



Comparison between TiO₂NPs and ZnONPs in Combating The House Fly, *Musca domestica* (Diptera: Muscidae)

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ABSTRACT: This study aims to explore the larvicidal potency of zinc oxide nanoparticles (ZnONPs) and titanium dioxide nanoparticles (TiO₂NPs) against the house fly (*Musca domestica*) larvae. Twenty-five third instar larvae were incubated with larval medium and different serial concentrations of ZnONPs. For each concentration, four replicates were concerned for a total of 100 larvae. A set of the control group using distilled water was included. The number of surviving larvae was counted after 24 hours of incubation. Results revealed that LC₁₀, LC₅₀ and LC₉₀ were 0.08, 1.00 and 12.9 mg/ ml, respectively. Levels of total protein displayed a significant increase, while levels of albumin revealed a significant decrease. A significant decreasing pattern was observed in levels of oxidative stress enzymes among different larval groups, including superoxide dismutase, catalase enzyme and glutathione reductase. On the other hand, levels of cellular damage enzymes showed a significant increase in lipid peroxidase enzyme and nitric oxide levels. In conclusion, the results of this study showed that ZnONPs exhibit larvicidal potency against house flies (*Musca domestica*) decreasing the activities of oxidative stress enzymes and increasing the levels of cellular damage.

Keywords: House fly, *Musca domestica*, metal nanoparticles, TiO₂NPs, ZnONPs, larvicidal effects

INTRODUCTION

In addition to being an annoyance to people, the housefly, *Musca domestica* Linnaeus (Diptera: Muscidae), is a significant pest since it may spread several infectious pathogens to both humans and animals (Mohamadeen and Hassona, 2024). A worldwide problem that impedes effective insect control is the house fly, *Musca domestica*, a medical pest that is a carrier of numerous harmful organisms that have demonstrated pesticide resistance against common active chemical ingredients (Ragheb et al., 2023). This species of Diptera is widely spread and frequently found in a variety of animal and human communities across the world (Chintalchere et al., 2021; Olagunju, 2022). *M. domestica* is a major public health concern because of its intimate ties to human activity (Norris, 2023). For instance, bacterial, parasitic, zoonotic, and viral infections can be spread by houseflies (Raele, 2021). They cause irritation and aid in the spread of infections because they are active throughout the day (Zahn and Gerry, 2020). *Musca domestica* is in charge of bringing harmful organisms from soiled areas like sewage and trash into the human diet (Otu-Bassey et al., 2022). Mechanical methods, such as contamination by the fly's exterior body parts or regurgitation and defecation that may follow meal consumption, can cause this transmission (Nayduch et al., 2022).

Therefore, *M. domestica* control is a critical and necessary necessity. The most often used control strategies include insecticides, trapping, and sanitation. Nonetheless, the emergence of insecticide-resistant house flies and the resulting toxicity have made it necessary to provide safer and more intelligent alternatives for controlling house flies (Abbas et al., 2013). Chemical pesticides are mostly used to control houseflies (Naqqash et al., 2016). Additionally, this approach to nanoparticle technology is more beneficial since it facilitates the synthesis of nanoparticles at low pH, pressure, and temperature (Raut et al., 2009). The effectiveness of certain plant-derived nanoparticles in controlling costly arthropod pests, such as mosquitoes, has been investigated (Benelli 2016a, b). Green-produced nanoparticles could take the place of artificial pesticides (Siddique et al., 2022). ZnONPs' simplicity, environmental friendliness, broad antibacterial action, and uses have drawn a lot of attention to research on their characterisation, synthesis, and characteristics in recent years (Kalpana et al., 2018).

Chemical pesticides were used carelessly, which led to a number of issues, including insecticide resistance and harm to non-target creatures, including humans (Naqqash et al., 2016). Therefore, there is a growing need to find highly effective and human-safe alternative control materials. A cost-effective and

ecologically benign method for synthesizing nanoparticles is necessary because chemical methods pose various risks to the atmosphere and the person using them (Agarwal *et al.*, 2017).

Research on nano-pesticides is a new area of study that focuses on using nanotechnology to manage pests. These areas of study encompass a wide range of research topics, such as examining how nanoscale materials interact with insect pests, forming active ingredients into nano-emulsions and dispersions using pesticides that are already on the market, creating new nano-pesticide formulations using nanomaterials as active pesticide agents, or modifying these nanomaterials as nano-carriers for their delivery (Benelli *et al.*, 2017).

