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Using the Nanopesticide Deltamethrin to Control *Eurygaster integriceps*

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ABSTRACT

Emulsifiable concentrate (EC) formulations pose an environmental risk due to the presence of toxic solvents such as xylene, and safer and more effective nanoformulations can be useful in developing new pest management methods. In this study, a 2.5% deltamethrin nanoformulation was prepared and its size, shape, and active ingredient content were confirmed using SEM, AFM, DLS, and TGA methods. Then, this nanoformulation was compared with a commercial pesticide for controlling wheat in the stages of wintering adults, fourth-instar nymphs, and a new generation. Treatments included deltamethrin nanoformulation, nanocarrier, deltamethrin EC 2.5%, and water as a control. The nanoformulation maintained its insecticidal effect well (73%) in vitro after 45 days, but the mortality rate in the commercial EC formulation was very low (13%). In greenhouse evaluations, this formulation at a concentration of 125 mg/L produced over 90% mortality against overwintered adults. Nymph mortality was also reduced to 40% after 45 days of spraying.

Keywords: Nanopesticide, *Eurygaster integriceps,* Deltamethrin, Nanoformulations*.*

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INTRODUCTION

Eurygaster integriceps Puton (Hemiptera: Scutelleridae) is a well-known and damaging insect of wheat and barley fields. This pest is distributed in 12 Asian countries [1, 2]. Its damage in wheat fields is greater than that of barley and, if not controlled, can destroy 100% of the wheat crop [3]. In years of pest outbreaks, the amount of quantitative and qualitative damage can reach 9 million tons [4, 5].

Chemical control is the most common management method for wheat borer control. The annual spraying area in Southwest Asia against wheat borer is about 4 million hectares and its cost is equivalent to $150 million [6].

Although in recent years several formulations of tablets, suspension concentrate, capsuled suspension (SC), emulsifiable concentrate (EC), and granule, using technical pesticides trichlorophene, fenitrothion, deltamethrin, and cyhalothrin have been registered against wheat borer, but currently deltamethrin EC2.5% is the most common and well-known insecticide among farmers. Inadequate planning and lack of appropriate equipment among farmers have caused most of the formulations used for chemical control to be ineffective, and the dosage of deltamethrin 2.5% is usually higher than the optimal and even recommended dosage [7, 8].

The EC formulation is a base oil and its carrier is often xylene or cyclohexanone. This compound has a high risk of environmental and human pollution due to the presence of a benzene ring. This formulation is widely used in agriculture today, and its only drawback is that it does not last long and is affected by leaching from rainfall. Also, due to the presence of petroleum solvents, there is a possibility of burning plants. Since spraying against overwintered adults coincides with the first rainfall of the season, the presence of rainfall less than 24 hours after spraying can be effective in reducing wheat grain losses, and the probability of ineffectiveness increases with increasing rainfall and the time interval between spraying and rainfall [9, 10].

Therefore, formulations must be both safe and able to improve the physicochemical stability of the active ingredient against destructive factors of the active ingredient (during storage and foliar spraying), the degree of adhesion to the leaf surface and the insect body, and the bioavailability of the active ingredient, which has always been considered by researchers in this field. In this regard, the use of nanotechnology can be effective in reducing the adverse effects of pesticides and increasing their effectiveness. Nanocapsules are a new generation of formulations that are more environmentally friendly with the ability to release gradually and increase the insecticidal effect and persistence of the poison, and therefore nanotechnology can implement some agricultural programs [11]. Also, in line with a sustainable and healthy future for global agriculture and reducing biotic and abiotic stresses, nanotechnology has gained significant momentum [12-14].

Considering the damaging effects of wheat age at different growth ages and the potential of nanotechnology that can provide the possibility of achieving effective formulations with a lasting effect (and even, in cases where required, achieving slow and controlled release of the active ingredient) and the effect of silica in responding to biotic stresses, the present study aimed to achieve a nanoformulation of deltamethrin based on silica nanoparticles to prove the hypothesis based on controlling the age of the mother, nymph, and adult of the new generation with single spraying in the laboratory and greenhouse. Accordingly, a deltamethrin nanoformulation was prepared and its toxicity was evaluated on mature winter wheat, fourth-generation nymphs, and new-generation nymphs.

