3.47 $\pm$ 1.44 Aa
	<i>S. gigantea</i> L*	3.25 $\pm$ 1.08 Abc	6.22 $\pm$ 1.82 Ac	7.48 $\pm$ 1.72 Acd	10.32 $\pm$ 2.62 Ac	13.60 $\pm$ 3.00 B
	<i>S. gigantea</i> F*	2.32 $\pm$ 0.75 Ab	2.32 $\pm$ 1.07 Ab	2.32 $\pm$ 1.37 Aab	3.57 $\pm$ 1.68 Aab	4.04 $\pm$ 1.84 Aa
	Wood ash	57.72 $\pm$ 3.66 Bd	59.10 $\pm$ 3.71 Be	59.41 $\pm$ 3.71 Ad	61.09 $\pm$ 3.44 Ad	61.34 $\pm$ 3.50 Ac
	SilicoSec	100.00 $\pm$ 0.00 Ae	100.00 $\pm$ 0.00 Af	100.00 $\pm$ 0.00 Ae	100.00 $\pm$ 0.00 Ae	100.00 $\pm$ 0.00 Ad
	<i>A. altissima</i> L	2.20 $\pm$ 0.18 Ab	2.20 $\pm$ 0.00 Ba	2.20 $\pm$ 0.65 Ab	2.20 $\pm$ 0.66 Ab	2.24 $\pm$ 1.18 Aa
25 °C	<i>R. typhina</i> L	2.54 $\pm$ 1.02 Bb	2.54 $\pm$ 1.02 Abc	2.60 $\pm$ 1.20 Ab	2.83 $\pm$ 1.16 Aab	2.83 $\pm$ 1.11 Aa
	<i>A. fruticosa</i> L	3.35 $\pm$ 0.93 Abc	3.35 $\pm$ 0.78 Ac	3.35 $\pm$ 0.85 Abc	3.35 $\pm$ 1.13 Abc	3.35 $\pm$ 1.14 Aab
	<i>S. canadensis</i> L	1.16 $\pm$ 0.13 Aa	1.16 $\pm$ 0.00 Aa	1.16 $\pm$ 0.00 Aa	1.16 $\pm$ 0.23 Aa	1.16 $\pm$ 0.61 Aa
	<i>S. canadensis</i> F	1.76 $\pm$ 1.00 Aab	1.76 $\pm$ 1.20 Aab	1.76 $\pm$ 1.05 Aab	1.95 $\pm$ 1.46 Aab	2.43 $\pm$ 1.45 Aa
	<i>S. gigantea</i> L	5.30 $\pm$ 1.05 Ac	5.30 $\pm$ 1.00 Ad	5.30 $\pm$ 1.38 Ac	5.30 $\pm$ 1.84 Ac	5.30 $\pm$ 1.84 Ab
	<i>S. gigantea</i> F	4.16 $\pm$ 0.53 BCE	4.16 $\pm$ 0.49 Bcd	4.16 $\pm$ 0.31 Ac	4.16 $\pm$ 0.31 Ac	4.16 $\pm$ 0.31 Ab

