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The ability of several plant species and inert dusts to suppress adults of rice weevil *Sitophilus oryzae* (Coleoptera: Curculiontdae)

Manar, Y. Amin and Essam, M. Sayed

Plant Protection Research Institute, Agricultural Research Center, Dokki, Giza, Egypt.

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Abstract

This research aimed to compare the efficacy of different inert dusts, like zeolite and diatomaceous earth (DE), in controlling *Sitophilus oryzae* (L.) (Coleoptera: Curculiontdae) at 30+1°C and 65+5% relative humidity, in comparison to some plant dusts such as radish seed dust (*Raphanus sativus*), galangal rhizome dust (*Alpina officinarum*), and black pepper seed dust (*Piper nigrum* L.). The results indicated that the mortality of adults was influenced by the duration of exposure and the concentration of the dust. Higher concentrations and longer exposure times resulted in increased adult mortality. Based on the findings, DE was the most effective dust in controlling *S. oryzae* adults, followed by zeolite, radish seed dust, galangal dust, and the least effective was black pepper seed dust.

Introduction

The rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculiontdae), is a well-known primary insect that causes significant damage to cereal grains and other seeds globally. A major challenge faced by the global grains industry is finding safe substances to protect stored commodities from insect pests. Many insect species that infest stored products have developed resistance to commonly used toxic protectants and fumigants. Inert dust, such as diatomaceous earth (DEs) and zeolites, are showing potential as alternative methods for protecting stored products rather than traditional chemical approaches. Zeolites are hydrated aluminosilicates containing alkali and alkaline earth metals. Following approval as safe for human use by the FDA of the USA and deemed non-toxic by the WHO International Agency for Research on Cancer, their use in agriculture has increased. The method of using inert dust has been gaining attention as a safer alternative for protecting stored commodities from insect pests. The history of controlling pests in stored grain has been thoroughly researched by various authors, including (Ebeling, 1971; Loschiavo, 1988; Shawir *et al*., 1988 and Aldryhim, 1990 and 1993).

In addition to its low toxicity to mammals, inert dust, such as radish seed dust (*R. sativus)*, galangal rhizome dust (*Alpina* officinarum), black pepper seed dust (*Piper nigrum* L.), diatomaceous earth (DE), zeolite, and some plant dust, are safe and do not affect the quality of baked goods made from grains (Ebeling, 1971 and Aldryhim, 1990).

The main goal of this study was to evaluate the effectiveness of these safe, cost-effective, and readily available inert dust against rice weevil adults *S. oryzae* in controlled laboratory settings.

Materials and methods

1. Tested insect:

In this research project, scientists chose *S. orzyae* as the focus, as it is known as a highly destructive pest to cereal crops. To initiate the study, a significant number of adult insects were gathered from grain storage facilities in the Zagazig area. These insects were then cultivated in large numbers over several generations, with a controlled temperature of 28± 2˚C and humidity levels of 60± 5%.

2. Rearing technique of stock cultures:

2.1. Rearing medium:

The insects were raised using a type of wheat grain called Sakha 93. Prior to use, the grains were carefully inspected for any toxins. They were then packed in plastic bags and stored in a deep freezer at -13˚C for at least 48 hrs. to prevent infestation. The moisture content of the grains was adjusted to around 14% before starting any rearing or experiments. Dry yeast was also added at a rate of 120 g/kg. To start with the cultures, 500 adult insects (1-2 weeks old) per kilogram were introduced into the rearing material. Glass jars holding 2 kg were filled partially with the prepared medium and covered with muslin cloth secured with rubber bands. These jars were placed in a room with a temperature of 28 ± 2˚C and a relative humidity of 60 ± 5%. After allowing the adults to lay eggs for 3 days, they were removed by sifting through a No. 10 or 12 sieve. The medium with the eggs was then returned to the jars and kept under the same environmental conditions.

3. Grain protectants tested:

3.1. Diatomaceous earth (DE) dust:

The dust formulation is made up of 97% silicon dioxide and is produced by Fabrique Par, a company under Hedley Pacific Ventures LTD., situated in Vancouver, British Columbia, Canada.