MATERIALS AND METHODS

Preparation of nano-formulation and spray sample

To prepare the nano-carrier, first tetraethyl orthosilicate was added to the acidic solution of P123 at 35 °C and reacted for 24 hours, and then the resulting mixture was placed at 100 °C for 24 hours. Then the obtained nano-carrier was filtered and washed thoroughly with water, and after drying, it was heated for 6 hours at 550 °C. Next, to prepare the nano-formulation, 500 mg of nanoparticles in deionized water, and 150 mg of deltamethrin dissolved in acetone solvent were added to it and the reaction was carried out for 24 hours. The obtained solid material was then filtered and washed thoroughly with deionized water and acetone, and dried under vacuum. Next, the amount of deltamethrin loaded by the thermal analysis method showed 25 mg of deltamethrin per 100 mg of nanoparticles. To prepare the samples required for treatment, the required amounts of deltamethrin nanoformulation were sonicated in a solution consisting of water, Tween 80 in a ratio of 100:0.5 for 10 minutes and after uniform dispersion of the particles in the solution, they were prepared for foliar spraying. It should be noted that in the case of technical deltamethrin, the problem of insolubility in water and the issues arising from it is very serious, which requires the importance and necessity of more effective formulations.

Collection of wheat instars

To conduct bioassay tests, overwintered instars were collected from under sagebrush and wheat plants. The collection of instars began after breaking forced diapause. All instars collected from the mountain were used in bioassay tests within less than three days.

Preparation of wheat instar nymphs and new generation wheat instars

Nymphs of different ages of wheat instars were collected from wheat fields and then transferred to the laboratory. Wheat instar nymphs and new-generation wheat instars of the same age were separated and used for bioassay tests. It should be noted that the use of nymphs of the same age from breeding is effective in the uniformity of bioassay, but due to the single generation of wheat age, it is not possible to prepare a large population, therefore, nymphs were first collected from the field and then an attempt was made to separate nymphs of the same age, size and volume and test them.

Bioassay by filter paper method

To determine the lethal concentrations in bioassay tests, a series of preliminary and main tests were conducted, in such a way that concentrations of 1-1000 mg/L of active ingredient were used and 1 mg a.i./L was selected as the minimum index for the tests. Finally, two different concentrations of deltamethrin nanoformulation and nanocarrier at concentrations of 1, 4 mg a.i./L, and 1 mg a.i./L of commercial pesticide EC were selected and used for the test. In this method, Whatman filter paper with a diameter of 9 cm was placed inside a glass Petri dish, then one milliliter of different concentrations was poured into each Petri dish in such a way that all parts were wet, water and Tween was also used in the control treatment. After the filter paper dried, 10 overwintered adults were released into each Petri dish. During the bioassay period, soaked wheat was used for feeding to reduce the mortality of the instars inside the Petri dish. At the end of this stage, to examine the persistence of the poison in the nanoformulation during the life cycle of the wheat instars, the treated plates were stored in the experimental area at room temperature and reused at different time intervals during the life cycle of the wheat instars. In such a way that the treated plates were used again after being stored for 30 and 45 days for the bioassay of the fourth instar and the new generation instars, respectively. The mortality of instars and nymphs was evaluated after 24 and 48 hours of contact with surfaces contaminated with insecticide. Insects that were unbalanced and unable to move when struck were considered dead.