Within each column and treatment, means followed by the same uppercase letter do not differ significantly by Tukey HSD test at $P = 0.05$. For comparison within column between the same treatment, $df = 1,65$ (Day 8, Wood ash, $F = 23.55$, $P < 0.01$; for SilicoSec, $F = 45.55$, $P = 0.09$; for *A. altissima* leaves, $F = 17.42$, $P < 0.01$; for *R. typhina* leaves, $F = 40.47$, $P = 0.07$; for *A. fruticosa*, $F = 45.14$, $P = 0.06$; for *S. canadensis* L, $F = 9.55$, $P = 0.71$; for *S. canadensis* F, $F = 17.09$, $P = 0.18$; for *S. gigantea* L, $F = 22.01$, $P = 0.13$, for *S. gigantea* F, $F = 14.10$, $P < 0.01$; Day 9, for Norway Spruce, $F = 34.16$, $P < 0.01$, SilicoSec, $F = 22.55$, $P = 0.19$; for *A. altissima* leaves, $F = 19.22$, $P = 0.09$; for *R. typhina* leaves, $F = 12.77$, $P < 0.05$; for *A. fruticosa*, $F = 22.44$, $P = 0.07$; for *S. canadensis* L, $F = 10.55$, $P = 0.19$; for *S. canadensis* F, $F = 42.09$, $P = 0.27$; for *S. gigantea* L, $F = 23.01$, $P < 0.01$, for *S. gigantea* F, $F = 44.10$, $P < 0.01$; Day 10, for wood ash, $F = 88.09$, $P = 0.07$; for SilicoSec, $F = 45.45$, $P = 0.07$; for *A. altissima* leaves, $F = 50.32$, $P < 0.01$; for *R. typhina* leaves, $F = 14.15$, $P = 0.08$; for *A. fruticosa*, $F = 19.12$, $P < 0.01$; for *S. canadensis* L, $F = 24.75$, $P < 0.01$; for *S. canadensis* F, $F = 14.12$, $P < 0.01$; for *S. gigantea* L, $F = 14.01$, $P = 0.06$, for *S. gigantea* F, $F = 35.10$, $P < 0.01$; Day 11, for wood ash, $F = 77.10$, $P = 0.07$; for SilicoSec, $F = 40.33$, $P = 0.07$; for *A. altissima* leaves, $F = 30.32$, $P = 0.18$; for *R. typhina* leaves, $F = 12.85$, $P < 0.01$; for *A. fruticosa*, $F = 30.12$, $P < 0.01$; for *S. canadensis* L, $F = 24.75$, $P < 0.01$; for *S. canadensis* F, $F = 30.12$, $P = 0.17$; for *S. gigantea* L, $F = 10.01$, $P < 0.01$, for *S. gigantea* F, $F = 7.10$, $P = 0.42$; Day 14, for wood ash, $F = 29.01$, $P < 0.05$; for SilicoSec, $F = 33.33$, $P = 0.07$; for *A. altissima* leaves, $F = 77.32$, $P = 0.44$; for *R. typhina* leaves, $F = 33.15$, $P < 0.01$; for *A. fruticosa*, $F = 30.12$, $P < 0.05$; for *S. canadensis* L, $F = 20.95$, $P < 0.01$, for *S. canadensis* F, $F = 27.12$, $P = 0.31$; for *S. gigantea* L, $F = 20.01$, $P < 0.01$, for *S. gigantea* F, $F = 33.10$, $P = 0.19$).

Within each column temperature, means followed by the same lowercase letter do not differ significantly by Tukey HSD test at $P = 0.05$. For comparison within column within the same temperature between treatments, $df = 1,16$ (Day 8, for 20 °C, $F = 19.12$, $P < 0.01$, for 25 °C, $F = 44.20$, $P < 0.01$; Day 9, for 20 °C, $F = 31.23$, $P < 0.01$, for 25 °C, $F = 33.17$, $P < 0.01$; Day 10, for 20 °C, $F = 43.21$, $P < 0.01$, for 25 °C, $F = 13.13$, $P < 0.05$; Day 11, for 20 °C, $F = 27.41$, $P < 0.01$, for 25 °C, $F = 66.17$, $P < 0.05$; Day 14, for 20 °C, $F = 15.91$, $P < 0.01$, for 25 °C, $F = 47.13$, $P < 0.01$).

Table 12
Mean mortality (±SE) of *Sitophilus oryzae* adults exposed from the 8th to 14th day to a lower dose of powders (20 g/m²) at two temperatures within 75% RH.

