Enhanced the activity of insecticides of Mospilan and Sivanto by Zinc Oxide Nanoparticles to control *Phenacoccus solenopsis* (Hemiptera: Pseudococcidae)

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Abstract

The mealybug, *Phenacoccus solenopsis* is one of the extreme agricultural pests. In this study a series of field and laboratory experiments were conducted to evaluate the efficacy of zinc oxide nanoparticles and chemical pesticides Mospilan, Sivanto and Ovitex oil and their combinations against adults of *Phenacoccus solenopsis*, cotton mealybug. Laboratory study results showed that the corrected percentage of adult mortality of *P. solenopsis* when using zinc oxide nanoparticles (ZnO-NPs) at concentrations of 25, 50 and 75 ppm was 34, 40 and 48%. The results also confirmed that loading ZnO-NPs at 25, 50 and 75 ppm with Mospilan at the recommended concentration (0.5g/L) caused 50, 62 and 75% mortality, respectively. The use of ZnO-NPs at 25, 50, and 75ppm with Sivanto at the recommended concentration (1ml/L) affected the adults by 54, 67.5, and 73.3%, respectively, after 72 hours of treatment. The results of field evaluation of control treatments ZnO-NPs, Mospilan, Sivanto, ZnO -Mospilan, ZnO - Sivanto, Ovitex, Ovitex + Sivanto, Ovitex + Mospilan, in the spring season 2023 showed that decrease on the numerical density of adults the mealybug, *Phenacoccus solenopsis* in the field of okra. Tthe average number density of adults reached 1.733, 1.686, 1.752, 1.200, 1.543, 1.633, 1.576, 1.471 adult / leaf, respectively. These results suggest that applying ZnO-NPs, ZnO - ZnO -Mospilan and ZnO – Sivanto can be used as an eco-friendly controlling strategy for *P. solenopsis*.

Keywords: mealybug, okra, Zinc Oxide Nanoparticles, Mospilan, Sivanto

Introduction

The mealybug, *Phenacoccus solenopsis* (Tinsley), is one of the most invasive and widespread mealybug species in the world. It causes significant economic losses on vegetable crops, ornamental plants, and many agricultural crops. This pest has biologically and ecologically adapted to tolerate a wide range of temperature and relative humidity, these features allowed it to infect more than 219 plant species belonging to more than 50 different plant families (1; and 2), At the same time, Fand and Suroshe (3) indicated that it infects 202 plant species belonging to 55 families, the mealybug cause yellowing and defoliation, which leads to reduced plant growth and, in some cases, plant death (4). This insect can be found in the roots, which form scales that limit the absorption of water and nutrients, resulting in the plant's dehydration (5). Mealybugs prefer to feed on nitrogen-rich succulent tissues, and more nitrogen contents in host plants have resulted in increased survival, longevity, and fertility (6). Therefore, excessive fertilization and watering can lead to problems with these pests (7). Chemical pesticides were used to control the mealybug, *P. solenopsis* to increasing cultivar productivity (8). In the past two decades, attention has gone to the use of nanoparticles to control insect pests, as the production of nanocomposites increased in the form of commercial preparations such as nano-zinc oxide, nano-silica oxide, nano-aluminum oxide, and others, as they have a different physiological effect on insects, The nanoparticles penetrate the exoskeleton of the insect, and the nanoparticles bind to the sulfur present in the protein or phosphorous present in the DNA inside the cells, which leads to cellular dysfunction and cell death or compounds toxic or repellent substances or cause a decrease in female fecundity (9), thus becoming an effective alternative to chemical insecticides as they are environmentally-friendly insecticides compared to industrial insecticides (10). In a test conducted to estimate the effectiveness of zinc oxide nanoparticles compared with malathion pesticide in controlling the insect *T. castaneum*, the results indicated the high ability of the nanomaterial in the percentage of weight loss, killing, and low offspring of the insect (11). A study by Das et al. (12) to evaluate the efficiency of zinc nanoparticles on adult *Sitophilus oryzae* insects under laboratory conditions revealed that the mortality rate was 90% after 14 days of treatment.The objectives of this study are devoted to investigating the efficacy ofMospilan, Sivanto**,** oil and zinc nanoparticles and their combinations against *P. solenopsis*.