3.2. Zeolites dust:

Zeolite, which belongs to the microporous crystalline aluminosilicates group, is commonly known as molecular sieves (Auerbach *et al*., 2004). The structure of zeolite is comprised of interconnected $[SiO4]^{4}$- and $[AlO4]^{5}$- tetrahedral units bonded by oxygen atoms, forming three-dimensional networks. They are mostly found in volcanic and sedimentary rocks. Zeolite is a mineral that naturally occurs from volcanic origin in the South Aegean volcanic arc region of Turkey- Clariant.

4. Bioassay tests:

Test arenas comprised of glass jars with 50 ml capacity were used to assess the insecticidal properties of the dust and insecticides. In each jar, 30 grams of uninfested wheat kernels were mixed by handshaking with a specific amount of the tested dust to achieve the desired insecticide concentration. A group of 30 unsexed adults, aged 1 to 2 weeks, was introduced to the jars, with each species tested separately. The jars were covered with muslin, secured with rubber bands, and placed in the laboratory under controlled conditions. Each treatment was replicated three times. To separate the insects from the grains, the contents of the jars were sifted through a sieve with a 2 mm opening. The number of live and dead adults was recorded to calculate mortality percentages at different time intervals post-treatment (1, 2, 3, 5, 7, 10, and 14 days). Additionally, the F_1 progeny was monitored after 30, 45, 60, and 75 days following the treatment.

5. Plant dusts radish seed dust:

The combination of wheat grains and dust from *Raphanus sativus* was analyzed at different concentrations of 6, 4, 2, 1, and 0.5% (w/w). These grains contain erucic, oleic, and linolenic acids. The dust made of *A. officinarum* mixed with wheat grains was also tested at concentrations of 6, 4, 2, 1, and 0.5% (w/w). *A. officinarum* rhizomes contain minerals like K, Ca, Fe, Mg, and Mn, unsaturated fatty acids such as elaidic and linoleic acids, and phenolic compounds like catechin, quercetin, catechol, isorhamnetin, and gallic acid. Seeds bought from the local market were ground finely using an electric mill and then mixed with the insect feeding media to achieve the desired concentration.

5.1. Rhizome dust:

The dust, which consisted of *A. officinarum* mixed with wheat grains, was tested at concentrations of 6, 4, 2, 1, and 0.5% (w/w). The rhizomes of *A. officinarum* contain various minerals (K, Ca, Fe, Mg, and Mn), unsaturated fatty acids (Elaidic and linoleic acids), and phenolic compounds such as catechin, quercetin, catechol, isorhamnetin, and gallic acid. Seeds purchased from the local market were ground into a fine powder using an electric mill. This powder was then mixed with the insect feeding media to achieve the desired concentration.

5.2. Black pepper dust:

The dust of *P. nigrum*, also known as black pepper, was combined with wheat grains and examined at varying concentrations of 6, 4, 2, 1, and 0.5% (w/w). *P. nigrum* consists of volatile oil, piperine, and resin1.

6. Statistical analysis:

Finney (1971) developed a probit computer program that was used to analyze the dose-response relationship for both dust and insecticides.

Results and discussion

1. Effect of some plant dusts against *Sitophilus oryzae*:

Table (1) shows the results of a study on the impact of radish seed dust *R. sativus* on the mortality of adult *S. oryzae* and the decrease in F_1 progeny at 30±1ºC and 65±5% R.H. The findings indicate that mortality is affected by both the concentration of the dust and the duration of exposure. High concentrations and longer exposure periods resulted in higher mortality rates. For example, when the concentration was 6%, mortality was 65.5% after one day of exposure and increased to 99.9% after 14 days. Similarly, at a concentration of 4%, mortality was 63.6% after one day of exposure and increased to 98% after 14 days. At a concentration of 2%, mortality was 16.4% after one day and rose to 90% after 14 days. At a concentration of 1%, mortality was 6.2% after one day and increased to 60% after 14 days. For a concentration of 0.5%, mortality was 0% after one day and increased to 40% after 14 days. The decrease in F_1 progeny ranged from 33.11% to 98.2% for the different concentrations of black pepper powder that were tested.

Information is given regarding the lethal concentrations of radish seed dust *R. sativus* in adult *S. oryzae* (Table 2). The study shows that lethal concentrations are affected by the duration of exposure, with longer exposure periods resulting in lower values. After 3 days of post-treatment, the LC_{50} value was 2.2% (w/w), which decreased significantly to 0.7% (w/w) to 14 days post-treatment. Similarly, the LC_{90} value was 7.1% (w/w) at 3 days and decreased to 2% (w/w) at 14 days post-treatment. The LC_{95} value was 10% (w/w) in 3 days and decreased to 2.5% (w/w) at 14 days post-treatment.