		Day 8	Day 9	Day 10	Day 11	Day 14
20 °C	Wood ash	10.60 ± 2.74 Bd	11.32 ± 2.62 BCE	13.21 ± 2.72 Ac	14.40 ± 2.23 Bd	15.97 ± 2.56 Bd
	SilicoSec®	96.23 ± 1.32 Ae	98.87 ± 0.57 Ba	100.00 ± 0.00 Ad	100.00 ± 0.00 Be	100.00 ± 0.00 Be
	<i>A. altissima</i> L*	2.14 ± 0.92 Abc	2.51 ± 0.96 Aab	3.23 ± 0.88 Ab	3.41 ± 0.80 Ae	4.56 ± 1.20 Abc
	<i>R. typhina</i> L*	0.58 ± 0.25 Aa	1.04 ± 0.54 Aa	1.42 ± 0.89 Aa	1.64 ± 0.80 Aa	1.64 ± 0.77 Aa
	<i>A. fruticosa</i> L*	1.42 ± 0.52 Ab	1.42 ± 0.50 Aa	1.42 ± 0.50 Aa	1.89 ± 0.68 Ba	2.28 ± 0.60 Aab
	<i>S. canadensis</i> L*	1.42 ± 0.69 Ab	1.42 ± 0.69 Aa	1.76 ± 0.63 Aa	1.76 ± 0.57 Aa	2.95 ± 1.01 Aab
	<i>S. canadensis</i> F*	1.22 ± 0.52 Aab	1.38 ± 0.50 Aa	2.30 ± 0.88 Aab	2.77 ± 1.21 Aab	3.37 ± 1.51 Ab
	<i>S. gigantea</i> L*	1.55 ± 0.47 Ab	2.85 ± 1.04 Aab	3.98 ± 1.01 Ab	4.79 ± 1.37 Abc	4.56 ± 1.33 Abc
	<i>S. gigantea</i> F*	3.06 ± 0.94 Ac	3.40 ± 0.82 Ab	3.77 ± 0.80 Ab	5.68 ± 1.14 Ac	7.60 ± 1.51 Ac
	Wood ash	3.72 ± 0.74 Ab	4.13 ± 1.26 Ab	4.56 ± 1.65 Abc	5.70 ± 1.90 Ac	5.96 ± 2.29 Ac
25 °C	SilicoSec®	53.53 ± 3.68 Ad	72.93 ± 3.18 Ad	76.04 ± 3.78 Ae	77.18 ± 3.95 Ag	77.22 ± 4.01 Af
	<i>A. altissima</i> L*	3.42 ± 0.83 Ab	4.30 ± 0.86 Ab	5.62 ± 2.17 Abc	6.38 ± 2.45 Bcd	6.38 ± 2.39 Acd
	<i>R. typhina</i> L*	7.93 ± 2.92 BCE	10.53 ± 2.46 BCE	11.02 ± 2.35 Bd	13.31 ± 2.23 Bf	14.28 ± 1.92 Be
	<i>A. fruticosa</i> L*	1.32 ± 0.52 Aa	1.32 ± 0.33 Aa	1.32 ± 0.43 Aa	1.32 ± 0.56 Aa	1.32 ± 0.40 Aa
	<i>S. canadensis</i> L*	3.76 ± 1.20 Bb	3.93 ± 1.54 Bab	3.92 ± 1.51 Bd	4.10 ± 1.42 Aa	4.10 ± 1.38 Abc
	<i>S. canadensis</i> F*	2.35 ± 0.69 Bab	2.59 ± 0.71 Ba	2.87 ± 1.04 Aab	3.63 ± 1.38 Bb	3.63 ± 1.23 Ab
	<i>S. gigantea</i> L*	4.21 ± 1.42 Bbc	7.31 ± 1.70 BCE	8.28 ± 1.92 BCE	8.28 ± 1.92 Be	7.12 ± 1.81 Bd
	<i>S. gigantea</i> F*	2.06 ± 1.06 Ab	4.30 ± 0.86 Ab	4.78 ± 1.09 Ab	5.23 ± 1.03 Ac	5.24 ± 1.10 Abc
	Wood ash	3.72 ± 0.74 Ab	4.13 ± 1.26 Ab	4.56 ± 1.65 Abc	5.70 ± 1.90 Ac	5.96 ± 2.29 Ac
	SilicoSec®	53.53 ± 3.68 Ad	72.93 ± 3.18 Ad	76.04 ± 3.78 Ae	77.18 ± 3.95 Ag	77.22 ± 4.01 Af

