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Evaluation the Efficacy of Abamectin and Spinosad Against Stored Grain Pests: Mortality, Persistence, and Residual Activity

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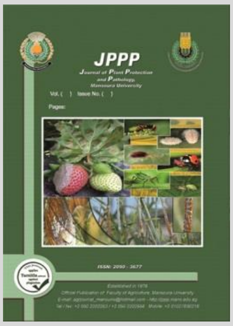

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ABSTRACT

This study evaluates the efficacy, persistence, and residual activity of abamectin and spinosad against three major stored grain pests: *Rhyzopertha dominica*, *Sitophilus oryzae*, and *Tribolium castaneum* under controlled laboratory conditions (30±1ºC, 65±5% RH). Wheat grains were treated with varying concentrations of abamectin (0.01–0.06% w/w) and spinosad (0.012–0.192% w/w), and adult mortality was assessed after 1, 3, 5, 7, and 14 days. Progeny production was evaluated 60 days post-treatment. Mortality increased with higher doses and prolonged exposure, with all species exhibiting significant mortality after seven days. *R. dominica* was highly susceptible to both insecticides, with mortality ranging from 58.3% to 100% abamectin and 38.3% to 100% for spinosad. Similarly, *S. oryzae* showed high susceptibility, with mortality rates between 53.3% and 100%. *T. castaneum* was less affected, with mortality ranging from 15.0% to 100% abamectin and 3.3% to 100% for spinosad. Abamectin demonstrated greater residual efficacy than spinosad over six months. These findings highlight abamectin's potential as a superior grain protectant; it offers long-lasting control against key storage pests and contributes to more effective pest management strategies in stored wheat grain.

Keywords: Stored grains insects Wheat protection, Pest management

INTRODUCTION

Increasing concerns over environmental safety, mammalian toxicity, consumer demand for residue-free products, and the rising resistance of stored-product pests to conventional pesticides have necessitated the reevaluation and withdrawal of many commonly used grain protectants in integrated pest management (IPM). Stored grains, pulses, and cereal products are highly susceptible to insect damage, leading to significant post-harvest losses, estimated to range from 10% to 40% globally (Manandhar *et al.,* 2018). The rapid reproductive rates of storage beetles have exacerbated these losses in recent years (Abbas *et al.,* 2014).

Chemical control remains a critical component of stored-grain protection strategies, despite efforts to explore botanical, inert, microbiological, and biological alternatives. Conventional pesticides, particularly organophosphates and pyrethroids, have historically provided effective protection against storage pests (Golic *et al*., 2018; Ghimire *et al.,* 2017). For instance, pirimiphos-methyl (25 mg/kg) was effective for eight months against *Callosobruchus maculatus* on cowpea seeds (Abo-Elghar *et al.,* 2004), while *Sitophilus granarius* was controlled for seven months with 2.0 mg/kg of the same pesticide (Rumbos *et al.,* 2018). Similarly, pyrethroid insecticides such as deltamethrin, beta-cyfluthrin, and alpha-cypermethrin have demonstrated long-term efficacy against *Sitophilus oryzae* and *Tribolium confusum* (Athanassiou *et al.,* 2004a, 2004b). However, concerns over their persistence, insect resistance, and potential harm to beneficial organisms necessitate the search for safer alternatives (Phillips and Throne, 2010).

Microbial insecticides, such as spinosad and spinetoram, have shown promising long-term protection against stored-product pests. Spinosad, derived from the fermentation of *Saccharopolyspora spinosa*, is considered a low-risk insecticide with minimal mammalian toxicity and environmental impact (Thompson *et al.*, 2000; Bret *et al.*, 1997). Spinosad affects insect nervous systems by targeting nicotinic acetylcholine and gamma-aminobutyric acid (GABA) receptor sites, proving effective against multiple stored-product insect species at 1 mg (a.i.)/kg of grain (Huang *et al.,* 2004; Flinn *et al.,* 2004).

Abamectin, a member of the avermectin family produced by *Streptomyces avermitilis*, also presents a viable alternative. It acts as a GABA agonist, exerting insecticidal and acaricidal properties (Kim *et al.*, 2017). While abamectin has been extensively documented for its effectiveness against various agricultural insect and mite pests (Ahmad *et al.*, 2003; Seal *et al.*, 2006), its potential as a stored-grain protectant remains underexplored. However, studies suggest its efficacy against *Tribolium castaneum* larvae (Athanassiou and Korunic, 2007), particularly in combination with diatomaceous earth.

Given the increasing restrictions on conventional pesticides and the need for effective alternatives, this study evaluates the efficacy, persistence, and residual activity of abamectin and spinosad against three common stored-grain insect pests: *Rhyzopertha dominica* (F.), *Sitophilus oryzae* (L.), and *Tribolium castaneum.* The study assesses adult mortality rates across varying insecticide concentrations and exposure durations, with progeny production analyzed after 60 days. The findings contribute to the development of safer and more sustainable pest management strategies for stored wheat grain.