Table (1): Effect of radish seed dust *Raphanus sativus* on adult mortality and reduction in F_1 progeny of *Sitophilus oryzae*.

Conc. (w/w)	% Adult mortality after indicated period (Days)							Average no. of emerged adults after 75 days	% Reduction F_1 progeny
	1	2	3	5	7	10	14		
6	65.5	79.9	88.8	96.6	97.3	98.7	99.9	20.3	98.2
4	63.6	65.5	84.4	92.2	96.6	97.7	98	26.3	87.1
2	16.4	18.63	25.5	43.3	49.9	88.4	90	41.6	63.7
1	6.2	7.63	15.3	23.3	30.8	50.9	60	49	57.2
0.5	0	6.4	13.2	17.7	25.2	36.4	40	76.6	33.11
Control	0	0	0	0	0	2.2	3.3	114.6	0

Table (2): Lethal concentration of radish seed dust (*Raphanus sativus*) against the adults of *Sitophilus oryzae* at various exposure periods.

Exposure periods (Days)	Lethal concentration (%w/w) and their 95% confidence limits			Slope ± SD	R.
	LC_{50}	LC_{90}	LC_{95}		
3	2.2 (2-3)	7.1 (5-10.3)	10 (6.4-15.4)	2.5 ± 0.72	0.9319
5	1.5 (1.2-2)	4.4 (3.2-6)	6 (4.1-9)	3 ± 1.56	0.9549
7	1.3 (1.1-2)	4 (3-5)	5 (3.4-7)	3 ± 0.70	0.9467
14	0.7 (0.6-0.9)	2 (1.5-2.4)	2.5 (2.3.4)	3.03 ± 0.23	0.9849

R = Correlation Coefficient of regression line.
SD = Standard deviation of the mortality regression line

The impact of galangal rhizome dust (*A. officinarum*) on the mortality of adult *S. oryzae* and the reduction in F_1 progeny at 30 ± 1ºC and 65 ± 5% R.H. is demonstrated in the results (Table 3). It is evident from the findings that mortality is influenced by both the concentration of the dust and the duration of exposure. Higher concentrations and longer exposure periods resulted in higher mortality rates. For example, with a 6% concentration, the mortality rate was 50.5% after one day of treatment, increasing to 99.11% after 14 days of exposure. Similarly, at a 4% concentration, the mortality rate was 40.86% after one day and rose to 91.4% after 14 days. At 2%, mortality was 14.8% after one day and increased to 70.2% after 14 days, while at 1%, the mortality rate was 5.1% after one day and rose to 55.75% after 14 days. Furthermore, at 0.5%, the mortality rate was 0% after one day and increased to 39.6% after 14 days. The reduction in F_1 progeny varied from 24.4% to 97% with different concentrations of Galangal rhizome dust in the study.

The study presents the lethal concentrations of galangal rhizome dust against adult *S. oryzae* (Table 4). The results show that lethal concentrations change depending on the duration of exposure, with longer exposure leading to lower values. For example, after 7 days of treatment, the LC_{50} value was 2% (w/w), but this significantly decreased to 0.59% (w/w) after 14 days. Similarly, the LC_{90} value was 15.5% (w/w) in 7 days and decreased to 2.5% (w/w) in 14 days. Finally, the LC_{95} value was 28.1% (w/w) after 7 days and decreased to 4% (w/w) after 14 days.

Table (3): Effect of galangal rhizome dust (*Alpina officinarum*) on adult mortality and reduction in F_1 progeny of *Sitophilus oryzae*.

Conc. (w/w)	% Adult mortality after indicated period (Days)							Average no. of emerged adults after 75 days	% Reduction F_1 progeny
	1	2	3	5	7	10	14		
6	50.5	56.4	60.3	75.5	84.4	97.88	99.11	19.80	97
4	40.86	50.95	59.9	73.86	82.06	92.4	91.4	28.33	89.9
2	14.8	15.90	24.06	49.8	53.3	59.77	70.2	40.8	61.61
1	5.1	6.01	14.8	29.16	27.2	35.6	55.75	50.66	46.72
0.5	0	5.6	11.86	15.2	17.5	24.5	39.6	75.55	24.4
Control	0	0	0	0	2.2	3.3	3.3	112.33	0

Table (4); Lethal concentrations of galangal rhizome dust against the adults of *Sitophilus oryzae* at various exposure periods.