Within each column and treatment, means followed by the same uppercase letter do not differ significantly by Tukey HSD test at $P = 0.05$. For comparison within column between the same treatment, $df = 1,65$ (Day 8, for wood ash, $F = 41.66$, $P < 0.01$; for SilicoSec, $F = 45.55$, $P < 0.01$; for *A. altissima* leaves, $F = 17.42$, $P < 0.01$; for *R. typhina* leaves, $F = 40.47$, $P < 0.01$; for *A. fruticosa*, $F = 45.14$, $P = 0.09$; for *S. canadensis* L, $F = 45.55$, $P < 0.01$; for *S. canadensis* F, $F = 30.09$, $P < 0.01$; for *S. gigantea* L, $F = 22.01$, $P = 0.13$, for *S. gigantea* F, $F = 14.10$, $P < 0.01$; Day 9, for wood ash, $F = 11.16$, $P < 0.01$, SilicoSec, $F = 22.55$, $P < 0.05$; for *A. altissima* leaves, $F = 23.22$, $P = 0.07$; for *R. typhina* leaves, $F = 12.77$, $P < 0.05$; for *A. fruticosa*, $F = 22.44$, $P = 0.07$; for *S. canadensis* L, $F = 10.55$, $P = 0.19$; for *S. canadensis* F, $F = 42.09$, $P = 0.27$; for *S. gigantea* L, $F = 30.10$, $P < 0.01$, for *S. gigantea* F, $F = 44.10$, $P < 0.01$; Day 10, for wood ash, $F = 88.09$, $P = 0.07$; for SilicoSec, $F = 45.45$, $P = 0.07$; for *A. altissima* leaves, $F = 50.32$, $P < 0.01$; for *R. typhina* leaves, $F = 14.15$, $P = 0.08$; for *A. fruticosa*, $F = 19.12$, $P < 0.01$; for *S. canadensis* L, $F = 24.75$, $P < 0.01$; for *S. canadensis* F, $F = 14.12$, $P < 0.01$; for *S. gigantea* L, $F = 41.01$, $P < 0.01$, for *S. gigantea* F, $F = 41.10$, $P = 0.07$; Day 11, for wood ash, $F = 77.10$, $P = 0.07$; for SilicoSec, $F = 40.33$, $P = 0.07$; for *A. altissima* leaves, $F = 30.32$, $P = 0.18$; for *R. typhina* leaves, $F = 12.85$, $P < 0.01$; for *A. fruticosa*, $F = 30.12$, $P < 0.01$; for *S. canadensis* L, $F = 24.75$, $P < 0.01$; for *S. canadensis* F, $F = 30.12$, $P = 0.17$; for *S. gigantea* L, $F = 10.01$, $P < 0.01$, for *S. gigantea* F, $F = 7.10$, $P = 0.42$; Day 14, for wood ash, $F = 29.01$, $P < 0.05$; for SilicoSec, $F = 33.33$, $P = 0.07$; for *A. altissima* leaves, $F = 77.32$, $P = 0.34$; for *R. typhina* leaves, $F = 50.15$, $P < 0.01$; for *A. fruticosa*, $F = 30.12$, $P < 0.05$; for *S. canadensis* L, $F = 20.95$, $P < 0.01$, for *S. canadensis* F, $F = 27.12$, $P = 0.31$; for *S. gigantea* L, $F = 27.01$, $P < 0.01$, for *S. gigantea* F, $F = 33.10$, $P = 0.23$). Within each column and temperature, means followed by the same lowercase letter do not differ significantly by Tukey HSD test at $P = 0.05$. For comparison within column within the same temperature between treatments, $df = 1,16$ (Day 8, for 20 °C, $F = 11.12$, $P < 0.01$, for 25 °C, $F = 44.20$, $P < 0.01$; Day 9, for 20 °C, $F = 45.23$, $P < 0.01$, for 25 °C, $F = 25.17$, $P < 0.01$; Day 10, for 20 °C, $F = 27.21$, $P < 0.01$, for 25 °C, $F = 13.13$, $P < 0.05$; Day 11, for 20 °C, $F = 27.41$, $P < 0.01$, for 25 °C, $F = 22.17$, $P < 0.05$; Day 14, for 20 °C, $F = 15.91$, $P < 0.01$, for 25 °C, $F = 33.13$, $P < 0.01$).

Table 13
Mean mortality (±SE) of *Sitophilus oryzae* exposed from the 8th to 14th day to a higher dose of powders (40 g/m²) at two temperatures within 75% RH.