Greenhouse bioassay

For this purpose, pots with a diameter of 20 cm were used, inside of which there were three cultivated wheat plants of the same growth. The entire aerial part of the plant was covered with a transparent plastic container with a mesh lid for air exchange that was adjusted according to the height of the plant. The bioassay of the overwintered adult was examined at the tillering stage and the bioassay of the 4th instar nymph was examined at the wheat heading stage. The pots were sprayed only once, at the tillering stage. The amount of solution used for each pot was 20 ml, and a hand-held hydraulic sprayer with a conical nozzle was used for spraying. A plastic cover was used to prevent contamination of the pot soil surface during spraying. Thus, only the surface of the wheat plants was impregnated with three concentrations of 10, 25, and 125 mg of active ingredient per liter. The selection of these concentrations followed how the farmers used the pesticides; Thus, the recommended amount of insecticide (250 ml/ha) and the amount of water consumed by farmers were 50, 250, and 600 liters/ha, so the concentration of the solution used was 10, 25, and 125 mg of active ingredient/liter, respectively. Based on this conventional method, these values were considered as concentrations similar to natural conditions. Deltamethrin nanoformulation, nanocarrier, and 2.5% Deltamethrin EC were used for spraying the pots. Evaluations were carried out in two stages: tillering (on overwintered adults; 7 days after spraying) and clustering stage (on nymphs 4; 45 days after spraying). In this experiment, the nymphs were in contact with the treated plants for only 24 hours. Nymph mortality was recorded at 24 and 48 hours after the start of the experiment. Wheat nymphs that were unable to move were considered dead.

Egg laying

To study the number of eggs and the way they were laid, adults (10 female insects and 5 male insects in each of the pots enclosed with thin and transparent Plexiglas cages) were released one week after spraying. After 24 hours, the insects were removed from the pots, counted, and the eggs were evaluated.

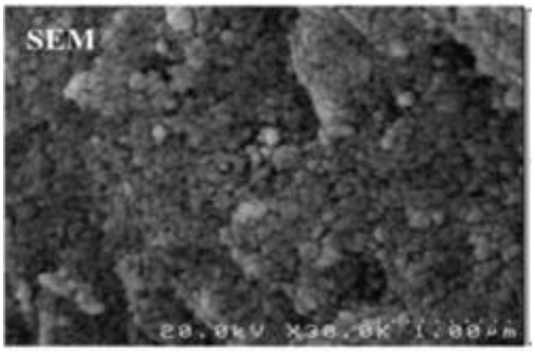
Data analysis

First, the data were evaluated for normality; the logarithm base method was used to normalize some of the data. Then, the analysis of the variance of the insect mortality data for the experiment in laboratory conditions and greenhouse conditions was performed through a factorial test in the form of a completely randomized basic design, and the analysis of variance of the data from the egg laying experiment was also performed in the form of a completely randomized basic design. To compare the means of mortality and egg-laying data, the Tukey statistical test was used at a probability level of 5%. Given the significant effect of the variable factor of pesticide treatments and the factor of different insect ages in the periods after the spraying treatment, the variable effect was cut off for each of the factors in the mean comparison test, and SAS and Excel software were used in this stage.

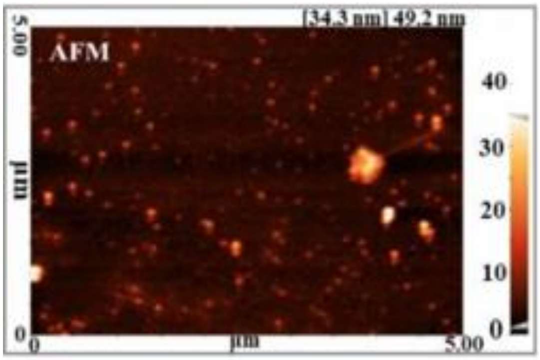
RESULTS AND DISCUSSION

The shape, size, and physical properties of the deltamethrin T nanoformulation after preparing the nanocarrier and loading the deltamethrin on its surface were confirmed by using scanning electron microscopy (SEM), dynamic light scattering (DLS), thermal gravimetric analysis, and atomic force microscopy (AFM). As shown in the SEM and AFM images **(Figure 1)**, the morphological characteristics of the particles can be determined, and in this particular case, the particles were spherical and had dimensions smaller than 50 nm. In the DLS method, unlike microscopic methods that examine the particle size in the dry state of the material, the measurement is performed in a solution environment and based on the hydrodynamic diameter of the particles; therefore, the hydrodynamic diameter of the particles was greater than the SEM results and the actual particle size was estimated to be 146 nm **(Figure 1)**.