MATERIALS AND METHODS

Insect culture

The test insects included the lesser grain borer, *Rhyzopertha dominica* (F.), the rice weevil, *Sitophilus oryzae* (L.), and the red flour beetle (*Tribolium castaneum* (Herbst)). All species were maintained under controlled laboratory conditions at 27± 1°C and 65 ± 5% relative humidity. *T.*

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castaneum was reared on wheat flour, while *R. dominica* and *S. oryzae* were reared on whole wheat grains. Adult insects used in the experiments were 7-14 days old.

Insecticides used:

The insecticides were used as follows:

1- Trade name: Agrimec Gold 8.4% SC.

Common name: Abamactin.

Molecular formula: $C_{48}H_{72}O_{14}$ (avermectin B_{1a}) + $C_{47}H_{70}O_{14}$ (avermectin B_{1b})

Chemical name: 5-*O*-dimethylavermectin B_{1a}(i) mixture with5-*O*-demethyl-25-de(1-methylpropyl)-25-(1-methylethyl) avermactin B_{1b}(ii). The products were obtained from Syngenta company, South Africa.

Mode of action: Targets the insect nervous system

Rate of application: 15cm^3/100 L of water.

2- Trade name: Tracer 24% SC.

Common name: Spinosad.

Molecular formula: $C_{83}H_{132}N_2O_{20}$

Chemical name: A a natural insecticide synthesized by the soil bacterium, Saccharopolyspora spinosa, mixture of spinosyn A and spinosyn D. (Thompson *et al.,* 2000). The products were obtained from : Nile valley for Agricultural Development, Giza, Egypt..

Mode of action: Works as an agonist for nicotinic acetylcholine receptor in the central nervous system, causing hyperexcitation, then, involuntary muscle contractions and tremors

Rate of application: 65 ml/100L of water.

Grain treatments

Abamectin granules were ground into powder before being mixed with wheat grains to enhance pesticide efficacy. The abamectin powder was applied to 50 g of wheat grains for *R. dominica, S. oryzae* while *T. castaneum* adults were exposed to crushed wheat at concentrations of 0.01, 0.02, 0.04, and 0.06% (w/w). Spinosad powder was mixed with 30 g of wheat grains and tested at concentrations of 0.012, 0.024, 0.048, 0.096, and 0.192% (w/w) for initial efficacy. For residual efficacy evaluation, the LC_{90} value and its multipliers were used.

Bioassay of dusts

Glass jars (50 ml) were used as test arenas. Each jar contained 10 g of treated wheat (from a total of 30 g divided into three replicates). The grains were thoroughly mixed by handshaking with the weighed quantity of pesticide dust to achieve uniform distribution. Twenty adult beetles (7-14 days old) were introduced into each jar. Each treatment had three replicates, and three untreated wheat replicates were used as controls. Jars were covered with muslin cloth and secured with rubber bands before being stored under laboratory conditions.

Efficacy assessment

The initial efficacy was evaluated at 1, 3, 5, 7, and 14 days post-treatment, while residual efficacy was assessed over a six-month storage period using LC_{90} values and their corresponding multipliers. The experiment was conducted again at 1, 2, 4, and 6 months after storage. Mortality was recorded after 1 day for abamectin and after 7 days for spinosad at 1, 2, and 4 months. At 6 months, mortality data for both insecticides were collected after 14 days.

Statistical analysis

Mortality percentages were corrected using Abbott's formula (Abbott, 1925). The corrected mortality data were analyzed statistically following Finney's (1971) method. The toxicity regression lines were obtained by plotting the computed mortality percentages against the corresponding concentrations using the LDP line software. Lethal concentration (LC_{50} and LC_{90}) values were determined. Treatment means were tested for significance using the LSD test ($p<0.05$) to separate data for each dependent variable.

This methodology provides a structured approach for evaluating the efficacy, persistence, and residual activity of abamectin and spinosad in controlling stored grain pests.

The reduction of F1 progeny at 45 days after treatment was calculated according to according to Tapondjou *et al.* (2002). the following equation::

Reduction (%) = [(No of emerged adults in control – No. of emerged adults in treatment) / No. of emerged adults in control] × 100

RESULTS AND DISCUSSION

Results

A. The effects of Abamectin

The effects of abamectin powder concentrations on the mortality and reduction rate in adult F1-progeny of *R. dominica, S. oryzae*, *and T. castaneum* are summarized in Tables 1, 2, and 3**.**

Mortality of *Rhyzopertha dominica* adults

Data in Table 1 proved that the mortality of *R. dominica* adults exposed to wheat grains treated with abamectin at different application rates showed significant variation over time. After 1 day, mortality ranged from 58.33% at 0.01 mg/kg to 86.67% at 0.06 mg/kg. By day 3, mortality increased across all treatments, with 0.01 mg/kg resulting in 91.67%, and the higher doses (0.04 and 0.06 mg/kg) reaching 100%. This trend continued through the subsequent days, with mortality remaining at 100% for all doses by days 5, 7, and 14,. The *F*-value for mortality across time was highly significant ($P < 0.0001$). The reduction in F1 progeny was positively correlated with the application rate, increasing from 73.3% at 0.01 mg/kg to 97.9% at 0.06 mg/kg.

