Plant Protection, 10 (05) 2026. 877-886 DOI:10.33804/pp.010.05.6201

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Available Online at EScience Press
Plant Protection
ISSN: 2617-1287 (Online), 2617-1279 (Print)
http://esciencepress.net/journals/PP

Research Article

Toxicity of Selected Chemical Insecticides against Different Life Stages of the Black Carpet Beetle, *Attagenus unicolor*, and the Variegated Carpet Beetle, *Anthrenus verbasci*

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ARTICLE INFO

Article history
Received: 13th July, 2026
Revised: 24th September, 2026
Accepted: 27th September, 2026

Keywords
Attagenus unicolor
Anthrenus verbasci
Chemical insecticides
Life-stage susceptibility
Carpet beetles

ABSTRACT

Carpet beetles, particularly *Attagenus unicolor* and *Anthrenus verbasci*, can damage stored wheat, with larvae representing the principal destructive stage. This study evaluated the toxicity of selected chemical insecticides against different life stages of these species under direct spray, residual exposure, and treated-grain conditions. Mortality was assessed at 24, 48, and 72 h after treatment. Ultracide consistently showed the highest efficacy across exposure methods and insect stages. Under direct treatment, Ultracide caused up to 90% and 100% mortality of *A. unicolor* larvae and *A. verbasci* larvae, respectively, at 72 h, while adult *A. unicolor* and *A. verbasci* mortality reached 100%. Residual exposure produced 100% mortality of larvae and adults of both species within 72 h in several treatments. Grain treatment with Ultracide resulted in 100% mortality of larvae of both species by 72 h and similarly high mortality in adults. Malathion generally showed the second-highest efficacy, whereas Deltamax was comparatively less effective under residual exposure. Mortality generally increased with exposure duration, and *A. verbasci* was more susceptible than *A. unicolor* across most treatments. Adults were generally more susceptible than immature stages under residual exposure, although susceptibility varied with insecticide and exposure method. Significant differences were observed among insecticides and the untreated control. Overall, Ultracide demonstrated strong contact, residual, and grain-treatment activity against both carpet beetle species and may provide effective chemical control; however, further studies on formulation, residue persistence, grain safety, and application rates are warranted before practical adoption.

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Introduction

Chemical pesticides are among the most important tools used to control insect pests affecting stored products, textiles, and museum artifacts, owing to their rapid action and efficiency in reducing pest populations compared to other control methods. Despite the widespread adoption of Integrated Pest Management (IPM) programs, chemical pesticides remain a fundamental component of control strategies. However, their repeated use has led to several challenges most notably the development of insect resistance, environmental impacts, and potential risks to non-target

organisms necessitating continuous evaluation of the efficacy and toxicity of various pesticides against target pests (Desneux et al., 2007; Guedes et al., 2026).

Carpet beetles belong to the family Dermestidae and are among the most economically significant insects affecting homes, warehouses, museums, and libraries. Their larvae feed on materials of animal origin such as wool, silk, leather, feathers, fur, and preserved insect specimens-causing substantial economic losses and damaging items of historical and scientific value (Houseman, 2016; Dellinger and Day, 2021). The black carpet beetle *Attagenus unicolor* and the varied carpet beetle *Anthrenus verbasci* are the most widespread and destructive species within this family. They are characterized by their ability to utilize a wide range of organic materials and are found globally in residential, commercial, and museum environments (Holloway et al., 2024).

Larvae represent the most destructive stage in the carpet beetle life cycle due to their prolonged growth period and voracious feeding habits. In contrast, adult beetles primarily feed on pollen and nectar and do not cause direct damage to stored materials (Day, 2022). Susceptibility to chemical pesticides varies among the egg, larvae, pupae, and adult stages owing to differences in physiological characteristics, cuticle thickness, and metabolic rates, making it essential to study the impact of pesticides across all life stages to devise effective control programs based on precise application timing and appropriate pesticide selection. Furthermore, understanding the biology and life cycle of these species is fundamental to explaining the varying responses to pesticides observed across the different developmental stages.

Numerous studies have examined the efficacy of various chemical insecticides, repellents, and fumigants in controlling dermestid beetles, revealing clear variations in toxicity levels depending on the type of pesticide and the insect's life stage. Research by Linnie and Keatinge (2000) demonstrated that pesticide effectiveness differs significantly across eggs, larvae, pupae, and adults; certain compounds proved more effective against larvae and adults than against other stages, underscoring the importance of evaluating toxicity for each life stage individually before implementing chemical control programs.