Exposure periods(days)	Lethal concentration (%w/w) and their 95% confidence limits			Slope ± SD	R.
	LC_{50}	LC_{90}	LC_{95}		
7	2 (1.4-2.2)	7.5 (5-12)	11.3 (7-9.12)	2.05 ± 0.76	0.9884
14	1.5 (1.2-2)	5.6 (4-8.10)	8.2 (5.2-13)	2.2 ± 0.041	0.9947

R = Correlation Coefficient of regression line.

SD = Standard deviation of the mortality regression line.

The effects of dust produced from black pepper seeds (*P. nigrum*) on the survival of adult *S. oryzae* and the decrease in F_1 offspring at a temperature of 30 ± 1ºC and relative humidity of 65 ± 5% can be found in Table (5). The findings clearly show that the mortality rates were influenced by both the concentration of dust and the length of exposure. With the highest concentration tested, 6% w/w, the mortality rates were 15.5%, 18.8%, 40.5%, 63.3%, 76.6%, 96.5%, and 97% after 1, 2, 3, 5, 7, 10, and 14 days of treatment, respectively. At a concentration of 4%, the mortality rates were 12.2%, 17.1%, 34.4%, 55.5%, 69.9%, 91.06%, and 92.13% after 1, 2, 3, 5, 7, 10, and 14 days of treatment, respectively. Similarly, at a concentration of 2%, the mortality rates were 13.3%, 14.7%, 22.2%, 41.06%, 44.4%, 58.7%, and 69.7% after 1, 2, 3, 5, 7, 10, and 14 days of treatment. Meanwhile, at a concentration of 1%, the mortality rates were 0%, 4.4%, 8.86%, 21.5%, 23.8%, 31.00%, and 50.11% after 1, 2, 3, 5, 7, 10, and 14 days of treatment. When the concentration was 0.5%, the mortality rates were 0%, 3.3%, 7.7%, 11.5%, 14.9%, 21.33%, and 35.3% after 1, 2, 3, 5, 7, 10, and 14 days of treatment. The decline in F_1 offspring ranged from 10.60% to 63.63% for various concentrations of black pepper seed dust (*P.nigrum*). The lethal concentrations of black pepper seed dust (*P. nigrum*) for adult *S. oryzae* can be found in Table (6). The results reveal that lethal concentrations are influenced by the length of exposure. There was a noticeable decrease in the values with longer exposure periods. The LC_{50} value decreased from 2% (w/w) in 7 days after treatment to 1.5% (w/w) in 14 days. Similarly, the LC_{90} value was 7.5% (w/w) in 7 days and decreased to 5.6% (w/w) to 14 days post-treatment. Additionally, the LC_{95} value was 11.3% (w/w) at 7 days after treatment and decreased to 8.2% (w/w) after 14 days of treatment.

Table (5): Effect of Black pepper seeds dust (*Piper nigrum*) on adult mortality and reduction in F_1 progeny of *Sitophilus oryzae.*

Conc.(w/w)	% Adult mortality after indicated period (Days)							Average no. of emerged adults after 75 days	% ReductionF_1 progeny
	1	2	3	5	7	10	14		
6	15.5	18.8	40.5	63.3	76.6	96.5	97	32	63.63
4	12.2	17.1	34.4	55.5	69.9	91.06	92.13	37.33	57.57
2	13.3	14.7	22.2	41.0	44.4	58.7	69.7	52.33	40.53
1	0	4.4	8.86	21.5	23.8	31.00	50.11	72.33	17.80
0.5	0	3.3	7.7	11.5	14.9	21.33	35.3	97.33	10.60
Control	0	0	0	0	2.2	3.3	4.4	114.1	0

Table (6): Black pepper seeds dust (*Piper nigrum)* against the adults of *Sitophilus oryzae* at various exposure periods.