Extensive research on nano-pesticides has led to the development of innovative nano-based formulations that maintain stability and efficacy in targeted environments, allowing them to effectively penetrate the bodies of target organisms, such as insects. Additionally, these formulations are designed to withstand pest defenses while remaining harmless to plants, mammals, and other non-target organisms. It is also important to note that these formulations are expected to be cost-effective in production and may incorporate novel modes of action (Benelli, 2016a and Benelli, 2016b).

In the effort to manage housefly populations, the use of insecticides has been the predominant approach, with various chemical agents such as organophosphates (Abobakr *et al.*, 2022), chlorinated hydrocarbons, pyrethroids, and carbonates being applied for many years (Ranian, 2021; Cenon *et al.*, 2022). However, the adverse environmental impacts and high costs associated with these chemical insecticides have led entomologists to investigate alternative, environmentally friendly, and economically viable strategies for housefly control. Consequently, researchers have acknowledged the necessity of moving away from chemical insecticides and have highlighted the significance of employing natural pesticides to address housefly infestations (Ramadan *et al.*, 2020). Insecticides have long been the most popular way to deal with houseflies; for the past few decades, chemical compounds like carbonates, pyrethroids, chlorinated hydrocarbons, and organophosphates (Abobakr *et al.*, 2022) have been used (Ranian, 2021; Cenon *et al.*, 2022).

Because chemical insecticides have a negative impact on the environment and are expensive, entomologists are looking at more economical, environmentally beneficial, and alternative ways to manage houseflies. In order to tackle housefly infestations, experts have therefore acknowledged the necessity of moving away from conventional insecticides and have

underlined the significance of using natural pesticides (Ramadan *et al.*, 2020). Biopesticides, which are made from a variety of organisms like fungi, bacteria, nematodes, algae, or natural products, are essential for many applications and the ongoing development of novel formulations (Rajamani and Negi, 2021; Schnarr *et al.*, 2022). Bio-pesticides, which are made via biological synthesis using microbes and plant extracts, have the advantages of stability, cost, and environmental compatibility. These nano-pesticides are very attractive since they may be produced without the use of hazardous materials or high-energy methods (Helmy *et al.*, 2023). Numerous green-produced nanoparticles, like ZnO, have been used in technical and biomedical applications (Vinothini *et al.*, 2023). When it comes to controlling house flies, green-synthesized nanoparticles are more effective than pesticides, more affordable, biodegradable, and present fewer hazards to both people and the environment (Abdel-Gawad, 2018; Saad *et al.*, 2022).

Because of their unique qualities, nanomaterials have been shown to be a valuable tool in pest management during the past ten years, reducing reliance on conventional pesticides and preventing the emergence of resistance. When incorporated into pest management systems, nanomaterials, which range in size from 1 to 100 nm, can produce faster and more effective reactions against pests than traditional-sized particles (El-Ashram *et al.*, 2020; Dikshit, 2021). Because of their small size and unique configuration, nanoparticles have remarkable physicochemical properties that enable them to be highly versatile in a wide range of applications (El-Ashram *et al.*, 2022). The widespread usage of metal nanoparticles in the environment has led to the development of a strain of the housefly that is resistant to numerous chemical control techniques. According to (Mohamadeen and Hassona, 2024), titanium dioxide nanoparticles (TiO₂) have been found to have a lower toxicity, making them more environmentally beneficial. Furthermore, by using natural extracts, the biogenic production process guarantees that the nanoparticles are directed by biomolecules such as proteins and enzymes, which adds to their distinct forms and functions (Si, 2020).

The decrease in the adult emergence of *M. domestica* as a result of treatment with the tested nanoparticles was in accordance with previous findings on other insect species, as reported against *S. littoralis* treated with ZnONPs (Osman *et al.*, 2015).

Therefore, the predominant objective of this lookup was to check out the impact of the inexperienced synthesis of silver nanoparticles as alternative insecticide on the house fly, *Musca*

domestica, L. (Diptera: Muscidae) in laboratory prerequisites for their two strains, susceptible and resistant.