Controlling pests in storage facilities requires selecting and using the appropriate treatment method and determining the correct dosage based on three key factors: the time it takes for the pesticide to reach the insects, environmental conditions such as temperature and humidity, and the duration required for the pesticide to reach the target insects to ensure successful eradication (Bell, 2014). Chemical insecticides are considered the most effective method and the cornerstone of pest control for stored goods and materials worldwide (Valiota et al., 2022). Stored products rely primarily on the use of chemical insecticides for protection against insect pests. Chemical pest control has been employed in various ways to prevent insect infestations in stored materials. Two types of insecticides have been used: contact insecticides and respiratory (gaseous) insecticides (Valiota et al., 2022).

Given the economic importance of *A. unicolor* and *A. verbasci* and the direct damage they cause to furnishings, textiles, museum collections, and stored materials, evaluating the toxicity of chemical pesticides against various life stages of these two species is a crucial step. Such evaluation helps identify the most effective pesticides, reduce unnecessary usage, and improve integrated pest management strategies, thereby achieving optimal control while minimizing the environmental and health impacts associated with excessive pesticide use (Gunstone et al., 2021). The selective use of chemical insecticides is a fundamental pillar for the success of IPM strategies and for limiting the development of resistance in storage insects and pests to chemical insecticides (Stejskal et al., 2021). The study, therefore, aimed to evaluate the effectiveness of the pesticides used against various life stages of the two insect species under investigation, employing three different methods to identify the most efficient one while minimizing pollution.

Materials and Methods

Preparation of colonies

Colonies of the black carpet beetle *A. unicolor* and the variegated carpet beetle *A. verbasci* were obtained from samples stored in the laboratories of the Department of Plant Protection, College of Agriculture, Anbar University. The two beetle species were placed in separate glass bottles. The bottles were covered with a piece of muslin cloth, secured with a rubber band, and placed in an incubator at a temperature of 35°C and a relative humidity of 60–70%. Relative humidity was monitored using a hygrometer.

Pesticide toxicity testing

This research was conducted at the Cell Biology Laboratory of the Department of General Sciences, College of Basic and Haditha Education, Anbar University, from

October 1, 2025, to July 1, 2026. The larvae, pupae, and adult life stages of the black carpet beetle and the variegated carpet beetle were treated with four chemical pesticides: Deltamax 5% EC, Ultracide 40% EC, Tetraniliprole 20% SC, and Malathion 50% EC. The recommended concentrations for each pesticide were used, in accordance with the manufacturer's recommendations (m/L), as shown in Table 1.

Table 1. Active ingredients and concentrations used for pesticides.

Pesticide name	Active ingredient IUPAC Name	Manufacturer	Pesticide concentration	Active Ingredient Concentration
Deltamax	Deltamethrin (S)-α-cyano-3-phenoxybenzyl (1R,3R)-3-(2,2-dibromovinyl)-2,2-	Bayer CropScience	0.5 – 1 ml	EC5%
Ultracide	Methidathion S-(5-methoxy-2-oxo-1,3,4-thiadiazol-3(2H)-ylmethyl) O, O-dimethyl phosphorodithioate	Syngenta	0.75 - 1 ml	EC40%
Tetraniliprole	Tetraniliprole 1-(3-chloropyridin-2-yl)-N-[4-cyano-2-methyl-6-(methylcarbamoyl) phenyl]-3-{[5-(trifluoromethyl)-2H-tetrazol-2-yl] methyl}-1H-pyrazole-5-carboxamide.	Bayer CropScience	1 ml -0.6	SC20%
Malathion	Malathion O, O-dimethyl S-(1,2-dicarboethoxyethyl) phosphorodithioate.	FMC Corporation	1ml	EC50%