Thermogravimetric analysis is used as a desirable method in evaluating the thermal stability of various materials and compounds. In this method, the mass of the material may increase (for example, due to absorption or oxidation) or decrease (for example, due to loss of water) as a result of applying heat to a material. The thermal curve of Deltamethrin shows that it has two main failures at temperatures of 195 and 220 °C. The curve related to the nanocarrier also shows a 3% decrease, which can be related to the removal of structural water. While the curve of deltamethrin nanoformulation shows a main decrease between temperatures of 250 and 450 °C, the amount of Deltamethrin present in the nanopesticide is about 25 mg per 100 mg.



a)



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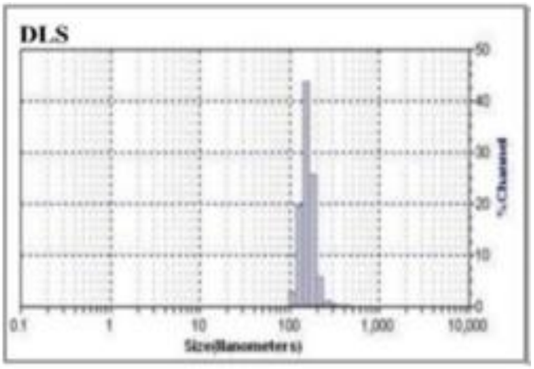

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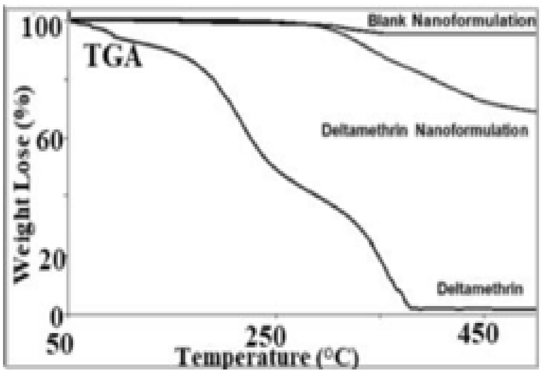

d)

Figure 1. DLS, SEM, TGA, and AFM images of the Deltamethrin nanoformulation.

Evaluation of deltamethrin nanoformulation in laboratory and greenhouse conditions showed that the studied nanoformulation had a higher percentage of efficacy and stability than the commercial EC over time. In laboratory conditions, a comparison of different concentrations of deltamethrin in terms of percentage of mortality showed that there was no significant difference between the concentrations in the nanoformulation treatment at 7 days after spraying for the overwintered adult, but this difference was obvious at 30 and 45 days after spraying. Also, by comparing different concentrations of deltamethrin (10, 25, and 125 mg/L) in terms of percentage of efficacy in greenhouse conditions, it was found that there was no significant difference between the concentrations in the nanoformulation treatment at 7 days after spraying for the overwintered adult, but this difference was obvious at 45 days after spraying and for the concentration of 125 mg a.i./L there was still maximum lethal efficacy compared to lower concentrations. Also, the nanoformulation, with a significant efficiency of releasing the poison over time compared to the commercial poison, was able to maintain the pesticidal effect; therefore, it can be said that there is a potential for reducing the consumption of poison in hydraulic spraying using nanoformulations. Examination of the formulations in laboratory conditions using the filter paper bioassay method showed that the nanoformulation was able to control 40% of the overwintered adult age in 7 days after treatment, which did not differ significantly in terms of percentage of deaths with the EC formulation of its equivalent concentration. Studies conducted 30 and 45 days later, the insecticidal effect of the nanoformulation at the desired concentration for the nymph and the new generation age was 53.3% and 56.6%, respectively. Comparison of concentrations of 1 and 4 mg/L of the nanoformulation showed that there was a significant difference between the concentration in terms of effectiveness over time and the type of pest age; there was no significant difference at 7 days after treatment (for overwintered adults), but there was a significant difference at 30 and 45 days after treatment (for the fourth instar nymph and the new generation adult insect, respectively) **(Table 1)**.

Table 1. Comparison of mean percentage mortality of nanocarrier, deltamethrin nanoformulation, and commercial EC at two concentrations of 1 and 4 mg active ingredient/liter, at different days after spraying: 7 days (overwintered adults), 30 days (fourth instar nymph), and 45 days (new generation adult) in vitro; Tukey grouping for the cut-off interaction effect of factor A on factor B.