MATERIALS AND METHODS

1. Insect rearing

For the purposes of this study, the house fly was raised in the economic entomology lab of the plant protection division of the Faculty of Agriculture at Omar Al-Mukhtar University in Libya.

Preparation of housefly colony:

Both sexes of houseflies were sorted and identified using taxonomic methods, and samples were examined under an endoscopic anatomy microscope.

Housefly breeding:

The adult stages were raised in $35 \times 35 \times 35$ cm cubic hardwood cages. The front portion of the cages had a muslin sleeve to control the insects within and provide food, while the cages themselves were covered with iron mesh.

2. Bioassay:

Different ZnO nanoparticle concentrations (10, 15, 20, 30, 40 and 50 mg) were dissolved in 10 milliliters of distilled water and then combined with 5 grams of the larvae meal in plastic jars for each of the six experimental groups. Three replicates of ten larvae each made up each batch. A 5 g piece of the larvae food, moistened with 10 ml of distilled water, was given to the control group (C).

• Preparation of titanium dioxide nanoparticles (TiO₂NPs)

We purchased titanium dioxide from Sigma Aldrich in China. A density of 4.2 g/cm³ and a molar mass of 79.87 g/mol were recorded. The bulk particles of titanium oxide (TiO₂BPs) had an average size of 550 nm.

• Preparation of zinc dioxide nanoparticles (ZnONPs)

Making ZnO nanoparticles green by use green leaves: The mixture consisted of 50 ml of a solution with 20% NaOH and 10 ml of green leaf extract. Following that, 50 mL of distilled water and 5 ml solutions of that mixture were added to a 250 ml beaker, and the mixture was swirled for an hour. Next, solutions of ammonium carbonate (0.96 g dissolved in 100 ml) and zinc acetate (2.1 g dissolved in 100 ml of water) was added to the beaker drop wise and simultaneously while being agitated. An hour was spent stirring the suspension at room temperature following the conclusion of the reaction.

3. Statistical analysis:

The parameters have been subjected to computerized statistical evaluation using SPSS 26 bundle for evaluation of variance (ANOVA) and ability of treatments had been in contrast using

LSD at 0.05. M. Excel used to be used in statistical evaluation.

RESULTS AND DISCUSSION

A) TiO₂ and ZnO nanoparticles' impact on larval

The third-instar larvae of *M. domestica* were treated to varying doses (10, 15, 20, 30, 40, and 50 mg/g diet) of two metal NPs, mixed TiO₂ and ZnO NPs, with their meal for 72 hours, according to the data displayed in **Table (1)** and **Fig. (1)**. When *M. domestica* larvae were exposed to TiO₂ and ZnONPs, their death rate was noticeably higher than that of the control group, which was not treated. The maximum incidence of mortality (72%) was generated by ZnO NPs at 50 mg/g food, whereas 96.24% larval mortality was achieved at 50 mg/g diet of TiO₂NPs. For TiO₂ and ZnO NPs, the LC₅₀ values were 37.93 and 48.61 mg/g diet, respectively. Furthermore, the identical chemicals' respective toxicity indices were 52.72 and 41.06. A significant prolongation of the larval phase was seen in treated larvae. In comparison to 4.81 days in control larvae, the longest durations were 6.57 days with TiO₂NPs at 50 mg/g food and 6.17 days with ZnO NPs, respectively.

Upon 72 hours following treatment, a notable reduction in the larval development rate was seen for all tested doses of ZnONPs and TiO₂. At 50 mg/g, the larval growth rate was reduced to its greatest extent. In the diet, ZnO NPs accounted for 17.71% and TiO₂NPs for 19.32% (**Table 2** and **Fig. 2**). Attention has a crucial role in larvicidal activity, as evidenced by the relationship between the mortality proportion and the concentration of TiNPs generated. A certain treatment was covered in each examination. According to current studies, after being administered for 72 hours, chemically synthesized titanium nanoparticles boosted larvicidal reproduction. Titanium nanoparticles are especially harmful to larvae in their third instar. According to the investigation's findings, the effect might be explained by TiO₂NPs absorbing into the insect's wall cuticular lipids and destroying the barrier wax layer.