Material and method

1 - Preparation of ZnO-NPs solution

Zinc oxide nano powdered (0.1 g) was dissolved in 3 ml of 10% hydrochloric acid and put the mixture on a magnetic stirrer for 45 minutes at 60 ° C to dissolve, then complete the solution to 1 liter by adding distilled water and placing the mixture on the magnetic mixer for another 30 minutes for homogeneity (13). The concentration of the prepared solution is 100 ppm, from which the concentrations were prepared as 25, 50 and75ppm

2 - Preparation of ZnO-NPs loaded on the Mospilan or the Sivanto

Zinc oxide nanoparticles were loaded on the pesticide by preparing 1 liter of zinc oxide nanoparticles solution at 75 ppm was prepared 1 liter. Mospilan 0.5 g / liter Mospilan was added to the solution of ZnO-NPs at 75 ppm prepare the nanocomposite ZnO-NPs loaded Mospilan. As for the pesticide Sivanto, 1 ml/liter was added to the solution of ZnO-NPs, and then the mixture was placed in a magnetic stirrer for 30 minutes at a temperature of 27 °C, leaving the solution in the laboratory for one hour at a temperature of 27°C, then the solution was placed in a water bath for one hour at a temperature of 50°C, and the same operations were carried out for 25,50 ppm concentrations(14).

3 - Testing the effect of ZnO-NPs on the adults of *P. solenopsis* in the Laboratory

Uninfected okra leaf was collected from the field. Then, the mealybug adults were transferred from the infected okra leaves by a small and soft brush. A circular filter paper of the same diameter as the plate(9cm) was placed, and then uninfected okra leaves were placed., Ten individual mealybug adults were transferred over the paper, the petri dish was closed (Figure 1) and they were transferred to the incubator at a temperature of 2 ± 26 °C and a relative humidity of 5 ± 65%. Five replications were used for each concentration were done by spraying zinc oxide nanoparticles at concentrations (25, 50, 75ppm), a volume of 1 ml by using a manual sprayer (15). As for the comparison treatment, it included two controls, the first spraying adults with distilled water only, and the second spraying with distilled water mixed with 3 ml / liter of 10% hydrochloric acid (HCL). Then the readings of mortality rates were taken after 24, 48 and 72 hours of treatment.

4 - Testing the effect of loading ZnO-NPs on Mospilan and Sivanto on the adults of *P. solenopsis* in the Laboratory

The treatment was carried out by spraying zinc oxide nanoparticles at concentrations of 25, 50 and 75 ppm loaded on Mospilan at the recommended concentration in a volume of 1 ml by using a manual sprayer. As for the comparison treatment, it included three treatments, the first: treatment of adults with the pesticide, the second: spraying with distilled water only, and the third: spraying with distilled water mixed with 3 ml / liter of 10% hydrochloric acid. The dishes were placed in the incubator at a 2 ± 26 °C and a relative humidity of 5 ± 65%. Then the readings were taken after 24, 48 and 72 hours of treatment, respectively. A second experiment was conducted by loading zinc oxide nanoparticles with Sivanto pesticide under the same laboratory conditions.

5 - Efficiency study of Mospilan, Sivanto, oil and zinc nanoparticles and their combinations on *P. solenopsis* in the field

A piece of land ($90m^2$) was selected in the village of Abu Shareesh in Al-Muthanna Governorate, prepared for cultivation by conducting all necessary agricultural operations Figure (2). It was divided into three replicates, and was divided into 10 experimental units. Each experimental unit contained 8 okra plants. Okra seeds were sown with a local Hasnawi variety on 3/21/2023. The distance between one seedling and another was 15 cm, the distance between an experimental unit and another was 40 cm. The experiment was conducted according to the randomized complete block design as a factorial experiment with three replications of RCBD. The treatments included (Mospilan, Sivanto, ZnO-NPs, ZnO Mospilan, ZnO -Sivanto, Control is water only, Oil Crop, Mospilan + oil, Sivant+ oil + and- Control Water + HCl 3ml). The insect was transferred from the infected fields of Al-Younis orchards in the Al-Muthanna governorate to the field on date 25/5/2023. The infection was carried out manually by transferring an infected plant from the okra plant infected with the cotton mealybug insect to a healthy okra plant, a dorsal sprinkler was used to carry out the spraying process for the treatments with a capacity of 16 liters. Samples were taken from the okra plant. Three leaves of each plant were taken in three levels: upper, middle, and lower. They were placed in polyethene bags, and then the numbers of adults were counted. The sampling process continued one day before the treatment, and after (1, 3, 5, 7, 10, 14) days. The coefficients were evaluated according to the Henderson and Tilton equation (16).

Statistical analysis

The laboratory experiments were analyzed according to Completely Randomized Design by applying the Prism version 7 program, insect mortality was corrected according to Abbott's formula. In contrast, the results of field experiments were analyzed according to the complete randomized block design (RCBD) and at a probability level 0.05 by using the GenStat 12 program.