Table 1. Mean mortality (% ± SE) of *Rhyzopertha dominica* adults exposed to wheat grains treated with abamectin at different application rates for 1, 3, 5, 7, and 14 days.

Treatment (mg/kg)	Mortality (% ± SE) after 1day	3days	5days	7days	14days	Reduction % in F1 progeny
0.01	58.33±3.33d	91.67±1.6b	100.0±0.0a	100.0±0.0a	100.0±0.0a	73.3
0.02	71.67±1.6c	98.33±1.7a	100.0±0.0a	100.0±0.0a	100.0±0.0a	82.6
0.04	83.33±1.7c	100.0±0.0a	100.0±0.0a	100.0±0.0a	100.0±0.0a	91.6
0.06	86.67±1.67b	100.0±0.0a	100.0±0.0a	100.0±0.0a	100.0±0.0a	97.9
F-value	63.93	11.75	0	0	0	-
P- value	<.0001	0.0009	0	0	0	-
LSD 0.05	6.21	3.32	0	0	0	-

Means followed by the same letters in the same column are not significantly different at P ≤ 0.05.

Mortality of *Sitophilus oryzae* adults

From Table 2, the mortality of *S. oryzae* adults also increased with abamectin exposure. On day 1, mortality ranged from 53.33% at 0.01 mg/kg to 80.00% at 0.06 mg/kg. By day 3, all treatments had shown a substantial increase in mortality, with 0.01 mg/kg reaching 86.67%, and the higher doses showing 100%. This was maintained across the 14-day exposure period, with the lowest treatment (0.01 mg/kg) reaching 100% by day 7. Significant differences in mortality were observed across all time points, with the *F*-values for days 1, 3, and 5 being highly significant (P < 0.0001). The reduction in F1 progeny also increased with the application rate, from 70.4% at 0.01 mg/kg to 97.0% at 0.06 mg/kg.

Mortality of *Tribolium castaneum* adults

For *T. castaneum* adults exposed to crushed wheat treated with abamectin, mortality at day 1 ranged from 15.00% at 0.01 mg/kg to 41.67% at 0.06 mg/kg. Mortality continued to increase across all doses, with 0.01 mg/kg reaching 81.7% by day 14, while the higher doses reached 100% by the same time. The *F*-value analysis indicated significant differences for all exposure times (P < 0.05), especially for days 7 and 14, where mortality peaked at 100% for the highest application rates. The reduction in F1 progeny ranged from 52.5% at 0.01 mg/kg to 85.7% at 0.06 mg/kg Table 3.

Table 2. Mean mortality (% ± SE) of *Sitophilus oryzae* adults exposed to wheat grains treated with abamectin at different application rates for 1, 3, 5, 7, and 14 days.

Treatment (mg/kg)	Mortality (% ± SE) after 1day	3days	5days	7days	14days	Reduction % in F1 progeny
0.01	53.33±3.3d	86.67±1.6b	91.67±1.67b	100.0±0.0a	100.0±0.0a	70.4
0.02	70.00±2.89c	98.33±1.7a	100.0±0.0a	100.0±0.0a	100.0±0.0a	79.5
0.04	78.33±1.67b	100.0±0.0a	100.0±0.0a	100.0±0.0a	100.0±0.0a	87.2
0.06	80.00±2.8b	100.0±0.0a	100.0±0.0a	100.0±0.0a	100.0±0.0a	97.0
F-value	46.91	30.50	25.0	0	0	-
P- value	<.0001	<.0001	<.0001	0	0	-
LSD 0.05	7.78	3.32	2.34	0	0	-

Means followed by the same letters in the same column are not significantly different at P ≤ 0.05.

Table 3. Mean mortality (% ± SE) of *Tribolium castaneum* adults exposed to crushed wheat treated with abamectin at different application rates for 1, 3, 5, 7, and 14 days.

Treatment (mg/kg)	Mortality (% ± SE) after 1day	3days	5days	7days	14days	Reduction % in F1 progeny
0.01	15.00±5.0c	23.33±4.40b	43.33±4.4c	51.67±1.6c	81.7±1.6c	52.5
0.02	18.33±4.41bc	30.00±2.89b	48.33±1.67bc	53.33±3.3c	85.0±2.8c	62.0
0.04	36.67±7.27ab	45.00±5.77a	58.33±6.01b	70.00±2.8b	93.3±1.7b	77.1
0.06	41.67±6.01a	48.33±3.32a	73.33±1.67a	93.33±1.7a	100.0±0.0ab	85.7
F-value	5.24	7.90	11.45	85.75	20.30	-
P- value	0.0272	0.0089	0.0029	<.0001	<.0001	-
LSD 0.05	18.82	13.85	12.74	7.42	5.25	-

Means followed by the same letters in the same column are not significantly different at P ≤ 0.05.