Direct exposure test of insect life stages to chemical pesticides

Adult insects aged 1-2 days, as well as final-instar larvae and pupae of both *A. unicolor* and *A. verbasci,* were placed in separate sterile Petri dishes with a diameter of 9 cm and a height of 1.5 cm, with three replicates for all life stages of each species. Each sample contained 10 adults (5 males and 5 females), 10 larvae, and 10 pupae, each in a separate dish. The treatment was applied to the inner underside of the Petri dish. The dishes were sprayed with the recommended concentrations of chemical pesticide solutions at a rate of 1 mL/L. This is equivalent to 0.0157 ml/cm^2 per sample using a small sprayer at a constant pressure of 1 bar 15 psi to ensure uniformity and even distribution of droplets, in addition to a control, treatment that was sprayed with sterile distilled water only. The area treated amounted to 63.6 cm^2 {(Area of a circle = π × radius^2) (A = 3.144 × 4.5^2 = 63.585 ≈ 63.6). After spraying was completed, ground wheat grains and 10 g of flour were added to each dish to feed the insects and larvae. The dishes were then covered with a cotton cloth secured with a rubber band and incubated at a temperature of 35°C and a relative humidity ranging from 60 to 70%. The relative humidity was measured using a hygrometer and the number of dead individuals was recorded at 24, 48, and 72 h after treatment.

Testing the exposure of insect life stages to pesticide residues

Petri dishes were sprayed with pesticide solutions using a small sprayer at a concentration of 1 mL/L per 9-cm-diameter Petri dish lined with filter paper. After spraying, the Petri dishes were left open to drain and dry under the laboratory fume cupboard at a laboratory temperature of 25 ± 2°C and a relative humidity of 65 ± 5 per cent for 90 min to ensure complete evaporation of the solvent and stabilization of the active substance on the surface before the insects were introduced. Then, 10 adult insects (5 males and 5 females) aged between one and two days, 10 larvae, and 10 pupae, each group separately for each of the two insect species used in the study, were placed in three replicate groups per treatment. For the control treatment, the dishes were sprayed with sterile distilled water. The life stages of both insect species were left for 8 h in the pesticide-treated Petri dishes, after which crushed wheat grains mixed with 10 g of flour were added to each Petri dish to feed the insects.

The dishes were then covered with a piece of gauze, secured with a rubber band, and placed in an incubator at a temperature of 35°C and a relative humidity ranging between 60 and 70%. The number of dead insects was recorded at 24, 48, and 72 h after treatment.

Testing the treatment of wheat grains with chemical pesticides

Wheat grains were placed in Petri dishes in three replicate groups, at a rate of 10 g per dish, and treated with chemical pesticides at a concentration of 1 mL/L, in addition to a control treatment with distilled water. After spraying, the Petri dishes were left open to drain and dry under the laboratory fume cupboard at a laboratory temperature of 25 ± 2°C and a relative humidity of 65 ± 5 per cent for 90 min to ensure complete evaporation of the solvent and stabilization of the active substance on the surface before the insects were introduced. Afterwards 10 adult insects (1–2 days old), 10 larvae, and 10 pupae of each of *A. unicolor and A. verbasci* were added. The dishes were then covered with muslin, secured with rubber bands, and placed in an incubator at 35°C with relative humidity ranging from 60 to 70%. The number of dead insects was recorded at 24, 48, and 72 h after the start of treatment.

Statistical analysis

The study results were analyzed using a completely randomized design (CRD). The mortality rate was calculated, and statistically significant differences between treatments were compared using the "least significant difference" (LSD) method at a significance level of 0.01.

Results and Discussion

Direct insect treatment by spraying

The results presented in Table 2 showed that the insecticide "Ultracide" outperformed the other insecticides used in the direct exposure tests, with mortality rates of 90%, 100%, and 100% for black carpet beetle larvae exposed to "Ultracide" while for mixed carpet beetle larvae, the mortality rates were 96.6%, 100%, and 100%, respectively, 24, 48, and 72 h after treatment. Malathion ranked second in terms of efficacy, with mortality rates for black carpet beetle larvae at 53.3%, 86.6%, and 100%, and for mixed carpet beetle larvae at 86.6%, 93.3%, and 100%, respectively, at 24, 48, and 72 h after treatment. The results showed statistically significant differences among all insecticides and the control treatment, where the mortality rate was 0% for all insect stages. As for the effect of insecticides on the larval stage, the results showed that the insecticide Ultracide was the most effective under direct exposure, with pupae mortality rates of 46.6%, 73.3%, and 90% for the black carpet beetle, and 53.3%, 86.6%, and 100%, respectively for variegated carpet beetle. Malathion ranked second in terms of efficacy at 24, 48, and 72 h after treatment, with larval mortality rates for the black carpet beetle reaching 30, 56.6%, and 83.3%, respectively, while the pupae mortality rate for the variegated carpet beetle was 40%, 70%, and 93.3%, respectively, 24, 48, and 72 h after pesticide treatment, compared to the control treatment, which had a mortality rate of 0%. The results showed that direct exposure of adult specimens of both insect species to chemical pesticides revealed that the pesticide Ultracide was more effective than the other pesticides, with mortality rates for adult black carpet beetles reaching 63.3%, 100%, and 100% at 24, 48, and 72 h after treatment, respectively, and mortality rates for adult carpet beetles reaching 100.0% within 24 h of treatment. Malathion ranked second in terms of efficacy, with mortality rates of 53.3%, 83.3%, and 100% for adult black carpet beetles 24, 48, and 72 h after treatment, while the mortality rate for adult carpet beetles of various species reached 100% within 24 h of treatment compared to the control treatment, which had a mortality rate of 0%. Statistical analysis revealed statistically significant differences between all chemical pesticides and the control treatment, which had a mortality rate of 0%. The results indicated that adult carpet beetles of the species *A. verbasci* are more sensitive than adult carpet beetles of the species *A. unicolor* when directly exposed to chemical insecticides, with a 100% mortality rate for adults for all insecticides within 72 h of treatment. Statistical analysis revealed statistically significant differences between all insecticides and the control treatment.