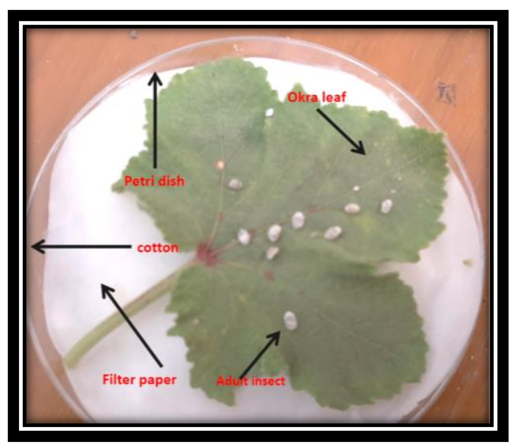

Figure 1. A petri dish containing 10 adults of *P. solenopsis*, prepared for an experiment laboratory

Figure 2. The field is planted with a local variety (Hasnawi) of okra

Results and Discussion

1 - Scanning Electron Microscope (SEM) of ZnO – Mospilan and ZnO-Sivanto

Microscopic examination images to determine the average diameter of zinc oxide nanoparticles loaded on Mospilan (Figure 3) and zinc oxide loaded on Sivanto (Figure 4) were 30.4 and 42.2 nm,respectively.

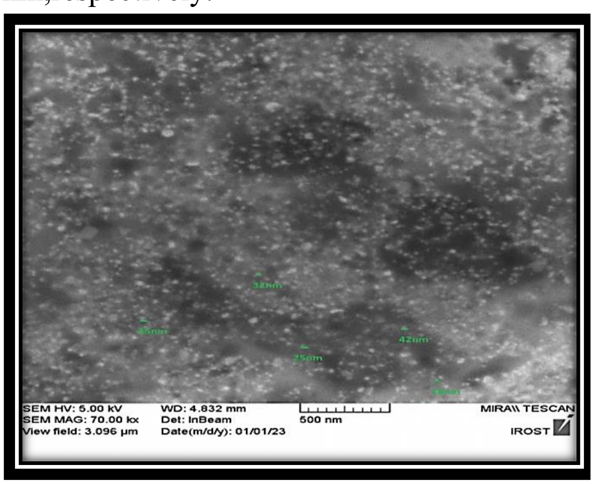

Figure 3. Microscope electron picture shows the diameter of zinc oxide nanoparticles loaded on Mospilan

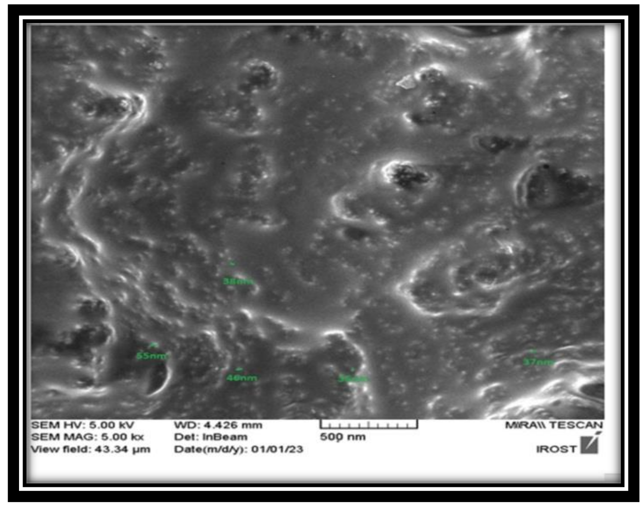

Figure 4. A scanning electron microscope shows the diameter of zinc oxide nanoparticles loaded on Sivanto

2 - Effect of Zinc Oxide Nanoparticles on the adult of *P. solenopsis* in the Laboratory

The results of current study indicated that the effect of different concentrations of zinc oxide nanoparticles and exposure time the adult mortality of *P. solenopsis*. (Figure 5). The results showed that the highest percentage of mortality reached 48% at 75ppm. As for the effect of the time after 72 hours the mortality percentages were 34, 40 and 48 % at concentrations of 25, 50 and 75 ppm, respectively. The results show that there are significant differences ($x2$ = 42.99, $P<0.0001$) between the treatments of different concentrations of ZnO- NPs and the two control treatments, Ctr1and Ctr2, where the mortality percentage was 9.3 and 9.5%, respectively. At the same there was no significant difference between control Ctr1 and Ctr2. The effectiveness of zinc oxide nanoparticles is attributed to causing damage to the insect body wall (17). Its toxicity can also be attributed to the penetration of the body wall (18), and then binds to sulfur in proteins or to phosphorus in DNA, destroying organelles and enzymes, the cell loses its function and death occurs (19). Nanoparticles are more acceptable because they are safe on the plant and less are safe on the plant and less pollute the environment than conventional chemical pesticides (20, and 21). Moreover, applying, the application of nanoparticles to leaves and stems does not affect the processes of photosynthesis and respiration in many plants (22, and 23).