Exposure periods (Days)	Lethal concentration (%w/w) and their 95% confidence limits			Slope ± SD	R.
	LC_{50}	LC_{90}	LC_{95}		
7	2 (1.4-3)	15.5 (7-35)	28.1 (10.3-77)	1.4± 0.45	0.9851
14	0.59 (0.42-0.8)	2.5 (2-4)	4 (2.4-6)	2.04± 0.32	0.9533

R = Correlation Coefficient of regression line.
SD = Standard deviation of the mortality regression line.

The results from the study on the effects of diatomaceous earth dust on adult mortality and decrease in offspring of *S. oryzae* under controlled temperature and humidity conditions are outlined in Table (7). The findings indicated that mortality rates rose with higher dust concentrations and longer exposure durations. For instance, at a 6% concentration, mortality was 56.63% after one day of exposure, increasing to 100% after 14 days. Similarly, at a 4% concentration, mortality was 42.2% after one day and reached 100% after 14 days. At a 2% concentration, mortality was 32.2% after one day and rose to 100% after 14 days. At a 0.5% concentration, mortality was 8.8% after one day and also reached 100% after 14 days. These outcomes indicated total adult mortality for all tested diatomaceous earth concentrations after 14 days.

The lethal concentrations of diatomaceous earth against adult *S. oryzae* are detailed in Table (8). The decrease in offspring ranged from 92-100% for the different dust concentrations examined. The results emphasized that lethal concentration varied based on the exposure duration, with lower values observed for longer periods. During the 2 days post-treatment, the LC_{50} value was 1.3% (w/w), decreasing significantly to 0.435% (w/w) in 3 days. The LC_{90} value was 5.3% (w/w) in 2 days post-treatment and dropped to 3.3% (w/w) at 3 days post-treatment. The LC_{95} value was 7.9% (w/w) at 2 days post treatment and decreased to 5.9% (w/w) after 3 days post treatment.

Table (7): Effect of diatomaceous earth dust on adult mortality and reduction in F_1 progeny of *Sitophilus oryzae*.

Conc.(w/w)	% Adult mortality after indicated period (Days)							Average no. of emerged adults after 75 days	% Reduction F_1 progeny
	1	2	3	5	7	10	14		
6	56.63	92.2	93.3	95.4	99	100	100	0	100
4	42.2	76.6	91.06	94.5	97	100	100	2	99
2	32.2	77.7	89.9	92.2	94	98.86	100	7.3	99
1	23.3	41.06	73.3	77.7	88	97.9	100	9	98
0.5	8.8	15.5	45.5	49.9	85	95	100	49.9	92
control	0	0	0	0	2.2	2.2	3.3	622.3	0

Table (8): Lethal concentrations of Diatomaceous earth dust against the adults of *Sitophilus oryzae* at various exposure periods.

Exposure periods (Days)	Lethal concentration (%w/w) and their 95% confidence limits			Slope ± SD	R.
	LC_{50}	LC_{90}	LC_{95}		
2	1.3 (1.03-2)	5.3 (4-8)	7.9 (5-13)	2.1± 0.24	0.9655
3	0.435 (0.24- 0.77)	3.3 (2.1-5.4)	5.9 (3.1-11.4)	1.5±0.77	0.9499
7	0.076 (0.0081- 0.61)	1.13 (0.63-2.04)	2.5 (1.2-5.3)	1.06±0.16	0.9176

R = Correlation Coefficient of regression line.
SD = Standard deviation of the mortality regression line.

Outlines the results of a study on the effects of zeolite powder on adult *S. oryzae* mortality and F_1 progeny reduction at a temperature of 30 ± 1ºC and relative humidity of 65±5% (Table 9). The findings indicate that higher concentrations of zeolite dust and longer exposure periods result in increased mortality rates. For example, at a 6% concentration, the mortality rate was 70.66% after one day and reached 100% after 14 days. Similarly, at concentrations of 4%, 2%, and 0.5%, the mortality rates were 50.2%, 40.2%, and 10.8%, respectively after one day, reaching 100% after 14 days. The data also reveal complete adult mortality at all zeolite dust concentrations tested after 14 days. Table (10) presents the lethal concentrations of zeolite dust against adult *S. oryzae*, showing a reduction in F_1 progeny from 94% to 100% with varying concentrations of zeolite powder. Additionally, the results suggest that lethal concentrations are influenced by exposure duration, with lower values observed for longer periods. For instance, the LC_{50} value decreased from 1.50% (w/w) after 2 days of post-treatment to 0.522% (w/w) after 3 days. Similarly, the LC_{90} value decreased from 6.7% (w/w) after 2 days to 4.5% (w/w) after 3 days, and the LC_{95} value declined from 8.9% (w/w) after 2 days to 7.8% (w/w) after 3 days.