According to **Mohammed (2020)**, who discovered that TiO₂NPs have been highly effective against *Eurygaster testudinaria*, the results of this study support the effect, which may also be caused by the absorbance of TiO₂NPs into the insect's wall cuticular lipids, which destroys the barrier wax layer (which is composed of a variety of fatty acids and lipids that provide excellent protection against water loss) and causes death via desiccation. As concentration increased over the days following application, the death rates of both adults and nymphs had significantly increased. **Haroun et al. (2020)** have reported similar findings, stating that high concentrations

of hydrophilic silica nanoparticles (SiO₂NPs) and zinc oxide nanoparticles (ZnO NPs) resulted in high mortality rates of *Sitophilus oryzae*, *T. castaneum*, and *Callosobruchus maculatus*. Disparities in nanoparticle effectiveness could be caused by coating concentrations, exposure durations, nanoparticle sizes, and their mechanism

of action, which typically involves adhering to the insect's surface and entering through its exoskeleton because of a decrease in membrane permeability. According to Jiang *et al.* (2015), that could potentially be a reference to DNA damage and enzyme denaturation.

Table (1): Impact of ZnO and TiO₂ NPs on the duration (days) of the third instar larvae of *M. domestica*, the toxicity index, and the larval mortality (%)

Conc. (mg/g)	Larval mortality (%)		Larval duration (Days)	
	TiO ₂ NPs	ZnONPs	TiO ₂ NPs	ZnONPs
Control	0	0	4.81±0.04d	4.81±0.04de
10	5.88±0.9f	3.92±0.4f	4.92±0.06c	4.88±0.08d
15	15.68±0.7e	12.74±0.9e	5.27±0.07bc	5.11±0.10cd
20	30.38±1.7d	26.46±1.1d	5.68±0.09b	5.39±0.05c
30	43.12±2.3c	33.32±0.7c	5.88±0.11b	5.51±0.05bc
40	65.84±1.2b	46.18±1.7b	6.08±0.04ab	5.68±0.04b
50	96.24±1.1a	70.56±1.5a	6.57±0.09a	6.17±0.04a
LC ₅₀	37.93	48.61	-	-
Toxicity index*	52.72	41.06	-	-

Averages followed by the same letter in the same assay are not significantly different at P < 0.05 level.

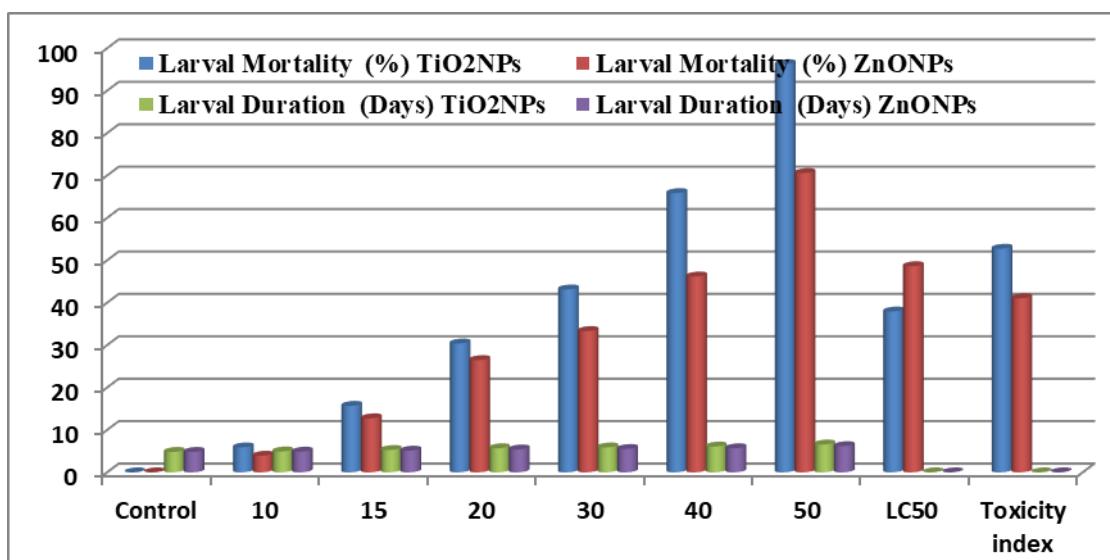


Fig. (1): Impact of ZnO and TiO₂ NPs on the duration (days) of the third instar larvae of *M. domestica*, the toxicity index, and the larval mortality (%)