The study results showed that the larvae, pupae, and adults of the variegated carpet beetle are more susceptible to chemical insecticides compared to the larvae, pupae, and adults of the black carpet beetle. The results of the study conducted by Al-Hayali et al., (2025) showed that the chemical pesticide alphacypermethrin at a 30% concentration was most effective in achieving the highest mortality rate of 93.3% against the olive mealybug after 24 h, while biological alternatives such

as the bacterium *Bacillus amyloliquefaciens* and neem oil demonstrated 63.3% efficacy after 48 h, with oxymathrin standing out for its superior insect repellency. In addition, the results of the study conducted by Al-Hayali et al., (2024), which evaluated the efficacy of certain biopesticides and chemical pesticides against the insect *Hyalopterus pruni*, showed that oxymathrin achieved the highest repellency rate of 91.1% after 15 min and the highest mortality rate of 82.2% after 24 h, while *B. amyloliquefaciens* showed 100% repellency after 10 min at concentrations of 20% and 30%. Oxymathrin recorded the highest mortality rate of 82.2% after 24 h, whereas spinosad recorded 55.5% after 48 h. Meanwhile, oxymathrin was at 20%.

Table 2. Effect of direct pesticide spraying on the mortality rates of the life stages of *A. unicolor* and *A. verbasci*.

Insect Species	Life Stage	Pesticide Name	Mortality %			Overall Mean (%)	Cumulative
			24 h	48 h	72 h		
A. unicolor	larvae	Ultracide	90.0	100	100	96.6	100
		Malathion	53.3	86.6	100	79.9	100
		Tetraniliprole	60.0	90.0	93.3	81.1	93.3
		Deltamax	33.3	56.6	70.0	53.3	70.0
	pupae	Ultracide	46.6	73.3	90.0	69.9	90.0
		Malathion	30.0	56.6	83.3	56.6	83.3
		Tetraniliprole	26.6	50.0	76.6	51.1	76.6
		Deltamax	13.3	33.3	50.0	32.2	50.0
	adults	Ultracide	63.3	100	100	87.7	100
		Malathion	53.3	83.3	100	78.8	100
		Tetraniliprole	40.0	76.6	93.3	69.9	93.3
		Deltamax	26.6	43.3	66.6	45.5	66.6
L.S.D 0.01			4.5	3.75	2.9	3.15	2.8
A. verbasci	larvae	Ultracide	96.6	100	100	98.8	100
		Malathion	86.6	93.3	100	93.3	100
		Tetraniliprole	90.0	93.3	100	94.4	100
		Deltamax	46.6	70.0	83.3	66.6	83.3
	pupae	Ultracide	53.3	86.6	100	79.9	100
		Malathion	40.0	70.0	93.3	67.7	93.3
		Tetraniliprole	36.6	66.6	86.6	63.2	86.6
		Deltamax	30.0	53.3	76.6	53.3	76.6
	adults	Ultracide	100	100	100	100	100
		Malathion	100	100	100	100	100
		Tetraniliprole	93.3	100	100	97.7	100
		Deltamax	60.0	86.6	100	82.2	100
L.S.D 0.01			3.3	2.15	1.9	2.1	1.85