		Day 8	Day 9	Day 10	Day 11	Day 14
20 °C	Wood ash	22.47 ± 2.75 BCE	25.09 ± 2.43 Ba	28.83 ± 2.54 BCE	34.21 ± 3.04 Bb	37.73 ± 2.99 BCE
	SilicoSec®	97.38 ± 0.94 Ad	99.62 ± 0.37 Bd	100.00 ± 0.00 Bd	100.00 ± 0.00 BCE	100.00 ± 0.00 Bd
	<i>A. altissima</i> L*	2.00 ± 0.77 Aab	1.99 ± 0.77 Aab	2.99 ± 1.04 Aa	3.17 ± 0.89 Aa	3.39 ± 0.82 Aa
	<i>R. typhina</i> L*	2.00 ± 0.77 Aab	2.00 ± 0.81 Aa	3.74 ± 1.21 Aab	4.30 ± 1.03 Aa	6.03 ± 1.13 Ab
	<i>A. fruticosa</i> L*	2.74 ± 1.23 Aab	3.37 ± 1.22 Ab	4.24 ± 1.33 Ab	4.88 ± 1.43 Ad	6.79 ± 1.40 Ab
	<i>S. canadensis</i> L*	1.75 ± 0.33 Aa	2.37 ± 0.48 Aab	2.99 ± 0.49 Ab	4.13 ± 0.80 Aa	4.90 ± 0.80 Aab
	<i>S. canadensis</i> F*	2.50 ± 0.66 Aab	2.87 ± 0.75 Aab	3.24 ± 0.80 Bab	3.93 ± 0.90 Aa	4.91 ± 0.80 Aab
	<i>S. gigantea</i> L*	3.87 ± 1.81 Ab	3.87 ± 1.81 Ab	3.87 ± 1.81 Aab	4.09 ± 1.68 Aa	5.11 ± 1.79 Aab
	<i>S. gigantea</i> F*	2.75 ± 0.60 Bab	3.37 ± 0.79 Ab	3.37 ± 0.79 Aab	3.75 ± 0.82 Aa	4.52 ± 1.20 Aab
	Wood ash	3.23 ± 1.05 Aab	3.22 ± 0.96 Ab	5.38 ± 0.81 Abc	6.92 ± 1.07 Abc	9.26 ± 1.47 Ac
25 °C	SilicoSec®	69.06 ± 2.50 Ac	81.60 ± 2.81 Ad	84.62 ± 2.77 Ad	85.76 ± 2.91 Ad	86.87 ± 3.05 Ad
	<i>A. altissima</i> L*	1.63 ± 0.54 Aab	3.06 ± 1.07 Ab	4.02 ± 1.44 Ab	4.745 ± 1.37 Ab	5.49 ± 1.35 Aab
	<i>R. typhina</i> L*	4.20 ± 1.45 Bb	5.36 ± 1.53 BCE	7.35 ± 1.95 BCE	9.27 ± 2.41 BCE	12.74 ± 2.62 B
	<i>A. fruticosa</i> L*	1.63 ± 0.81 Aab	3.44 ± 1.15 Abc	4.31 ± 1.11 Abc	5.85 ± 1.34 Ab	7.42 ± 1.36 Abc
	<i>S. canadensis</i> L*	1.22 ± 0.52 Aa	1.53 ± 0.60 Aa	3.97 ± 1.33 Ab	5.85 ± 1.77 Ab	6.34 ± 1.65 Ab
	<i>S. canadensis</i> F*	1.39 ± 0.50 Aa	1.38 ± 0.50 Aa	1.75 ± 0.77 Aa	2.82 ± 1.02 Ab	3.64 ± 1.05 Aa
	<i>S. gigantea</i> L*	3.15 ± 2.05 Aab	4.98 ± 2.16 Abc	5.51 ± 2.27 Abc	7.05 ± 2.75 Abc	7.05 ± 2.72 Abc
	<i>S. gigantea</i> F*	1.38 ± 0.50 Aa	1.38 ± 0.38 Aa	2.09 ± 0.75 Aa	2.86 ± 1.17 Aa	3.34 ± 1.12 Aa
	Wood ash	3.23 ± 1.05 Aab	3.22 ± 0.96 Ab	5.38 ± 0.81 Abc	6.92 ± 1.07 Abc	9.26 ± 1.47 Ac
	SilicoSec®	69.06 ± 2.50 Ac	81.60 ± 2.81 Ad	84.62 ± 2.77 Ad	85.76 ± 2.91 Ad	86.87 ± 3.05 Ad