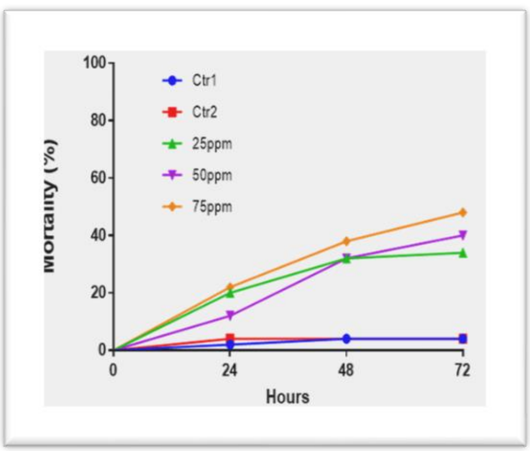

Figure 5. Effect of zinc oxide nanoparticles on the adults of *P. solenopsis*, Ctr1 = adult sprayed by water, Ctr2 = adult sprayed by water+Hcl 10%

3 - Effect of different concentrations of Zinc Oxide Nanoparticles loaded on Mospialn at the recommended concentration on the adult of *P. solenopsis* in the Laboratory

The results of this study (Figure 6) shows the effect of different concentrations of zinc oxide nanoparticles loaded on Mospilan pesticide at the recommended concentration and the effect of exposure time on the corrected percentage of mortality of adults of *P. solenopsis*. The mortality percentages reached 50, 62, and 75% at 25, 50, and 75 ppm respectively at 72 hours. The results show that there are significant differences ($x2 = 75.11$, $P<0.0001$) between the treatments of different concentrations of zinc oxide nanoparticles loaded on Mospilan at the recommended concentration and the control treatments Ctr1 and Ctr2, where the percentage of mortality was 9.3 and 9.5%, respectively, while there was no significant difference between the control treatments Ctr1 and Ctr2. The use of Mospilan pesticide alone at the recommended concentration gave a mortality percentage of 44%. Also, the results showed that the treatment of zinc oxide nanoparticles loaded on the Mospilan pesticide recorded the highest mortality percentage of adults, which was 75%, and these results were due to the interaction between the pesticide and the nanoparticles. It is worth noting that adding zinc oxide nanoparticles with the pesticide Mospilan gave a positive synergistic effect. Mospilan contains the active substance Acetamiprid, which works to stimulate the acetylcholine receptors present in the nervous system, specifically in the synapse area between the nerve cells responsible for transmitting nerve impulses, which affects the behavior of the insect and increases its activity through hyperactivity and repetition of the nerve impulse, which leads to its death (24).

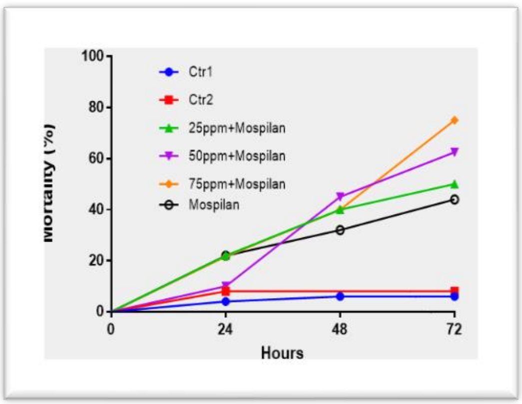

Figure 6. Effect of zinc oxide nanoparticles loaded on Mospilan on the adults of *P. solenopsis*, Ctr1 = adult sprayed by water, Ctr2 = adult sprayed by water+Hcl 10%

4 - Effect of testing of zinc oxide nanoparticles loaded on the Sivanto pesticide on the adult of *P. solenopsis* in the Laboratory