Table (2): Growth rate (%) and growth rate reduction (%) of *M. domestica* treated in the third larval instar as a result of TiO₂ and ZnO NPs

Concentration (mg/g diet)	TiO ₂ NPs		ZnONPs	
	Growth Rate (%)	Reduction (%)	Growth Rate (%)	Reduction (%)
Control	1.12±0.01a	-	1.12±0.01a	-
10	1.07±0.02a	4.03	1.10±0.01a	1.61
15	1.06±0.01a	4.83	1.08±0.01a	3.22
20	1.03±0.01a	8.05	1.04±0.02a	7.25
30	0.99±0.01ab	11.27	1.01±0.00a	9.66
40	0.94±0.01ab	15.30	0.98±0.00ab	12.07
50	0.89±0.00b	19.32	0.91±0.01b	17.71

Averages followed by the same letter in the same assay are not significantly different at P < 0.05 level.

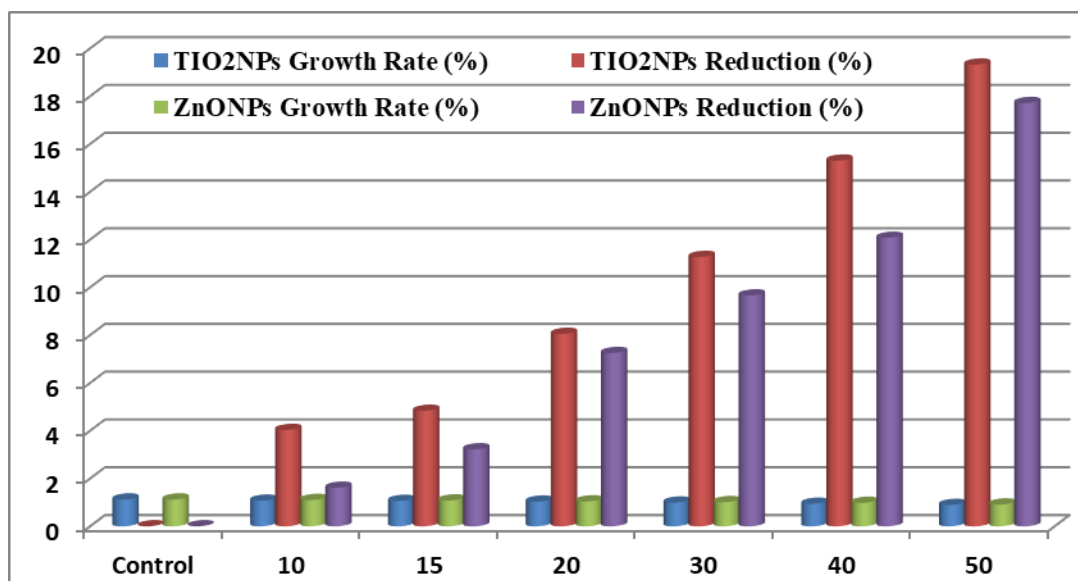


Fig. (2): Growth rate (%) and growth rate reduction (%) of *M. domestica* treated in the third larval instar as a result of TiO₂ and ZnO NPs

B) TiO₂ and ZnO NPs' impact on pupation, pupal weight, and weight loss (%):

The third-instar larvae of *M. domestica* were subjected to varying doses (10, 15, 20, 30, 40, and 50 mg/g diet) of two metal NPs mixed TiO₂ and ZnO NPs with their food for 72 hours, as indicated by the results in **Table (3)** and **Fig. (3)**. Furthermore, compared to 100% in untreated larvae, the pupation was considerably lower, containing 11.76% TiO₂ NPs and 27.44 percent ZnO NPs, respectively.

The pupal length was similarly extended to 8.75 and 8.25 days with TiO₂NPs and ZnO NPs, respectively, at 50 mg/g food, as compared to 6.98 days in the control group, according to the results in **Table (4)** and **Fig. (4)**. At 50 mg/g feed, the mean pupal weight dropped considerably to 8.64 and 9.24 mg with TiO₂NPs and ZnO NPs, respectively, compared to 10.88 mg/g diet in

control pupae. Pupal weight decreased by 20.13% and 14.74%, respectively, when fed a diet containing 20 mg/g of TiO₂NPs and ZnO NPs.