Within each column and treatment, means followed by the same uppercase letter do not differ significantly by Tukey HSD test at $P = 0.05$. For comparison within column between the same treatment, $df = 1,65$ (Day 8, for Wood ash, $F = 41.66$, $P < 0.01$; for SilicoSec, $F = 45.55$, $P < 0.01$; for *A. altissima* leaves, $F = 2.42$, $P = 0.07$; for *R. typhina* leaves, $F = 48.47$, $P < 0.01$; for *A. fruticosa*, $F = 45.14$, $P = 0.09$; for *S. canadensis* L, $F = 90.55$, $P = 0.09$; for *S. canadensis* F, $F = 58.09$, $P = 0.19$; for *S. gigantea* L, $F = 11.01$, $P = 0.19$, for *S. gigantea* F, $F = 19.10$, $P < 0.01$; Day 9, for Wood ash, $F = 11.16$, $P < 0.01$, SilicoSec, $F = 61.55$, $P < 0.01$; for *A. altissima* leaves, $F = 33.22$, $P = 0.17$; for *R. typhina* leaves, $F = 61.77$, $P < 0.01$; for *A. fruticosa*, $F = 16.44$, $P = 0.27$; for *S. canadensis* L, $F = 22.55$, $P = 0.33$; for *S. canadensis* F, $F = 42.09$, $P = 0.27$; for *S. gigantea* L, $F = 61.10$, $P = 0.19$, for *S. gigantea* F, $F = 23.10$, $P = 0.06$; Day 10, for Wood ash, $F = 88.09$, $P < 0.01$; for SilicoSec, $F = 31.45$, $P < 0.01$; for *A. altissima* leaves, $F = 11.32$, $P = 0.06$; for *R. typhina* leaves, $F = 23.15$, $P < 0.01$; for *A. fruticosa*, $F = 61.12$, $P = 0.07$; for *S. canadensis* L, $F = 4.75$, $P = 0.33$; for *S. canadensis* F, $F = 14.12$, $P < 0.01$; for *S. gigantea* L, $F = 41.01$, $P = 0.07$, for *S. gigantea* F, $F = 41.10$, $P = 0.11$; Day 11, for wood ash, $F = 77.10$, $P < 0.01$; for SilicoSec, $F = 40.33$, $P < 0.01$; for *A. altissima* leaves, $F = 30.32$, $P = 0.18$; for *R. typhina* leaves, $F = 27.85$, $P < 0.01$; for *A. fruticosa*, $F = 30.12$, $P = 0.06$; for *S. canadensis* L, $F = 30.11$, $P = 0.07$; for *S. canadensis* F, $F = 30.12$, $P = 0.17$; for *S. gigantea* L, $F = 25.01$, $P = 0.07$, for *S. gigantea* F, $F = 7.10$, $P = 0.22$; Day 14, for Wood ash, $F = 30.01$, $P < 0.01$; for SilicoSec, $F = 33.33$, $P < 0.05$; for *A. altissima* leaves, $F = 45.32$, $P < 0.01$; for *R. typhina* leaves, $F = 22.15$, $P < 0.01$; for *A. fruticosa*, $F = 13.12$, $P = 0.08$; for *S. canadensis* L, $F = 1.95$, $P < 0.01$, for *S. canadensis* F, $F = 23.12$, $P = 0.71$; for *S. gigantea* L, $F = 20.01$, $P = 0.12$, for *S. gigantea* F, $F = 33.10$, $P = 0.07$). Within each column and temperature, means followed by the same lowercase letter do not differ significantly by by Tukey HSD test at $P = 0.05$. For comparison within column within the same temperature between treatments, $df = 1,16$ (Day 8, for 20 °C, $F = 11.12$, $P < 0.01$, for 25 °C, $F = 21.20$, $P < 0.01$; Day 9, for 20 °C, $F = 22.23$, $P < 0.01$, for 25 °C, $F = 30.17$, $P < 0.01$; Day 10, for 20 °C, $F = 27.21$, $P < 0.01$, for 25 °C, $F = 12.13$, $P < 0.05$; Day 11, for 20 °C, $F = 27.41$, $P < 0.01$, for 25 °C, $F = 66.17$, $P < 0.05$; Day 14, for 20 °C, $F = 11.91$, $P < 0.01$, for 25 °C, $F = 30.13$, $P < 0.01$).