Factor A	**Factor B**		
	7 days (overwintered adults)	**30 days (fourth instar nymph)**	**45 days (new generation adult)**
Water	0^{b}	0^{d}	0^{d}
Nanocarrier (1 mg a.i./L)	36.66 ± 5.7^{a}	32 ± 1.7^{c}	29.16 ± 7.2^{c}
Nanocarrier (4 mg a.i./L)	36.66 ± 5.7^{a}	35.33 ± 4^{c}	33.33 ± 7.2^{c}
Deltamethrin nanoformulation (1 mg a.i./L)	40 ± 0.0^{a}	53.3 ± 12.3^{b}	56.66 ± 5.7^{b}
Deltamethrin nanoformulation (4 mg a.i./L)	50 ± 10^{a}	81 ± 3.4^{a}	73.33 ± 5.7^{a}
EC2.5% (1 mg a.i./L)	40 ± 0.0^{a}	33 ± 0.0^{c}	13.16 ± 1.6^{d}

Comparison between rows (Factor A)- The same letters in each column are not significant statistically (HSD 5%)

The study of the effect of persistence or the required durability of the active ingredient in different treatments shows that the EC formulation did not maintain its insecticidal effect in laboratory conditions; so that at 45 days after treatment, its mortality percentage decreased to 13.16%. While the nanoformulation at both concentrations (1 and 4 mg/L) for 30 and 45 days after treatment, it still had high efficacy (56.6 and 73.3%, respectively) and was in a statistical group with lethality at 7 days after treatment (except for the concentration of 4 mg/L in the 7-day period, which was less lethal, and with the passage of time and greater release of the toxin, the lethality rating of the nanoformulation at that concentration increased). These cases indicated a longer duration of efficacy of the nanoformulation in laboratory conditions compared to the commercial EC pesticide **(Table 2)**. Evaluation of maternal and nymph mortality in greenhouse conditions showed that the percentage of efficacy of the nanoformulation and the commercial EC pesticide did not differ significantly at 7 and 45 days after spraying.

Table 2. Comparison of the average percentage of losses of nanocarriers, nanoformulations of deltamethrin and commercial EC at two concentrations of 1 and 4 mg active ingredient per liter on different days after spraying 7 days (overwintering adults), 30 days (fourth instar pupae), and 45 days (new generation adults) in laboratory conditions; Tukey grouping for the cut-off interaction effect of factor A on factor B.

Factor A	**Factor B**		
	7 days (overwintered adults)	**30 days (fourth instar nymph)**	**45 days (new generation adult)**

Water	0^a	0^a	0^a
Nanocarrier (1 mg a.i./L)	36.66 ± 5.7^a	32 ± 1.7^a	29.16 ± 7.2^a
Nanocarrier (4 mg a.i./L)	36.66 ± 5.7^a	35.33 ± 4^a	33.33 ± 7.2^a
Deltamethrin nanoformulation (1 mg a.i./L)	40 ± 0.0^a	53.3 ± 12.3^a	56.66 ± 5.7^a
Deltamethrin nanoformulation (4 mg a.i./L)	50 ± 10^b	81 ± 3.4^a	73.33 ± 5.7^a
EC2.5% (1 mg a.i./L)	40 ± 0.0^a	33 ± 0.0^b	13.16 ± 1.6^c

Comparison between columns (Factor B) - The same letters in each row are not significant statistically (HSD 5%)

In the results of the tillering stage, the nanoformulation had a high percentage of efficacy against the overwintered adult stage at all concentrations, similar to the commercial EC pesticide. However, in the 45 days after spraying (in the nymph stage), the efficacy was a maximum of up to 40%, and statistical association was observed between the nanoformulation and EC treatments; with the difference that the nanoformulation is based on water and safe compounds, and the EC formulation is based on organic solvents.