The results of this study (Figure 7) shows the effect of different concentrations of zinc oxide nanoparticles loaded on the Sivanto pesticide at the recommended concentration and the effect of the exposure time on the corrected percentages for the mortality of adults of *P. solenopsis*. The results showed the highest mortality pesticide Sivanto. As for the time, the period of 72 hours was significantly superior to the rest of the periods, as the mortality percentage reached 54, 67.5, and 73.3% at concentrations of 75, 50, and 25 ppm, respectively. The results show that there are significant differences ($x2 = 78.36$, $P<0.0001$) between the treatments of different concentrations of zinc oxide nanoparticles loaded on Sivanto at the recommended concentration and the two control treatments ctr1 and ctr2, where the percentage of mortality was 9.3 and 9.5%, respectively. At the same time, there was no significant difference between the control treatments Ctr1 and Ctr2. Also, using the Sivanto pesticide alone at the recommended concentration gave the percentage of mortality was 39%. Sivanto can interact with nicotinic acetylcholine receptors located in the central nervous system of insects, thus preventing its binding to acetylcholine, which leads to complete paralysis and then death of insects (25). A study conducted by Vafaie (26) showed the effectiveness of Sivanto pesticide in controlling *P. solenopsis*, as the percentage of reducing the density of nymphs and adults reached 61.23% and 68.64%, respectively, after 14 days of treatment on ornamental plants under plastic house conditions.

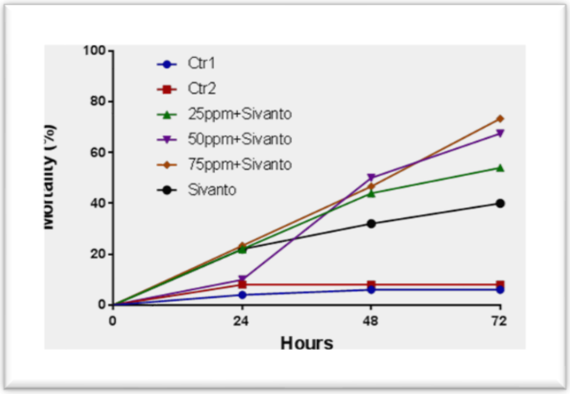

Figure 7. Effect of zinc oxide nanoparticles loaded on the Sivanto on the adults of *P. solenopsis*, Ctr1 = adult sprayed by water, Ctr2 = adult sprayed by water+Hcl 10%

5 - Evaluation of the effectiveness of Mospilan, Sivanto, ZnO-NPs and Ovitex oil and their combinations on the density of adults of *P. solenopsis* in the field

The results of this study show in Table (1) revealed that the effect of Mospilan, Sivanto, ZnO-NPs, Ovitex83 oil and the blend of them on the numerical density of adults of *P. solenopsis* in the field of okra, as the Mospilan pesticide treatment loaded on ZnO-NPs was highly effective in reducing numerical density of adults was 1.200 adult/leaf. the results of the statistical analysis indicate that there is a significant difference among ZnO- Mospilan, ZnO-NPs and Mospilan treatments, which recorded 1.733 and 1.686 adult / leaf for ZnO-NPs and Mospilan treatments, respectively. As for the treatment of Sivanto pesticide loaded with ZnO-NPs, the numerical density of adults was 1.543 adult/leaf, and it did not differ statistically significantly from the treatment of the chemical pesticide the Sivanto, which was 1.752 adult/leaf. The results also showed that the Ovitex oil treatment achieved a reduction in the density of the insect reached to 1.633 adult/leaf. The most efficient treatment in reducing the insect density was the pesticide and oil treatment, as the Ovitex + Mospilan treatment recorded a numerical density of adults was 1.471 adult / leaf. The Ovitex + Sivanto treatment recorded 1.576 adult/leaf. All treatments are significantly different from the control treatments (1,2). As for the days, the lowest rate for adults was the 7th day after treatment, and the average number of adults was 1.653 adults/leaf. In contrast, the highest rate of days for adults was the 1st day after treatment, which was 2.939 adults / paper. There were significant differences in the rate. The numerical density between the days in which the readings were taken except for days 5 and 7; there were no significant differences between them.

Regarding the interference, the lowest number of adults of *P. solenopsis* was recorded in the interaction treatments of ZnO-NPs + Mospilan for days 7, 10 and 14, and Ovitex + Mospilan treatment on day 7, as it reached 0.00 adult /leaf. It is worth noting that all treatments recorded a significant decrease in the numerical density of *P. solenopsis* adults compared to the control treatment (Control 1, 2). In Control 1, okra plants are sprayed with water only, and in Control 2, okra plants are sprayed with water + HCI.