that the difference in susceptibility to inert dusts between different beetle species from the same genus, we can cite the fact that after the 7th day of exposure at 25 °C and 55% RH in a previous study (Bohinc et al., 2018), we found more than 90% mortality of *S. zeamais* adults with three different ashes, while in the present study under the mentioned conditions, the mortality of beetles did not exceed 60% when using wood ash.

That dust from non-native invasive plants has a low insecticidal efficiency was already established in a recent study (Bohinc et al., 2020a), when dust was mixed together with grain and where the mortality of adult individuals of the *S. oryzae* in treatments where only dust from invasive species was used did not exceed 10% after day 21, assuming treatments were exposed to lower humidity (55% RH) and higher temperature (25 °C). A high content of catechin hydrate was found in the powder of the leaves of the tree of heaven, and although catechin hydrate is supposed to have a repellent effect on the caterpillars of the corn borer, *Ostrinia nubilalis* (Hübner) (Lepidoptera: Crambidae) (Ntalli and Menkissoglu-Spiroudi, 2011), we did not find a significant insecticidal effect on the *S. oryzae*. *Solidago* spp. is a plant species that contains many essential oils, which we already found in previous research by Bohinc et al. (2020a). Beta-copaene was among the most abundant essential oils in the powders of Canadian and giant goldenrod, and despite the high proportion of the mentioned substance in the studied samples, we did not find a higher mortality rate of the tested *S. oryzae* adults. We assumed that a higher efficiency of beta-copaene could be achieved if the mentioned active substance was applied to petri dishes in the form of essential oils (Ferraz et al., 2022) and not dust. It should also be tested an aromatized clay powder based on the mixture of clay and essential oil extracted from *Solidago* spp., since in a related study the authors proved that this way of using essential oil of *Clausena anisata* suppresses the bean weevil more effectively than with the independent application of essential oil (Ndomo et al., 2008).

With our research, we have confirmed that diatomaceous earth is still the most effective inert dust for suppressing the *S. oryzae*, but due to some of its undesirable properties, like health concerns, reduction in bulk density, influence of various commodities on the efficacy of diatomaceous earth etc. (Korunić, 2016), it is necessary to continue studying the insecticidal activity of other natural or environmentally acceptable substances or to study possible synergism in the simultaneous use of two or more environmentally acceptable pest control methods (Ashraf et al., 2017; Ertürk, 2021). Wood ash is less effective against the *S. oryzae*, so to achieve higher effectiveness and reduce the negative effects of diatomaceous earth on grain, these two substances should be used in a mixture. Some of our previous research (Bohinc and Trdan, 2017) already indicates the suitability of this way of using inert powders. We also note that powders obtained from invasive plants are not effective for suppressing storage beetles even in contact mode, so in the future, we want to test their independent effectiveness in liquid form (Stejskal et al., 2021) as well as combinations of essential oils with inert powders (Paponja et al., 2020).

The results of our research indicate that the powders of invasive plants are closer to fragrant roses in controlling the *S. oryzae*, while the gun for the pest in question is only diatomaceous earth. Nevertheless, it seems that the combination of diatomaceous earths with other control methods merit additional investigation, due to their complementary mode of action, in terms of both rapid knockdown and residual effect, as a result of the presence of plant extract and the inert material, respectively.

CRedit authorship contribution statement

Matej Podgornik Milosavljević: Investigation, Writing – original draft. **Monica Novljan:** Data curation. **Iztok Jože Košir:** Methodology. **Aleksander Horvat:** Methodology. **Urban Šilc:** Methodology. **Evangelia Lampiri:** Data curation. **Christos Athanassiou:** Conceptualization, Visualization, Writing – review & editing. **Tanja Bohinc:** Data curation, Writing – original draft. **Matej Vidrih:** Conceptualization. **Stanislav**

Trdan: Project administration, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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