The results of the mean comparison with the interaction cut in laboratory conditions indicate that different levels of factor B (different ages of wheat in the periods after spraying) in different levels of factor A (different toxins with control) have significant differences **(Table 1)**. Also, different levels of factor A (different toxins with control) in different levels of factor B (different ages of wheat in the periods after spraying), except for the deltamethrin nanoformulation treatment (concentration 4 mg a.i./L) and the commercial formulation, did not have significant differences **(Table 2)**. This means that although the formulations and pesticide treatments have significant differences from each other in terms of their effects on pest losses **(Table 1)**, only the two mentioned treatments have caused a significant effect on the formulations over time and with changes in the ages and life cycle of the pest (despite one spraying stage), and the rest of the treatments were placed in a statistical group for this comparison.

On the other hand, the results of the mean comparison and truncation of the interaction effect of factor A levels at each factor B level showed that after removing the significant interaction effect from the comparisons, there was no significant difference between the pesticide treatments and the formulation in the period of 7 days after spraying and the adult age of overwintered, except in comparison with the control treatment, and all treatments were in the same statistical group in terms of mortality index; however, with time up to 45 days and the difference in the type of pest and the use of fourth-generation nymphs (similar to the period of wheat age loss in the field), a statistically significant difference was created between the pesticide treatments and the formulation used **(Tables 1 and 2)**. In such a way that the deltamethrin nanoformulation (concentration of 4 mg a.i./L) with higher lethality at 7 days after spraying and lower mortality rate at 30 days after spraying had the highest statistical rank in terms of lethality, and after that the deltamethrin nanoformulation treatment (concentration of 1 mg a.i./L) was placed in a separate statistical group, then both concentrations of the blank nanoformulation were placed in a statistical group, and finally the control treatment and the commercial formulation were placed in the group with the lowest lethality. This could indicate the ability of the silica nanoformulation for a longer time.

The results of greenhouse and spraying studies on wheat plants exposed to overwintered adult insects at 7 days after spraying, after trimming the interaction effect of factor A in factor B **(Table 3)**, showed that all three concentration treatments of deltamethrin nanoformulation and commercial formulation (except for the concentration of 10 mg a.i./L) were in the same statistical group. However, with time at 45 days after spraying and exposure of the plants to fourth instar nymphs, treatments with the maximum concentration of nanoformulation and commercial formulation were in the same statistical group with the highest lethality rating (40%) but lower concentrations caused less mortality.

Table 3. Percentage of efficacy of nanocarrier, deltamethrin nanoformulation, and EC formulation at different concentrations on wheat plants with a single spraying at tillering stage and evaluation at 7 and 45 days after spraying on overwintered adults and fourth instar nymphs, respectively, under greenhouse conditions; along with the slicing of the interaction effect of factor A on factor B.

Factor A	**Factor B**		
	Concentration (mg a.i./L)	**7-DAT (Overwintered adults)**	**45-DAT (4th instar nymphs)**
Water	0	0 a	0 a
Nanocarrier	10	23 ± 3.6 a	0 b
	25	30.02 ± 6.4 a	13.33 ± 5.7 b
	125	64.12 ± 6 a	13.33 ± 5.7 b
Deltamethrin nanoformulation	10	96.78 ± 5.57 a	13.33 ± 5.7 b
	25	96.78 ± 5.57 a	20 ± 0.0 b
	125	100 a	40 ± 0.0 b
Deltamethrin EC2.5%	10	87.12 ± 5.57 a	20 ± 10 b
	25	100 a	20 ± 10 b
	125	100 a	40 ± 0.0 b

Comparison between rows (Factor A) - The same letters in each column are not significant statistically (HSD %5)

The results of trimming the interaction effect of factor B in factor A **(Table 4)** showed that there was a significant difference between all treatments except the control in causing mortality on different pest ages and in the time intervals of 7 and 45 days after spraying **(Table 4).** At this point, it should be noted that it might have been better to release the insecticide on the plants at shorter intervals, but due to the seasonal conditions prevailing at the experimental site, weather changes, and the inability to collect insects, this was not possible in this study. If such an approach had been achieved, a better interpretation could have been obtained for the trend of changes in statistical groupings and the change in mortality. For example, removing the significant interaction effect from the comparisons would have led to a better display of the effectiveness of each treatment and formulation in maintaining the effectiveness of the insecticide; in this way, the control treatments of nanocarrier and deltamethrin nanoformulation (concentration 1mg a.i./L) were all in the same statistical group and did not change in causing pest mortality in proportion to the passage of time and different types and ages. However, the deltamethrin nanoformulation (concentration 4mg a.i./L) and the commercial formulation had a significant change.