Table 1. The effect of Mospilan, Sivanto, ZnO-NPs, Ovitex oil and their combinations on the numerical density of *P. solenopsis* adults in the field

Numerical density of adult of *P. solenopsis* (adult/leaf)								
Treatment	Before Treatment	Day 1	Day 3	Day 5	Day 7	Day 10	Day 14	Average
ZnO-NPs	5.100	2.633	1.500	0.633	0.267	0.633	1.367	1.733
Mospilan	5.100	2.900	1.567	0.533	0.167	0.433	1.100	1.686
Sivanto	5.100	2.800	1.600	0.633	0.200	0.567	1.367	1.752
ZnO-Mospilan	5.100	2.200	0.900	0.200	0.000	0.000	0.000	1.200
ZnO-Sivanto	5.100	2.500	1.267	0.467	0.133	0.367	0.967	1.543
Ovitex	5.100	2.533	1.367	0.500	0.167	0.433	1.333	1.633
Ovitex+ Sivanto	5.100	2.833	1.433	0.400	0.067	0.267	0.933	1.576
Ovitex+ Mospilan	5.100	2.767	1.333	0.300	0.000	0.100	0.700	1.471
Control 1	5.100	4.600	5.733	6.933	8.100	9.067	10.433	7.138
Control 2	5.100	3.633	4.800	6.133	7.433	8.733	10.467	6.614
Average	5.100	2.939	2.15	1.673	1.653	2.06	2.866	
L.S.D	Time=0.1977		Treatment=0.2363			Interaction= 0.6252		

The basic measure to control the cotton mealybug is the use of effective insecticides to eliminate the adults because they have the ability to live for a relatively long time and have a very high reproductive capacity (27). The pesticides used in this study proved their ability to reduce the numerical density of the adults of *P. solenopsis* insect. The Sivanto insecticide can to interact with the Nicotinic acetylcholine receptor present in the central nervous system of insects and thus prevents its binding.

Acetylcholine, which leads to complete paralysis and then death of insects (25).As for Mospilan, it acts on the central nervous system of insects, causing paralysis and death of insects (28).Shah et al. (29) indicated that the pesticide Mospilan kills effect on *P. solenopsis*, where the mortality percentage was 56.68% after three days of treatment on cotton plants in the field. We note from the results that the zinc oxide nanoparticles affected the nymphs and adults of the cotton mealy bug, and the reason may be attributed to the fact that the nanoparticles may enter the plant through the stomata or stick to the base of the hairs on the leaf trichomes (30). Uzu et al. (31) reported that plant cells take up nanoparticles and transport them to the xylem and bark of the plant. Thus, it can be concluded that the nanomaterials act as a contact and systemic insecticide. Also, the treating of the insecticide loaded with ZnO-NPs was more efficient in reducing the numerical density than Mospilan and Sivanto alone or ZnO-NPs alone due to the synergistic effect of the two materials together. In this field, Al-Tamimi (32) mentioned improving the performance and effectiveness of pesticides by loading the pesticide with nanomaterials, where he loaded nano silver oxide on Oxymatrine pesticide to study their effect together at times and alone at other times on *Aphis gossypii*, where it recorded a percentage of mortality was 87%. In comparison, the treatment of oxymatrine alone recorded the percentage of mortality was 79%. The treatment of nanosilver oxide alone recorded a percentage of mortality was 52% after 7 days of treatment on field cucumber crop. Also, the summer oil increased the efficiency of the Mospilan and Sivanto pesticides. In this field, Sequeira et al. (33) mentioned that the summer oil increased the effectiveness of the spirotetramat pesticide by 5% against the adults of the cotton mealybug *P. solenopsis*, as the efficiency of the pesticide Spirotetramat reached 80%, and the oil increased it by 85%.

Conclusion

The results of the current study, suggest that ZnO-NPs, Mospilan, Sivanto and Ovitex oil could cause high mortality in adults of *P. solenopsis*. Our finding suggest that ZnO- Mospilan and ZnO-Sivanto solutions applied may be more effective management approach to control *P. solenopsis* in the field.

Conflict of interest

The author has no conflict of interest.

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References

1- **Ben-Dov, Y.; D. R. Miller and A. P. Gibson. 2017.** Scale Net. Available at: http://www.scale.info/catalogue/ Phenococcus%20solenopsis/ (Accessed June 2017).).: http://dx.doi.org/10.26842/binhm.7.2018.15.1.0093

2- **Caliscan–Kece, A. F. 2019.** Life table parameters of cotton mealybug, *Phenacoccus solenopsis* Tinsley, 1898 (Hemiptera: *Pseudococcidae*) on four different plants. Turkish Journal of Entomology, 43 (3): 271-278. https://doi.org/10.16970/entoted.561324

3- **Fand, B. B. and S. S. Suroshe. 2015.** The invasive mealybug *Phenacoccus solenopsis* Tinsley, a threat to tropical and subtropical agricultural and horticultural production systems–a review. Crop Protection, 69: 34-43. https://doi.org/10.1016/j.cropro.2014.12.001

4- **Culik, M.P. and P.J. Gullan. 2005.** A new pest of tomato and other records of mealybugs (Hemiptera: Pseudococcidae) from Espírito Santo, Brazil. Zootaxa 964: 1–8. www.mapress.com/zootaxa/