As expected from the data, the weight loss had a significant impact on the presence of anomalies in pupae, likely preventing human emergence. In the succeeding step of our research, we shall make this evident by doing various physiological tests. Additionally, compared to pupae in the modified treatment, which seemed larger and lighter in color, some pupae experienced morphological changes and appeared smaller and darker in assessment. Furthermore, some people perished before reaching the adult stage. In contrast to manipulation, which showed no morphological alterations, these morphological changes, which were previously fixed throughout the unique concentration, have been considerable.

Table (3): Pupal length (days) and pupation (percentage) of *M. domestica* treated as third instar larvae were affected by TiO₂ and ZnO NPs.

Concentration (mg/g diet)	Pupation (%)		Pupal Duration (Days)	
	TiO ₂ NPs	ZnONPs	TiO ₂ NPs	ZnONPs
Control	100.00±0.00a	100.00±0.00	6.98±0.11	6.98±0.11
10	92.12±0.55b	94.08±0.41	7.15±0.04	7.09±0.05
15	82.32±0.44c	85.26±0.48	7.55±0.06	7.35±0.02
20	94.08±0.48	71.54±0.46	8.07±0.05	7.74±0.07
30	63.7±0.43	64.68±0.29	8.20±0.03	7.85±0.04
40	41.16±0.65	57.82±0.45	8.33±0.01	8.07±0.03
50	11.76±0.38	27.44±0.35	8.75±0.07	8.25±0.06

Averages followed by the same letter in the same assay are not significantly different at $P < 0.05$ level.

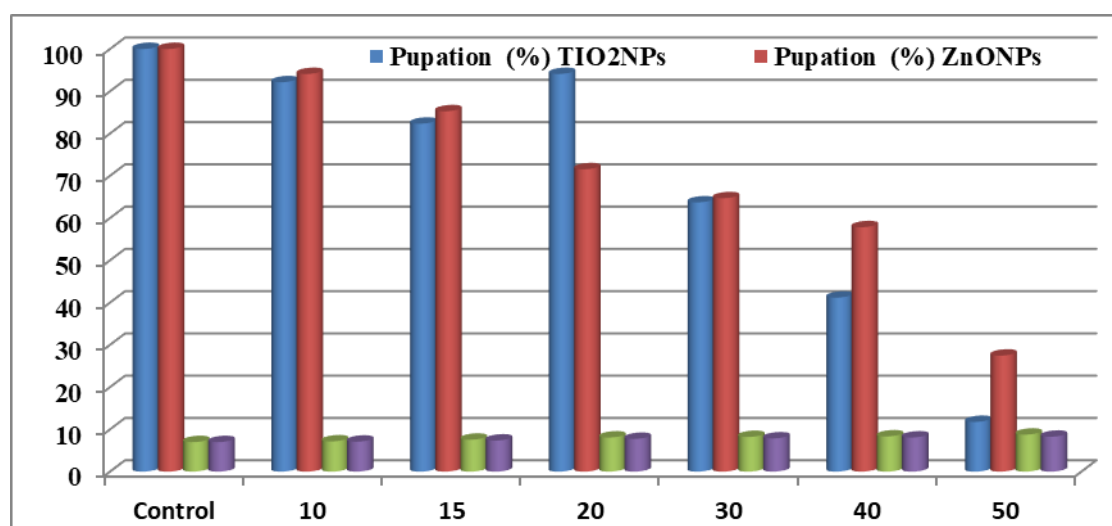


Fig. (3): Pupal length (days) and pupation (percentage) of *M. domestica* treated as third instar larvae were affected by TiO₂ and ZnO NPs.

Table (4): Impact of ZnO and TiO₂ NPs on the weight decrease (%) and pupal weight (mg) of *M. domestica* treated as third-instar larvae

Concentration (mg/g diet)	TiO ₂ NPs		ZnONPs	
	Pupal weight (mg)	Weight reduction (%)	Pupal weight (mg)	Weight reduction (%)
Control	10.88±0.09a	-	10.88a	-
10	10.29±0.04ab	5.30	10.41ab	4.23
15	9.63±0.07b	11.21	10.05bc	7.51
20	9.38±0.08bc	13.59	9.83c	9.45
30	9.25±0.06c	14.65	9.71cd	10.51
40	9.06±0.06cd	16.42	9.58d	11.65
50	8.64±0.08d	20.13	9.24de	14.74

Averages followed by the same letter in the same assay are not significantly different at $P < 0.05$ level.