Lethal concentrations of abamectin powder on *R. dominica, S. oryza*e, and *T. castaneum* are shown in Table 4. Lethal concentrations of abamectin powder for *R. dominica* and *S. oryza*e were after one day post-treatment, but for *T. castaneum*, it was after seven days post–treatment. The lethal concentration values (LC_{50} and LC_{90}) for *R. dominica*, *S. oryzae*, and *T. castaneum* treated with abamectin powder revealed that *R. dominica* exhibited the fastest mortality, with an LC_{50} of 0.008 mg/kg and an LC_{90} of 0.086 mg/kg. The confidence intervals for LC_{50} ranged from 0.004 to 0.018 mg/kg, and for LC_{90}, from 0.040 to 0.187 mg/kg. The species showed a strong dose-response relationship (slope 1.25, R = 0.999). *S. oryzae* had an LC_{50} of 0.009 mg/kg and an LC_{90} of 0.118 mg/kg, with a slope of 1.16 and a correlation coefficient of 0.949, indicating a good response but slightly weaker than *R. dominica*. *T. castaneum* had the slowest mortality, with an LC_{50} of 0.013 mg/kg and an LC_{90} of 0.078 mg/kg, showing a slope of 1.71 and a lower correlation coefficient of 0.753.

The data show that abamectin powder is highly effective in controlling all three insect species, with relatively rapid mortality times, as evidenced by the low LC_{50} values. Among the species, *R. dominica* exhibited the fastest mortality response, with the shortest LC_{50} value, and a strong dose-response curve (R = 0.999). *S. oryzae* also showed a quick response, although with slightly longer LC_{90} values and a moderate slope. *T. castaneum* exhibited slower mortality, reflected in the higher LC_{50} value, as well as a less pronounced dose-response relationship. These results suggest that abamectin powder effectively controlled pest populations in a relatively short time, with *R. dominica* being the most susceptible, followed by *S. oryzae* and *T. castaneum*.

Table 4. Lethal concentration values and confidence limits for *Rhyzopertha dominica*, and *Sitophilus oryzae* after one day post-treatment and Tribolium castaneum after seven days post-treatment with abamectin powder at 30±1°C and 65±5% R.H.

Insects	LC_{50} mg/kg	LC_{90} mg/kg	Confidence limits at 95% LC_{50} Lower	LC_{50} Upper	LC_{90} Lower	LC_{90} Upper	Slope±Sd	R
R. dominica	0.008	0.086	0.004	0.018	0.040	0.187	1.25±0.17	0.999
S.oryza	0.009	0.118	0.004	0.021	0.053	0.263	1.16±0.86	0.949
T. castaneum	0.013	0.078	0.007	0.023	0.044	0.139	1.71±0.58	0.753

The simple correlation and multiple regression analysis of abamectin's effect on *R. dominica*, *S. oryzae*, and *T. castaneum* are shown in Table 5. For *R. dominica*, a significant correlation was found between concentration and mortality (r = 0.41, P = 0.0410), with a slope of 63.88 (P = 0.0406), while time had a weak correlation (r = 0.20, P = 0.3142). For *S. oryzae*, time had a stronger effect (r = 0.49, P = 0.0119), with concentration showing a weaker correlation (r = 0.31, P = 0.1256). For *T. castaneum*, both concentration (r = 0.42, P = 0.0327) and time (r

= 0.81, P < 0.0001) had significant impacts, with time having the greatest effect and an E.V.% of 84.93%.

The analysis suggests that the concentration of abamectin significantly affects mortality in all three species, with the most notable impact in *T. castaneum*, where both concentration and time were highly significant. *S. oryza* showed a more pronounced effect of time, while for *R. dominica*, both concentration and time had moderate effects, with concentration showing a stronger influence. These findings highlight the importance of both concentration and exposure time for effective pest control using abamectin.

Table 5. Simple correlation and multiple regression values for the effect of abamectin at various concentrations on *Rhyzopertha dominica*, *Sitophilus oryzae*, and *Tribolium castaneum*.

Species	Factor	Simple correlation		Multiple regression				
		r	P	b	P	F	P	E.V.%
R. dominica	Con.%	0.41	0.0410	63.88	0.0406	2.98	0.0714	21.33
	Time	0.20	0.3142	0.47	0.2793			
S. oryza	Con.%	0.31	0.1256	56.0	0.0821	5.77	0.0097	34.41
	Time	0.49	0.0119	1.29	0.0089			
T. castaneum	Con.%	0.42	0.0327	221.4	0.0001	62.01	0.0001	84.93
	Time	0.81	<.0001	6.17	0.0001			

r = correlation, P= probability, b= slope, EV% = explanation variance, conc.= concentration.

B. The effects of spinosad

Data in Table 6 showed that the mean mortality (%) of *R. dominica* adults exposed to wheat grains treated with spinosad at different concentrations showed a dose- and time-dependent increase in mortality. At 0.012 mg/kg, mortality after 1 day was 38.33%, increasing to 100% by 14 days. The highest concentration (0.192 mg/kg) resulted in 100% mortality across all time points. Significant differences in mortality were observed across different concentrations (P < 0.05). The reduction in F1 progeny ranged from 61.1% at 0.012 mg/kg to 100% at 0.192 mg/kg.