Table 4. Percentage of the efficacy of nanocarrier, nanoformulation of deltamethrin, and EC formulation at different concentrations on wheat plants with one spraying at tillering stage and evaluation at 7 and 45 days after spraying on overwintered adults and fourth instar nymphs, respectively, under greenhouse conditions; along with the interaction effect of factor B on factor A.

Factor A	**Factor B**		
	Concentration (mg a.i./L)	**7-DAT (Overwintered adults)**	**45-DAT (4th instar nymphs)**
Water	0	0^{a}	0^{a}
Nanocarrier	10	23 ± 3.6^{a}	0^{b}
	25	30.02 ± 6.4^{a}	13.33 ± 5.7^{b}
	125	64.12 ± 6^{a}	13.33 ± 5.7^{b}
Deltamethrin nanoformulation	10	96.78 ± 5.57^{a}	13.33 ± 5.7^{b}
	25	96.78 ± 5.57^{a}	20 ± 0.0^{b}
	125	100^{a}	40 ± 0.0^{b}
Deltamethrin EC2.5%	10	87.12 ± 5.57^{a}	20 ± 10^{b}
	25	100^{a}	20 ± 10^{b}
	125	100^{a}	40 ± 0.0^{b}

Comparison between columns (Factor B) - The same letters in each row are not significant statistically (HSD 5%)

The trend of change in causing mortality was different for these two treatments; in a way, the efficiency of the commercial formulation in causing losses had a tangible decrease, but the controlled release of the silica formulation led to a relative increase in the effectiveness of the poison over time. The results of the evaluation of the number of egg layings performed in different treatment conditions showed that despite the ability of the nanocarrier to reduce the number of egg layings, this reduction was not to the extent that Betuland had a significantly different rank from the control conditions in this experiment **(Table 5)**. It was also observed that the deltamethrin nanoformulation had a suitable efficiency in terms of controlling the egg-laying of the wheat midge pest, in such a way that it was able to be statistically in the same group as the commercial poison (except in its high concentrations, which cause accelerated development, growth arrest, and plant burning).

Table 5. Tukey's mean comparison test for the number of oviposition of *Eurygaster integriceps* in different treatments.

Treatment	Concentration (mg a.i./L)	Total number of eggs
Water	0	197.67 ± 32.1[a]
Nanocarrier	10	160.67 ± 18.2[a]
	25	143 ± 24.1[ab]
	125	129.67 ± 27.1[abc]
Deltamethrin Nanoformulation	10	72.66 ± 8.51[bc]
	25	67 ± 5.56[c]
	125	64.00 ± 4.93[c]
EC2.5%	10	69.00 ± 7.54[bc]
	25	68.66 ± 7.85[bc]
	125	12.00 ± 2.00[d]

The same letters are not significant statistically (HSD 5%)

Due to the involvement of various factors, the results of the percentage of wheat and sorghum losses at the laboratory and greenhouse levels may not be similar, and some good laboratory results may be discarded due to greenhouse results. The results of laboratory bioassay on mother sorghum showed that the nanoformulation had similar efficacy to commercial EC. Although in the later stages of bioassay in laboratory conditions, the insecticidal efficacy of the tested nanoformulation presented better results in terms of persistence and efficacy, in greenhouse conditions, statistical similarity with the commercial poison was still evident. Many studies have shown a reduction in the environmental harm of the active ingredient after being placed in nanoformulation compared to commercial formulations. Today, types of nanoformulations have been developed, including nanosuspension [15], nanoemulsion [16], and nanocapsules [17]. One of the reasons for the low percentage of efficacy in the early days of spraying in laboratory and greenhouse conditions could be due to the slow release of deltamethrin in nanoformulations [18]. The use of nanoformulation protects the active ingredient from temperature and sunlight. It has been reported that silica compounds can protect abamectin. Nanosilica, by absorbing or scratching the cuticle of the insect body, causes the insect to lose its body water quickly and die [18]. Of course, the effectiveness of these materials will be higher in hot and dry conditions. Encapsulating the active ingredient of pesticides can reduce the amount of pesticide consumption and, as a result, reduce environmental concerns and the presence of pesticide residues in plant products. For example, toxicity testing at the cellular and genetic levels showed that encapsulated herbicides were less toxic than free compounds [19-21].