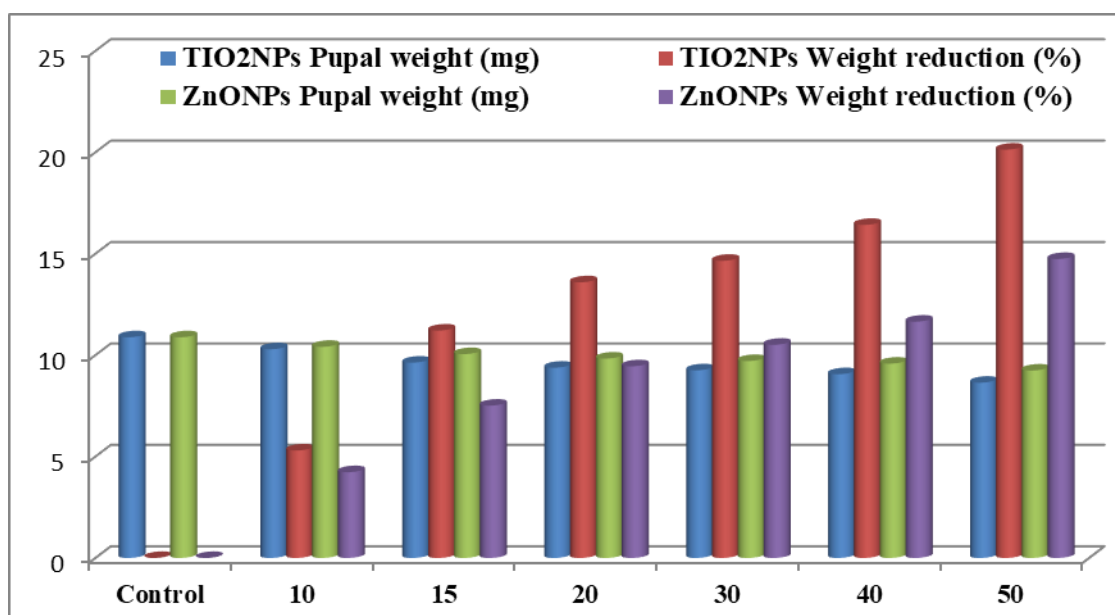


Fig. (4): Impact of ZnO and TiO₂ NPs on the weight decrease (%) and pupal weight (mg) of *M. domestica* treated as third-instar larvae

C) TiO₂ and ZnO NPs' effects on adult emergence and decline in it (%):

All tested concentrations of ZnONPs and TiO₂NPs reduced adult emergence, as can be shown from the findings in **Table (5)** and **Fig. (5)**. At 50 mg/g food, the percentage decrease in adult emergence was 64.68% and 61.54, respectively, with TiO₂NPs and ZnONPs showing the strongest inhibition as compared to the control group.

As observed against *S. littoralis* employing ZnONPs, the decrease in adult emergence of *M. domestica* following treatment with the tested NPs was consistent with earlier bioassays on other insect species (**Osman et al., 2015**). The reduction in *M. domestica* adult longevity (particularly oviposition period) brought about by treatment with the tested NPs may be the result of their accumulation during the various developmental phases. Negative effects on development and the number of days needed for the insect to complete its life cycle were documented, and the effectiveness of ZnONPs against *Spodoptera frugiperda* was also shown at different concentrations (100-500 ppm) (**Pittarate et al., 2021**). NPs are more reactive than their bulk counterparts due to their greater surface-to-volume ratio (**Vani and Brindhha, 2013**). Partial lysis of the midgut epithelial cells and damage to the apical

membrane of the epithelial cells may also be responsible for the toxicity of NPs (**Sultana et al., 2018**). By physically harming the bug and integrating into its lipids, they destroyed it (**Barik et al., 2008**). NPs typically harm the insect by piercing the exoskeleton and reaching the intracellular area (**Rai et al., 2014**). NPs' sizes, coatings, concentrations, and exposure times all affect how effective they are (**Jiang et al., 2015**). Nanoparticles' higher surface to volume ratio makes them more reactive than their bulk counterparts, according to **Vani and Brindhha (2013)**. The midgut epithelial cells' partial lysis, vesicles, and disrupted membranes at the apical side of the cells could be the cause of the nanoparticles' toxicity (**Sultana et al., 2018**). Furthermore, by physically damaging the cuticular lipids during absorption, nanoparticles killed insects (**Barik et al., 2008**). Furthermore, the insect's thorax and abdomen accumulated ZnO NPs, and exposure to ZnO NPs caused a number of morphological and histological abnormalities (**Abinaya et al., 2018; Ishwarya et al., 2018**). Thus, there aren't enough thorough research on how ZnO NP exposure may impact the physiology and genetics of insects (**Benelli 2018**).