Also, from Table 7, data proved that *S. oryzae* mortality was similarly influenced by both concentration and exposure duration. At 0.012 mg/kg, mortality after 1 day was 53.33%, and by 14 days, 100%. As with *R. dominica*, the highest concentration (0.192 mg/kg) led to complete mortality across all time points. The reduction in F1 progeny increased from 71.3% at 0.012 mg/kg to 100% at 0.192 mg/kg. Statistical analysis revealed significant effects of both concentration and exposure time on mortality (P < 0.05).

Moreover, in Table 8, in *T. castaneum*, the mortality rates were lower than those observed for the other two species. At 0.012 mg/kg, mortality after 1 day was 3.33%, increasing to 81.7% by 14 days.

Table 6. Mean mortality (% ± SE) of *Rhyzopertha dominica* adults exposed to wheat grains treated with spinosad at different application rates for 1, 3, 5, 7, and 14 days.

Treatment (mg/kg)	Mortality (% ± SE) after 1day	3days	5days	7days	14days	Reduction % in F1 progeny
0.012	38.33±3.33d	55.00±5.0c	70.00±2.89c	78.33±3.30b	100.0±0.0a	61.1
0.024	51.67±1.67c	66.67±4.41b	81.67±2.89b	93.33±4.41a	100.0±0.0a	72.1
0.048	66.67±1.67b	71.67±1.67ab	88.33±2.80 ab	100.0±0.0aa	100.0±0.0a	83.3
0.096	75.00±2.89a	81.67±1.67a	95.00±2.80a	100.0±0.0aa	100.0±0.0a	88.9
0.192	100.0±0.0a	100.0±0.0a	100.0±0.0a	100.0±0.0a	100.0±0.0a	100.0
F-value	42.19	9.83	20.46	13.67	0	-
P- value	<.0001	0.0046	0.0004	0.0016	0	-
LSD 0.05	8.15	11.53	7.68	9.01	0	-

Means followed by the same letters in the same column are not significantly different at P=0.05.

Table 7. Mean mortality (% ± SE) of *Sitophilus oryzae* adults exposed to wheat grains treated with spinosad at different application rates for 1, 3, 5, 7, and 14 days.

Treatment (mg/kg)	Mortality (% ± SE) after 1day	3days	5days	7days	14days	Reduction % in F1 progeny
0.012	53.33±3.33b	56.67±3.33c	83.33±3.30c	100.0±0.0a	100.0±0.0a	71.3
0.024	60.00±5.77b	70.00±5.77b	86.67±3.20bc	100.0±0.0a	100.0±0.0a	78.1
0.048	76.67±3.33a	83.33±3.33a	93.33±3.10ab	100.0±0.0a	100.0±0.0a	83.4
0.096	83.33±1.67a	95.00±2.89a	100.00±0.0a	100.0±0.0a	100.0±0.0a	90.2
0.192	100.0±0.0a	100.0±0.0a	100.0±0.0a	100.0±0.0a	100.0±0.0a	100.0
F-value	13.46	17.20	6.56	0	0	-
P- value	0.0017	0.0008	0.0151	0	0	-
LSD 0.05	12.45	13.03	9.41	0	0	-

Means followed by the same letters in the same column are not significantly different at P=0.05.

Table 8. Mean mortality (% ± SE) of *Tribolium castaneum* adults exposed to crushed wheat treated with spinosad at different application rates for 1, 3, 5, 7, and 14 days.

Treatment (mg/kg)	Mortality (% ± SE) after 1day	3days	5days	7days	14days	Reduction % in F1 progeny
0.012	3.33±1.6c	8.33±4.4c	10.00±2.9c	46.67±6.0b	81.7±1.6c	44.0
0.024	10.00±2.8bc	18.33±4.41bc	20.00±2.8b	55.00±2.8b	85.0±2.8c	53.4
0.048	13.33±4.4b	21.67±3.33b	25.00±2.9b	71.67±6.6a	93.3±1.7b	71.4
0.096	16.67±3.33b	25.00±2.89b	28.33±3.3b	80.00±2.9a	95.0±0.0ab	82
0.192	30.00±2.89a	55.00±2.9a	83.33±1.67a	98.33±1.6a	100.0±0.0a	89.7
F-value	9.78	23.08	106.6	9.52	20.30	-
P- value	0.0017	<.0001	<.0001	0.0051	<.0001	-
LSD 0.05	9.96	11.50	8.78	16.07	5.25	-

Means followed by the same letters in the same column are not significantly different at P=0.05.

At 0.192 mg/kg, mortality reached 100% at 14 days. Reduction in F1 progeny ranged from 44.0% at 0.012 mg/kg to 89.7% at 0.192 mg/kg. Statistical analysis indicated significant differences across concentrations (P < 0.05).

In conclusion, spinosad demonstrated a strong insecticidal effect on *R. dominica*, *S. oryzae*, and *T. castaneum*, with mortality and progeny reduction increasing with both concentration and exposure time. The highest concentration (0.192 mg/kg) consistently achieved 100% mortality and the greatest reduction in F1 progeny across all species, underscoring its potential for effective pest control in stored grains. These findings suggest that spinosad could be a viable alternative to traditional grain protection, with its efficacy being influenced by both the applied concentration and duration of exposure.