Pest control through exposure to pesticide residues and deposits

The results presented in Table 3 show variations in the effects of chemical pesticide residues and deposits on the life stages of the insects *A. unicolor* and *A. verbasci*, with Ultracide residues demonstrating remarkable superiority and proving more effective and potent against the larval stage compared to the other chemical pesticides used in the study. Mortality rates for black carpet beetle larvae reached 86.6%, 93.3%, and 100%,

while mortality rates for variegated carpet beetle larvae reached 80%, 96.6%, and 100%, respectively, 24, 48, and 72 h after treatment. Next in effectiveness was the insecticide malathion, which achieved mortality rates of 46.6%, 76.6%, and 100% for black carpet beetle larvae and 80.0%, 96.6, and 100.0% for variegated carpet beetle larvae, respectively, 24, 48, and 72 h after treatment, compared to the control treatment, where the mortality rate was 0%. The results of the statistical analysis showed statistically significant differences between all the chemical pesticides used and the control treatment.

The study results showed that residues of the pesticide Ultracide were significantly more effective and potent against the larval stage of both insect species compared to other chemical pesticides used in the study, with mortality rates for the larval stage of the black carpet beetle reaching 40.0%, 66.6%, and 86.6%, while for the pupal stage of the variegated carpet beetle, they were 50%, 83.3%, and 100%, respectively, 24, 48, and 72 h after treatment. Malathion ranked next in terms of efficacy, with mortality rates for the pupae stage of the black carpet beetle reaching 26.6%, 50%, and 76.6%, and for the larvae stage of the spotted carpet beetle, they were 36.6%, 66.6%, and 90%, respectively, 24, 48, and 72 h after treatment, compared to the control treatment, which had a mortality rate of 0%. The results of the statistical analysis showed statistically significant differences between all the chemical pesticides used and the control treatment. The results showed that the residues and deposits of the pesticide Ultracide were highly effective against adult black carpet beetles, with mortality rates of 60%, 86.6%, and 100%, respectively, 24, 48, and 72 h after treatment. The mortality rates for adult carpet beetles were 63.3%, 100%, and 100% 24, 48, and 72 h after treatment, followed by malathion, which achieved mortality rates of 40%, 73.3%, and 96.6% for adult black carpet beetles 24, 48, and 72 h after treatment, while the mortality rate for adult mixed carpet beetles was 60%, 86.6%, and 100% 24, 48, and 72 h after treatment with all pesticides. This compares to the control treatment, where the mortality rate was 0%.

Based on the study's results, it was concluded that adult insects are more susceptible than larvae and pupae because adults are more mobile than larvae and pupae, leading to greater exposure to insecticides, in addition to differences in body wall structure, which is more permeable to chemical pesticides compared to the larvae and pupal stages, where the body wall is surrounded by a layer of dense hairs, a finding consistent with that reported by Gerling (1990). Based on the study's results, we observe that Deltamax a pyrethroid insecticide, was less effective than other chemical insecticides because Deltamax is a non-systemic, short-acting contact insecticide that kills insects by inducing a strong shock, in addition to its low toxicity to mammals, as it breaks down in their bodies into non-toxic substances and leaves no long-term residues due to its rapid degradation. However, it affects the nervous system, causing rapid paralysis and death in exposed insects.

The results of a study by Ghemiri et al., (2016) demonstrated the residual efficacy of the insecticides beta-cyfluthrin and deltamethrin against two species of beetles, *Trogoderma variabile* and *T. inclusum*, showing that the larvae were more resistant to the insecticides than the adult insects. Arthur et al., (2009) evaluated the residual efficacy of pyriproxyfen and hydrobrin when applied to three different surfaces, including wood, metal, and concrete to control the larval stages of five species of storage insect pests: *T. confusum*, *T. castaneum*, *Oryzaephilus surinamensis*, *Lasioderma serricorne*, and *Plodia interpunctella.* The type of surface influenced both the persistence of the pesticide's residual activity and the insect's response to the pesticide. Arthur (1997) confirmed that more than 90% of red flour beetle *T. castaneum* adults had died or were immobilized after only one day of exposure to surfaces made of concrete, plywood, and tiles treated with deltamethrin. Our results also align with the findings of Arthur et al. (2018). This demonstrates that the type and formulation of the pesticide significantly affect its residual efficacy, which is consistent with the findings of (Giga and Kanhao 1991).