5- **Saeed, S.; M. Ahmad; M. Ahmad and Y. J. Kwon. 2007.** Insecticidal control of the mealybug *Phenacoccus gossypiphilous* (Hemiptera: Pseudococcidae), a new pest of cotton in Pakistan. Entomological Research, 37(2): 76-80. https://doi.org/10.1111/j.1748-5967.2007.00047.x

6- **Rezk, M.; A. N. T. Hassan; M. F. El-Deeb; N. Shaarawy and Y. Dewer. 2019.** The impact of insecticides on the cotton mealybug, *Phenacoccus solenopsis* (Tinsley): efficacy on potato, a new record of host plant in Egypt. Journal of Plant Protection Research, 50-59: 10.24425/jppr.2019.126042

7- **Huang, J.; F. Shen; M. Li; Y. Yu and Y. Lv. 2012.** Spatial distribution of female adults of *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) on *Portulaca grandiflora*. Chinese Journal of Applied Entomology, 49(6): 1648-1651.

8- **AlAVO, T. B. 2015.** The insect pathogenic fungus *Verticillium lecanii* (Zimm.) Viegas and its use for pest's control: A review. Journal of Experimental Biology and Agricultural Sciences, 3(4): 337-345. http://dx.doi.org/10.18006/2015.3(4).337.345

9- **Owolade, O. and D. Ogunleti 2008.** Effects of titanium dioxide on the diseases, development and yield of edible cowpea. Journal of Plant Protection Research. 10.2478/v10045-008-0042-5

10- **Nasr, M. 2015.** Impact of nanoparticle zinc oxide and aluminum oxide against rice weevil *Sitophilus Oryzae* (Coleoptera: Curculionidae) under laboratory conditions. Egyptian Journal of Plant Protection Research, 3(3): 30-38.

11- **Abd-El-Salam; S. A.; A. M. Hamzah and N. M. El-Taweelah. 2015.** Aluminum and zinc oxides nanoparticles as a new method in controlling the red flour beetle, *Tribolium castaneum* (Herbest) compared to Malathion insecticide. International Journal of Scientific Research in Agricultural Sciences, 2(Proceedings), 001-006. 10.21608/jppp.2015.53186

12- **Das, S.; A. Yadav and N. Debnath. 2019.** Entomotoxic efficacy of aluminium oxide, titanium dioxide and zinc oxide nanoparticles against *Sitophilus oryzae* (L.): A comparative analysis. Journal of Stored Products Research, 83: 92-96. https://doi.org/10.1016/j.jspr.2019.06.003

13- **Rasim, H. S.; B. H. Mohsen and B. K. Al-Gburi. 2021.** Acaricidal Effects of Silicon Oxide and Zinc Oxide Nanoparticles against *Tetranychus urticae* (Acari: Tetranychidae) on Tomato Plants. Journal of Agricultural and Urban Entomology, 37(1): 60-71. https://doi.org/10.3954/JAUE21- 08

14- **Jameel, M. S.; O. A. Noqta; M. A. Dheyab; A. A. Aziz and B. Mehrdel. 2020**. Synthesis and coating methods of biocompatible iron oxide/gold nanoparticle and nanocomposite for biomedical applications. Chinese Journal of Physics, 64: 305-325. https://doi.org/10.1016/j.cjph.2019.11.014

15- **Ardalan, R. B.; N. Jamshidi; H. Arabameri; A. Joshaghani; M. Mehrinejad and P. Sharafi. 2017**. Enhancing the permeability and abrasion resistance of concrete using colloidal nano-SiO2 oxide and spraying nanosilicon practices. Construction and Building Materials, 146: 128-135. https://doi.org/10.1016/j.conbuildmat.2017.04.078

16- . **Henderson, C. F. and E. W. Tilton. 1955.** Tests with acaricides against the brown wheat mite. Journal of Economic Entomology, 48(2): 157-161.

17- **Abinaya, M.; B. Vaseeharan; M. Divya; M. Sharmili, A. Govindarajan; M. Alharbi and G. Benelli. 2018**. Bacterial exopolysaccharide (EPS)-coated ZnO nanoparticles showed high antibiofilm activity and larvicidal toxicity against malaria and Zika virus vectors. Journal of Trace Elements in Medicine and Biology, 45: 93-103. https://doi.org/10.1016/j.jtemb.2017.10.002

18- **Rai, M.; K. Kon; A. Ingle; N. Duran; S. Galdiero and M. Galdiero. 2014**. Broad-spectrum bioactivities of silver nanoparticles: the emerging trends and future prospects. Applied Microbiology and Biotechnology, 98: 1951-1961. https://doi.org/10.1007/s00253-013-5473-x

19- **Benelli, G. 2016.** Green synthesized nanoparticles in the fight against mosquito-borne diseases and cancer—a brief review. Enzyme and Microbial Technology, 95: 58-68. https://doi.org/10.1016/j.enzmictec.2016.08.022

20- **Ratrout, N. T. and S. M. Rahman. 2009.** A comparative analysis of currently used microscopic and macroscopic traffic simulation software. The Arabian Journal for Science and Engineering, 34(1B): 121-133.