Lethal quantities of spinosad powder were reached one day after treatment, whereas for *T. castaneum*, they were reached seven days after treatment. The results from Table 9 present the lethal concentration (LC) values, including LC_{50} and LC_{90}, and their respective confidence limits for *R. dominica, S. oryzae,* and *T. castaneum* when treated with spinosad powder. For *R. dominica*, the LC_{50} and LC_{90} values were 0.011 mg/kg and 0.137 mg/kg, respectively, with the confidence limits ranging from 0.005 to 0.025 mg/kg for LC_{50} and 0.062 to 0.303 mg/kg for LC_{90}. The corresponding slope value was 1.19, indicating a moderate dose-response. For *S. oryzae*, the LC_{50} was 0.020 mg/kg, and the LC_{90} was 0.165 mg/kg, with confidence limits from 0.011 to 0.039 mg/kg for LC_{50} and 0.086 to 0.317 mg/kg for LC_{90}. The slope value for this species was 1.41. *T. castaneum* exhibited an LC_{50} of 0.015 mg/kg and an LC_{90} of 0.173 mg/kg, with confidence limits of 0.007 to 0.033 mg/kg for LC_{50} and 0.081 to 0.370 mg/kg for LC_{90}, accompanied by a slope of 1.22 ± 0.81. The R values for all three species were close to 1, suggesting a good fit for the dose-response relationship. The findings demonstrate that spinosad powder exhibits a rapid lethal effect on the adult stages of *R. dominica, S. oryzae,* and *T. castaneum*. The mortality rate increases with both spinosad concentration and exposure time, as evidenced by the correlation and regression analyses. The data suggest that *T. castaneum* is the most susceptible to spinosad, followed by *S. oryzae* and *R. dominica*.

Table 9. lethal concentration values and confidence limits for the adult of *Rhyzopertha dominica* and the adult of *Sitophilus oryzae* after one day post-treatment and the adult of *Tribolium castaneum* after seven days post-treatment with spinosad powder at 30±1°C and 65±5% R.H.

Insects	LC_{50} mg/kg	LC_{90} mg/kg	Confidence limits at 95%				Slope ± Sd	R
			LC_{50}		LC_{90}			
			Lower	Upper	Lower	Upper		
R. dominica	0.011	0.137	0.005	0.025	0.062	0.303	1.19±0.83	0.881
S.oryza	0.020	0.165	0.011	0.039	0.086	0.317	1.41±0.70	0.991
T. castaneum	0.015	0.173	0.007	0.033	0.081	0.370	1.22±0.81	0.920

Data in Table 10 highlight the correlation and regression analysis between spinosad concentration, time, and mortality in *R. dominica, S. oryzae,* and *T. castaneum*. Mortality showed a moderate positive correlation with concentration (R = 0.41, 0.43, and 0.53, respectively) and a strong positive correlation with time (R = 0.68, 0.77, and 0.79, $p < 0.005$). Multiple regression analysis indicated significant effects of concentration (b = 338.4, 409.0, 635.0) and time (b = 2.38, 3.13, 4.07), all $p < 0.05$. Explained variance was high (64.51%, 78.37%, 92.32%), confirming strong predictive power. Generally, the high explanation variance in the multiple regression analysis underscores the significant role of both concentration and exposure time in determining the lethality of spinosad. These results provide valuable insights for optimizing spinosad-based control strategies for these pests.

Table 10. Simple correlation and multiple regression values for the effect of Spinosad at various concentrations on *Rhyzopertha dominica*, *Sitophilus oryzae*, and *Tribolium castaneum*

Species	Factor	Simple correlation		Multiple regression				
		r	P	b	P	F	P	E.V.%
R. dominica	Con.%	0.41	0.0670	338.4	0.0102	15.45	0.0001	64.51
	Time	0.68	0.0008	2.38	0.0002			
S. oryza	Con.%	0.43	0.0566	409.0	0.0013	30.80	0.0001	78.37
	Time	0.77	<.0001	3.13	0.0001			
T. castaneum	Con.%	0.53	0.0153	635.0	0.0001	102.2	0.0001	92.32
	Time	0.79	<.0001	4.07	0.0001			

r = correlation, P= probability, b= slope, EV% = explanation variance, conc.= concentration.

Residual efficiency

Table 11 shows the residual effectiveness of abamectin against *R. dominica, S. oryzae,* and *T. castaneum* over a six-month storage period. At the LC_{90} concentration, the corrected mortality was consistently 100% across all species during the first, second, and fourth months of exposure, indicating high effectiveness. However, by the sixth month, the mortality for *R. dominica* decreased to 96.5%, while *S. oryzae* remained at 100%, and *T. castaneum* showed a significant drop to 75%. The multiplier values, reflecting the relative mortality across months, remained at 100% until the sixth month, where *T. castaneum* dropped to 83%, suggesting that the insecticide's effectiveness diminishes slightly over time, particularly for *T. castaneum*.