Nanoformulations can be most effective under optimal conditions, and this will be when they act intelligently and release the required amount when the pest is stimulated. Nanoformulations have a high coverage of spraying due to the small size of the particles and their dispersibility and solubility. The dynamic effect of pesticides and nanoparticles can affect the physiology, morphology, and antioxidant system of the plant. There is an antagonistic interaction between silver nanoparticles and diclofenac, and the presence of silver reduces the effectiveness of the general herbicide diclofenac [18].

One of the goals of nanoformulations is to increase efficiency by reducing the volume of the solution used. The use of nanocarriers increases the contact surface and dispersibility. According to research conducted in conventional foliar spraying, only 0.1% of the pesticide reaches the target and 99.9% of the solution used enters the environment; this inefficiency of the spraying system can cause water and environmental pollution, pest and disease resistance, and reduced species diversity due to the elimination of some soil biological species [22, 23].

Based on the results obtained, during greenhouse experiments and 7 days after spraying, similar losses were caused for treatments 10 and 25, which can be analyzed in several ways. First, the response of the nanocarrier to the persistence of the pesticide at different concentrations and its release over time may not be linear. Second, in expressing the number of losses, since it was determined in the assessments that lethargy cases progressed to death, the sum of the values related to death and lethargy was calculated. Also, over time, 45 days after spraying, there is a greater difference (although there is still a group) between the concentrations of 10 and 25 in the loss values.

On the other hand, one of the reasons for the low efficiency of nanoformulation and commercial formulation in greenhouse conditions 45 days after spraying could be due to the 10-fold increase in the area of wheat vegetation at the tillering stage compared to tillering [24]. Therefore, the stems, panicles, and higher leaves, which constitute the most active sites of the nymph and the new generation, are less exposed to spraying and are not contaminated with the toxin. This issue can justify the reduction in losses 45 days after treatment in greenhouse conditions. Another important point is the creation of losses of nano-carrier silica, which has been able to have good results, especially in the first stage (7 days after treatment). This issue has also been considered in recent studies and the usefulness of nanosilica in this regard has been indicated [25]. In this study, two approaches were proposed for how silica-based nanopesticides are useful, including the following: First, the use of these particles themselves (via physiological adsorption into cuticular lipids) as nanopesticides to kill insects and larvae [26-29] which could be a good explanation for the similar pesticidal effect observed with nanocarriers and commercial EC in this experiment. Second, nano silica formulations are designed to enhance the absorption and slow release of natural and hydrophobic active ingredients, which are economically viable and biocompatible. The use of silica-based nanocompounds reduces the release by 25-75% and reduces the leaching rate from the soil surface by 15%. These nanoemulsions caused extraordinary mortality rates in cabbage moth larvae even after 14 days [30-33].

CONCLUSION

In this study, a 2.5% deltamethrin nanoformulation was prepared and its size, shape, and active ingredient content were confirmed using SEM, AFM, DLS, and TGA methods. Then, this nanoformulation was compared with a commercial pesticide for controlling wheat in the stages of wintering adults, fourth-instar nymphs, and a new generation. Treatments included deltamethrin nanoformulation, nanocarrier, deltamethrin EC 2.5%, and water as a control. The results of this study show that the study of developing renewable silica nanostructures based on silica-accumulating plants can be very important and fruitful in providing effective formulations for the release of chemical and phytotoxicants for wheat senescence control. In summary, in this study, a water-based deltamethrin nanoformulation was prepared that can maintain its insecticidal effect to an acceptable level for 45 days and, given the biocompatibility of the nano-silica used, it can be a new horizon for the delivery of effective substances in the field of pest control. Considering the persistence effect of the nanoformulation, it is suggested that a comparison with the commercial EC formulation be investigated on the purslane stage of wheat senescence when the vegetation cover in wheat is complete; in terms of wheat early maturity efficiency and yield.

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