A study by Lampiri et al., (2023) examined the efficacy of three insecticides alpha-cypermethrin, delta-methrin, and Spinosad on four different surfaces ceramic, concrete, plastic, and metal against various insect pests that infest stored products, including the rice weevil, the serrated grain beetle, and the confused flour beetle. The results showed that Spinosad was the most effective against the target insects, and that the type of surface and the exposure period had an impact on the effectiveness of the insecticides used. Concrete reduced the effectiveness of deltamethrin, while ceramic reduced the effectiveness of Spinosad.

Table 3. Effect of exposure to pesticide residues and deposits on the mortality rates of the life stages of *A. unicolor* and *A. verbasci*.

Insect Species	Life Stage	Pesticide Name	Mortality %			Overall Mean (%)	Cumulative
			24 h	48 h	72 h		
A. unicolor	larvae	Ultracide	86.6	93.3	100	93.3	100
		Malathion	46.6	76.6	100	74.4	100
		Tetraniliprole	50.0	80.0	90.0	73.3	90.0
		Deltamax	30.0	46.6	66.6	47.7	66.6
	pupae	Ultracide	40.0	66.6	86.6	64.4	86.6
		Malathion	26.6	50.0	76.6	51.1	76.6
		Tetraniliprole	23.3	43.3	70.0	45.5	70.0
		Deltamax	10.0	26.6	46.6	27.7	46.6
	adults	Ultracide	60.0	86.6	100	82.2	100
		Malathion	40.0	73.3	96.6	69.9	96.6
		Tetraniliprole	36.6	66.6	90.0	64.4	90.0
		Deltamax	23.3	40.0	63.3	42.2	63.3
L.S.D 0.01			5.1	4.8	4.2	3.95	4.15
A. verbasci	larvae	Ultracide	80.0	96.6	100	92.2	100
		Malathion	33.3	76.6	100	69.9	100
		Tetraniliprole	40.0	83.3	100	74.4	100
		Deltamax	26.6	56.6	80.0	54.4	80.0
	pupae	Ultracide	50.0	83.3	100	77.7	100
		Malathion	36.6	66.6	90.0	64.4	90.0
		Tetraniliprole	33.3	63.3	83.3	59.9	83.3
		Deltamax	20.0	46.6	70.0	45.5	70.0
	adults	Ultracide	63.3	100	100	87.7	100
		Malathion	60.0	86.6	100	82.2	100
		Tetraniliprole	53.3	83.3	100	78.8	100
		Deltamax	40.0	73.3	96.6	69.9	96.6
L.S.D 0.01			4.6	4.3	3.8	3.55	3.75

Treatment of grains with chemical pesticides

The results of the study presented in Table 4 showed variation in the efficacy of the chemical pesticides used, with the pesticide Ultracide demonstrating marked superiority and greater efficacy compared to other chemical pesticides when treating wheat grains, with mortality rates for black carpet beetle larvae reaching 66.6%, 86.6%, and 100%, and for carpet beetle larvae reaching 96.6%, 100%, and 100%, respectively, within 24, 48, and 72 h of treatment. Next in terms of efficacy was the pesticide Tetraniliprole, with mortality rates for black carpet beetle larvae reaching 46.6%, 76.6%, and 100%, while for mixed carpet beetle larvae, mortality rates were 90%, 93.3%, and 100%, respectively, within 24, 48, and 72 h after treatment, compared to the control treatment, which recorded a mortality rate of 0%. Statistical analysis revealed statistically significant differences between all chemical pesticides and the control treatment.

The results showed that the insecticide Ultracide was more effective than other chemical insecticides, with mortality rates of 60%, 86.6%, and 100% for adult black carpet beetles and adult carpet beetles, respectively, and 96.6%, 100%, and 100% within 24,