Concerning Table 12, it presents the residual effectiveness of spinosad against *R. dominica, S. oryzae,* and *T. castaneum* over the same storage period. At the LC_{90} concentration, *R. dominica* exhibited high corrected mortality (98.3%) in the first month, which slightly decreased to 96.5% in the second month and further to 91.5% in the fourth month. However, the mortality dropped significantly to 8% in the sixth month. *S. oryzae* showed a stable high mortality (100%) in the first month, which decreased to 88.00% in the second month, but in the fourth month, it declined to 60%, and by the sixth month, it was reduced to 8%. For *T. castaneum*, the mortality was 80% in the first month but drastically dropped to 0% in the second month, with no residual effect in the fourth and sixth months. The multiplier values reflected a similar trend, with significant drops in the fourth and sixth months, especially for *T. castaneum*.

The findings demonstrate that both abamectin and spinosad exhibit high initial effectiveness against *R. dominica, S. oryzae,* and *T. castaneum*. Abamectin maintained its high mortality rates (100%) for up to four months, with a slight decline observed in the sixth month, especially for *T. castaneum*. On the other hand, spinosad's residual effectiveness decreased more rapidly, especially for *T. castaneum*, where mortality dropped to 0% within two months. These results suggest that while abamectin retains its effectiveness longer than spinosad, spinosad shows strong initial control, particularly in the first two months. The data highlight the need for timely reapplication of spinosad, especially for *T. castaneum*, to maintain effective pest control.

Table 11. The abamectin's residual effectiveness against *Rhyzopertha dominica*, *Sitophilus oryzae*, and *Tribolium castaneum.*

Storage period (months)	The corrected mortality % after indicated periods of exposure											
	The first month			The second month			The fourth month			The sixth month		
Concentration	*R.d*	*S.o*	*T.c*	*R.d*	*S.o*	*T.c*	*R.d*	*S.o*	*T.c*	*R.d*	*S.o*	*T.c*
LC_{90}	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	96.5	100.0	75.0
multiplier	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	83.0

R.d = Rhyzopertha dominica, S.o = Sitophilus oryza, T.c = Tribolium castaneum

Table 12. The spinosad's residual effectiveness against *Rhyzopertha dominica*, *Sitophilus oryzae*, and *Tribolium castaneum.*

Storage period (months)	The corrected mortality % after indicated periods of exposure											
	The first month			The second month			The fourth month			The sixth month		
Concentration	*R.d*	*S.o*	*T.c*	*R.d*	*S.o*	*T.c*	*R.d*	*S.o*	*T.c*	*R.d*	*S.o*	*T.c*
LC_{90}	98.3	100.0	80.0	96.5	88.0	0.00	91.5	60.0	0.0	8.0	8.0	0.0
multiplier	100.0	100.0	88.0	98.0	100.0	20.0	100.0	93.0	0.0	25.0	33.3	0.0

R.d = Rhyzopertha dominica, S.o = Sitophilus oryza, T.c = Tribolium castaneum

Discussion

The results of this study confirm the findings of previous research that demonstrated the high efficacy of abamectin and spinosad against storage insects, emphasizing the significant role of exposure duration in enhancing insecticidal effectiveness (Kavallieratos *et al.*, 2009). These results align with those of Andrić *et al.* (2011), which showed that higher concentrations and longer exposure periods increased the efficacy of both insecticides. *Rhyzopertha dominica* was found to be the most susceptible of the three species tested. Progeny production of all three species was significantly reduced on spinosad-treated grains compared to untreated grains. Based on these results, spinosad dust could be considered an effective alternative to traditional grain protectants; however, its insecticidal effect is influenced by several factors (Nikpay, 2007). In contrast, Huang and Subramaneyam (2007) found that spinosad at 2 mg/kg was 98% effective after 12 days of exposure to *Tribolium castaneum* adults. Andrić *et al.* (2011) indicated that a 14-day exposure period was required for both spinosad and abamectin to be highly effective against *Sitophilus oryzae* adults. In line with the findings of Perišić *et al.* (2020), the efficacy of abamectin increased significantly after 14 days of exposure. Following a 21-day exposure to abamectin at 0.5 and 1.0 mg/kg, respectively, *R. dominica* mortality reached 99% and 100%. After 10 weeks of treatment, all tested rates prevented progeny emergence. These rates of abamectin also effectively inhibited the development of *R. dominica* offspring in wheat and maize (Kavallieratos *et al.,* 2009). Andrić *et al.* (2011) observed that no insecticide provided complete (100%) progeny reduction in *S. oryzae*, although abamectin at 1 or 2 mg/kg achieved the highest progeny reduction (≥95%). For optimal suppression of *S. oryzae* populations in wheat, ≥2 mg/kg of abamectin or spinosad should be used.