21- **Mewis, K.; H. Ogura and Y. Otsubo. 2008.** Shear-thickening flow of nanoparticle suspensions flocculated by polymer bridging. Journal of Colloid and Interface Science, 321(2): 294-301. https://doi.org/10.1016/j.jcis.2008.02.022

22- **Singh, M. D. 2017.** Nano-fertilizers is a new way to increase nutrients use efficiency in crop production. International Journal of Agriculture Sciences, ISSN, 0975-3710.

23- **Zhao, L.; L. Lu; A. Wang; H. Zhang; M. Huang; H. Wu and R. Ji. 2020.** Nano-biotechnology in agriculture: use of nanomaterials to promote plant growth and stress tolerance. Journal of Agricultural and Food Chemistry, 68(7): 1935-1947. https://doi.org/10.1021/acs.jafc.9b06615.

24- **Pittarate, S.; J. Rajula; A. Rahman; P. Vivekanandhan; M. Thungrabeab; S. Mekchay and P. Krutmuang. 2021.** Insecticidal effect of zinc oxide nanoparticles against Spodoptera frugiperda under laboratory conditions. Insects, 12(11): 1017. https://doi.org/10.3390/insects12111017

25- **Nauen, R.; P. Jeschke; R. Velten; M.E. Beck; U. Ebbinghaus-Kintscher; W. Thielert and G. Raupach. 2015.** Flupyradifurone: a brief profile of a new butenolide insecticide. Pest Management Science, 71(6): 850-862. https://doi.org/10.1002/ps.3932

26- **Vafaie, E.2019.** Insecticidal Control of Madeira Mealybugs, Spring 2019. Arthropod Management Tests, 44(1): tsz083. 10.1093/amt/tsz083

27- **Vennila, S.; A.J. Deshmukh; D. Pinjarkar; M. Agarwal; V.V. Ramamurthy; S. Joshi; K.R. Kranthi and O. M. Bambawale. 2010.** Biology of the mealybug, *Phenacoccus solenopsis* on cotton in the laboratory. Journal of Insect Science, 10(1): p.115. https://doi.org/10.1673/031.010.11501

28- **Sparks, T. C. and R. Nauen. 2015.** IRAC: Mode of action classification and insecticide resistance management. Pesticide Biochemistry and Physiology, 121: 122-128.

29- **Shah, Z.H.; H. A. Sahito; G. A. Shar; T. A. S. N. E. E. M. Kousar; W.M. Mangrio and K. A. Kanhar. 2016.** Toxicity of different insecticides against mealybug, *Phenacoccus solenopsis* (*Tinsley*) under cotton field conditions. Pakistan Journal of Entomology, 31(1): 39-50.

30- **Eichert, T.; A. Kurtz; U. Steiner and H. E. Goldbach. 2008.** Size exclusion limits and lateral heterogeneity of the stomatal foliar uptake pathway for aqueous solutes and water-suspended nanoparticles. Physiologia Plantarum, 134(1): 151-160. https://doi.org/10.1111/j.1399-3054.2008.01135.x

31- **Uzu, G.; S. Sobanska; G. Sarret; M. Munoz and C. Dumat. 2010.** Foliar lead uptake by lettuce exposed to atmospheric fallouts. Environmental Science and Technology, 44(3): 1036-1042. https://doi.org/10.1021/es902190 u

32- **Al-Tamimi, M. S.; S.Z. Bakr and J. K. Mohammed. 2020.** The effect biosynthesis of silver nanoparticles by Oxymatrine Botanical Insecticide against Aphis gossypii on cucumber and their predator *Chrysoperla carnea*. Euphrates Journal of Agriculture Science, 12(2).

33- **Sequeira, R.V.; M. Khan and D. J. Reid. 2020.** Chemical control of the mealybug *Phenacoccus solenopsis* (Hemiptera: Pseudococcidae) in Australian cotton: glasshouse assessments of insecticide efficacy. Austral Entomology, 59(2): 375-385. https://doi.org/10.1111/aen.12578