48, and 72 h after seed treatment. The insecticide Tetraniliprole was the next most effective, with mortality rates for adult black carpet beetles reaching 40%, 73.3%, and 96.6%. For adult *A. verbasci* beetles, mortality rates were 93.3%, 100%, and 100%, respectively, within 24, 48, and 72 h after seed treatment, compared to the control treatment, which had a mortality rate of 0%. The results showed statistically significant differences in the interaction between time and insecticides in adult beetles of the species *A. unicolor* and *A. verbasci*. As the duration of exposure of adult beetles to chemical insecticides increased, the mortality rate rose in both species. The difference in mortality rates between larvae and adults upon exposure to chemical pesticides is attributed to differences in the efficacy and chemical compositions of the pesticides, as each pesticide acts on a specific sensitive site (Georghiou, 1983). The biological significance of treating wheat grains against carpet beetles, particularly the genera *A. verbasci* and *A. unicolor*, lies in understanding the behavior of these pests, which makes them a major threat to stored crops. Adult carpet beetles typically do not feed on stored grains but instead on plant flowers. The larvae, however, are the damaging stage that feeds on the grain embryo because of its high protein and fat content. Larval feeding increases free fatty acids and deteriorates the quality of the gluten protein in the grain (Hagstrum and Subramanyam, 2006). Chemical or physical treatment of grains preserves the essential nutritional components of wheat (carbohydrates, proteins, and vitamins) and prevents changes in the taste and odor of flour caused by oxidation and insect excreta (Cauvain and Young, 2009). The goal of surface treatment of wheat is to eliminate larvae or prevent eggs from hatching, thereby limiting insect reproduction before damage occurs. Early treatment of the grain protects wheat embryo from destruction, which preserves the seeds' ability to germinate and ensures the safety of wheat intended for cultivation.

Table 4. Effect of treating wheat grains with chemical pesticides on the mortality rates of the life stages of *A. unicolor* and *A. verbasci*.

Insect Species	Life Stage	Pesticide Name	Mortality %			Overall Mean (%)	Cumulative
			24 h	48 h	72 h		
A. unicolor	larvae	Ultracide	66.6	86.6	100	84.4	100
		Malathion	60.0	83.3	93.3	78.8	93.3
		Tetraniliprole	46.6	76.6	100	74.4	100
		Deltamax	30.0	46.6	66.6	47.7	66.6
	adults	Ultracide	60.0	86.6	100	82.2	100
		Malathion	36.6	66.6	90.0	64.4	90.0
		Tetraniliprole	40.0	73.3	96.6	69.9	96.6
		Deltamax	23.3	40.0	63.3	42.2	63.3
L.S.D 0.01			3.8	2.95	2.1	2.65	1.75
A. verbasci	larvae	Ultracide	96.6	100	100	98.8	100
		Malathion	90.0	93.3	100	94.4	100
		Tetraniliprole	86.6	93.3	100	93.3	100
		Deltamax	46.6	70.0	83.3	66.6	83.3
	adults	Ultracide	96.6	100	100	98.8	100
		Malathion	93.3	100	100	97.7	100
		Tetraniliprole	80.0	90.0	100	90.0	100
		Deltamax	60.0	86.6	100	82.2	100
L.S.D 0.01			2.9	1.85	1.5	1.9	1.3

Conclusion

The results of the study showed that the pesticide Ultracide outperformed the other pesticides in the direct exposure method, the pesticide residue method, and grain treatment, recording the highest mortality rates during the various exposure periods. Malathion ranked second in terms of effectiveness, while Tetraniliprole and Deltamax showed lower efficacy compared to other pesticides. The results confirmed that direct exposure to pesticides was more effective in terms of mortality rates compared to the pesticide residue exposure method or grain treatment, indicating the importance of the application method in control efficacy. Increasing the duration of exposure of insect life stages to pesticides leads to higher mortality rates, indicating a direct relationship between lethal effect and exposure time. The results demonstrated that differences in pesticide efficacy are due to variations in their rate of degradation within the insect's body, as well as the nature of their effect on insects, whether through contact or by affecting the nervous system.

Author Contributions

OTHAA and TSAA conceptualized and designed the experiment. OTHAA conducted the field investigations and performed the experimental work. TSAA provided overall supervision and ensured methodological and analytical consistency throughout the study. TSAA and RSD contributed to experimental design, data interpretation, and research refinement at various stages of the project. OTHAA and RSD prepared the initial manuscript draft, including content organization, compilation of results, and integration of preliminary interpretations. All authors subsequently critically reviewed and revised the manuscript, contributed to its intellectual refinement, verified the data and analyses, and approved the final version for submission.

Research Funding

This research did not receive any grant from funding agencies.

Conflict of Interest

The authors declare no conflict of interest.

Sustainable Development Goals Targeted

SDG 2: Zero Hunger
SDG 12: Responsible Consumption and Production
SDG 15: Life on Land

Policy Addressed

The findings support evidence-based pesticide stewardship within integrated pest management programs, emphasizing life-stage-specific efficacy, judicious application, resistance monitoring, insecticide rotation, and integration with non-chemical measures. For stored wheat, policies should also require evaluation of residue persistence, grain safety, application rates, and treatment intervals before adoption.

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