Both abamectin and spinosad significantly reduced adult mortality in *R. dominica*, *S. oryzae*, and *T. castaneum* over the six-month trial. Abamectin caused near-total adult mortality during this extended storage period, demonstrating its high persistence and residual efficacy. These results are consistent with previous research, such as Kavallieratos *et al.* (2009), who found that after seven days of exposure, abamectin at 1 mg/kg significantly reduced mortality in *S. oryzae* and *R. dominica*. Perišić *et al.* (2020) reported that after 10 weeks, abamectin at 1.0 mg/kg completely suppressed *R. dominica* offspring on various treated cereal grains. Similar outcomes were observed when maize and wheat grains were treated with spinetoram (1.0 mg/kg) over a five-month storage period (Ksoura *et al.,* 2022). Vayias *et al.* (2010) noted that during a six-month storage period, spinosad's residual efficacy against *Cryptolestes ferrugineus* (Stephens), *R. dominica*, *S. oryzae*, and *T. confusum* decreased on treated wheat, maize, and barley. The results are also in agreement with Abdelgaleil *et al.* (2023), who found that during a five-month storage period, abamectin exhibited superior residual activity compared to other insecticides against *C. maculatus* and *C. chinensis*, making it a promising option for protecting stored cowpea seeds. Abdelgaleil *et al.* (2024) evaluated the insecticidal efficacy of spinosad and seven monoterpenes against *S. oryzae* in stored wheat. Results showed complete mortality (100.0%) of *S. oryzae* adults in wheat treated with spinosad and carvone or P-cymene or menthone after 21 days. No progeny was produced in combined treatments after 45 and 90 days.

CONCLUSIONS

The study evaluated the effects of abamectin and spinosad powders on the mortality and F1 progeny reduction of *R. dominica, S. oryzae,* and *T. castaneum.* Mortality rates increased with concentration and exposure time. For *R. dominica*, abamectin achieved 100% mortality at doses ≥0.02 mg/kg by day 3, while *S. oryzae* reached complete mortality by day 7. *T. castaneum* exhibited slower mortality, reaching 100% only at higher doses by day 14. The LC_{50} and LC_{90} values confirmed *R. dominica* as the most susceptible species, followed by *S. oryzae* and *T. castaneum*. Spinosad showed a similar pattern, with *R. dominica* and *S. oryzae* achieving 100% mortality at higher doses, while *T. castaneum* was less susceptible. Lethal concentration values indicated rapid action, with *R. dominica* responding the fastest. Regression analysis confirmed strong dose-response relationships for both insecticides. Residual effectiveness analysis revealed that abamectin maintained high mortality (≥96%) for up to six months, whereas spinosad's effectiveness declined significantly, particularly against *T. castaneum*. These findings highlight abamectin's longer-lasting control and spinosad's rapid but short-term efficacy, suggesting reapplication is needed for prolonged pest management in stored grains. I recommend using abamectin as an alternative to malathion.

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تقييم فعالية الأبامكتين والسبينوساد ضد آفات الحبوب المخزنة: نسبة الموت، الاستدامة، والاثر المتبقي

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الملخص

تُقيِّم هذه الدراسة فعالية واستدامة والاثر المتبقى للمبيدين الحيويين أبامكتين وسبينوساد ضد ثلاثة من أهم آفات الحبوب المخزنة ثاقبة الحبوب الصغري وسوسة الارز و خنفساء الدقيق الكستنائية، وذلك في ظل ظروف معملية محكمة (٣٠±١°م، ورطوبة نسبية ٦٥±٥٪). تمَّت معاملة حبوب القمح بتراكيز مختلفة من أبامكتين (٠,٠١–٠,٠٦٪ وزن/وزن) وسبينوساد (٠,٠١٢–٠,١٩٢٪ وزن/وزن)، وتم قياس نسبة الموت بين الحشرات البالغة بعد ١ و ٣ و ٥ و ٧ و ١٤ يومًا. كما تم تقييم إنتاج الأجيال الجديدة بعد ٦٠ يومًا من المعاملة. ازدادت نسبة الموت مع ارتفاع الجرعات وزيادة مدة التعرض، حيث أظهرت جميع الأنواع نسبة موت مرتفعة بعد سبعة أيام. كانت ثاقبة الحبوب الصغري شديد الحساسية لكلا المبيدين، حيث تراوحت نسبة الموت بين ٥٨,٣٪ و ١٠٠٪ لأبامكتين، وبين ٣٨,٣٪ و ١٠٠٪ لسبينوساد. وبالمثل، أظهر سوسة الارز حساسية عالية، حيث تراوحت نسبة الموت بين ٥٣,٣٪ و ١٠٠٪. بينما كانت خنفساء الدقيق الكستنائية أقل تأثرًا، حيث تراوحت نسبة الموت بين ١٥,٠٪ و ١٠٠٪ لأبامكتين، وبين ٣,٣٪ و ١٠٠٪ لسبينوساد. أظهر أبامكتين فعالية متبقية أعلى من سبينوساد على مدار ستة أشهر. تؤكد هذه النتائج على إمكانيات أبامكتين كعامل حماية فعال طويل الأمد ضد آفات تخزين الحبوب، مما يساهم في استراتيجيات إدارة آفات أكثر كفاءة لحماية القمح المخزن

الكلمات المفتاحية: حشرات الحبوب المخزونة ، حماية القمح، وإدارة الآفات