Table (9): Effect of zeolite dust on adult mortality and reduction in F_1 progeny of *Sitophilus oryzae*.

Conc. (w/w)	% Adult mortality after indicated period (Days)							Average no. of emerged adults after 75 days	% Reduction F_1 progeny
	1	2	3	5	7	10	14		
6	70.66	94.2	95.3	98.4	99.12	100	100	0	100
4	50.2	80.6	93.06	95.12	96.55	100	100	3	98
2	40.2	74.13	86.91	91.55	95.1	98.12	100	8.12	98
1	30.13	50.66	80.3	89.14	90.10	96.7	100	11	97
0.5	10.8	17.8	50.15	60.19	89.13	96.11	100	52.1	94
Control	0	0	0	0	0	2.2	3.3	701	0

Table (10): Lethal concentrations of zeolite dust against the adults of *Sitophilus oryzae* at various exposure periods.

Exposure periods (Days)	Lethal concentration (%w/w) and their 95% confidence limits			Slope ± SD	R.
	LC_{50}	LC_{90}	LC_{95}		
2	1.50 (1.03-2)	6.7 (4-8)	8.9 (5-13)	3.1± 0.25	0.9754
3	0.522 (0.24-0.77)	4.5 (2.1-5.4)	7.8 (3.1-11.4)	2.5±0.97	0.9495
7	0.087 (0.0081-0.61)	1.17 (0.63-2.04)	4.6 (1.2-5.3)	1.09±0.76	0.9238

R = Correlation Coefficient of regression line.
SD = Standard deviation of the mortality regression line.

Based on the information presented in Table (11), it was found that diatomaceous earth (DE) and zeolite dust displayed the highest effectiveness in combating *S. oryzae* adults, while radish seed dust and Galangal rhizome dust showed moderate effects, and black pepper seed dust was the least effective.

Table (11): Toxicity index of various tested dusts against the adults of *Sitophilus oryzae*.

Treatment	Lethal concentration at 7 days (w/w%)		Toxicity index		Slope ±SD	R.
	LC_{50}	LC_{90}	LC_{50}	LC_{90}		
Diatomaceous earth dust	0.076	1.13	100	100	1.06 ± 0.16	0.9176
Zeolite dust	0.087	1.17	100	100	1.09±0.76	0.9238
Radish seed dust	1.3	4	58	28.25	3 ± 0.70	0.9407
Galangal rhizome dust	1.21	8.2	6.2	13.78	1.5 ± 0.11	0.9721
Black pepper seeds dust	2	7.5	3.8	15.06	2.06 ± 0.76	0.9884

R = Correlation Coefficient of regression line.
SD = Standard deviation of the mortality regression line.

In a study conducted by El-Lakwah *et al*. (1992), it was discovered that pulverized black pepper seed had a toxic impact on *S. oryzae* adults, decreased F_1 progeny, and deterred adults of *S. oryzae*, *Rhizopertha dominica* (F.) (Coleoptera: Bostrichidae), and *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). Moreover, the study indicated that black pepper powder could completely safeguard stored wheat after 7 days of treatment, indicating its potential as a safeguard against stored product insects. Nikpay (2006) also emphasized the potential of diatomaceous earth (DE) as an alternative to synthetic insecticides, especially in structural treatments for storage facilities. A dosage of 5 g/m2 of DE was found to be effective against *R. dominica* and *T. castaneum*, consistent with previous studies by El-Lakwah *et al*. (1992); El-Lakwah (1997); El-Kashlan (1999) and El-Lakwah *et al*. (2001). Additionally, Zeolite, an inert dust, presents itself as a promising alternative to traditional chemical insecticides due to its low toxicity to mammals and minimal impact on product quality when used at commercially applicable concentrations (Korunić, 1998 and Andric *et al*., 2012). Zeolites are crystalline, hydrated aluminosilicates of alkali and alkaline earth (Christidis *et al*., 2003). Although there is limited research on the efficacy of natural zeolites in controlling storage pests, the literature suggests that their application may help reduce infestations of stored products by insects (Ziaee *et al*., 2021).

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