Table (5): Impact of ZnO and TiO₂ NPs on *M. domestica* adult emergence and decline in adult emergence (%)

Concentration (mg/g diet)	TiO ₂ NPs		ZnONPs	
	Adult Emergence	Reduction	Adult Emergence	Reduction
Control	92.12	0	92.12	0
10	73.5	19.80	79.38	13.52
15	60.76	33.32	66.64	27.15
20	48.02	46.94	54.88	39.59
30	45.08	50.08	49.98	44.88
40	42.14	53.21	46.06	49.00
50	31.36	64.68	34.3	61.54

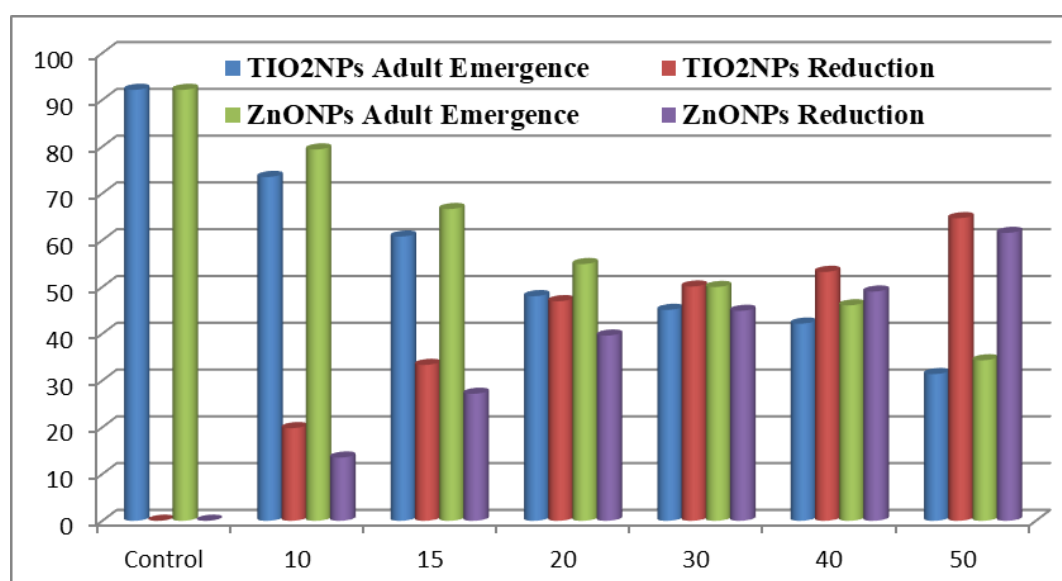


Fig. (5): Impact of ZnO and TiO₂ NPs on *M. domestica* adult emergence and decline in adult emergence (%)

CONCLUSION

The effectiveness of some nanoparticles extracted from plants has been studied, where nanoparticles produced through green methods replace synthetic pesticides. They are also environmentally friendly, as it has been found that titanium and zinc oxide nanoparticles have lower toxicity, making them more environmentally beneficial. The target species are subjected to severe morphological deformities and an increased mortality rate due to the enhanced interaction of nanoparticles with biological systems because of their small size and large surface area.

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الملخص العربي

مقارنة بين TiO_2NPs و ZnONPs في مكافحة الذبابة المنزلية

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تهدف هذه الدراسة إلى استكشاف فعالية جسيمات أكسيد الزنك النانوية (ZnONPs) وجسيمات ثاني أكسيد التيتانيوم النانوية (TiO_2NPs) في قتل يرقات الذباب المنزلي (*Musca domestica*). خُصنت خمس وعشرون يرقة من الطور الثالث في وسط غذاء يرقات وتركيزات تسلسلية مختلفة من جسيمات أكسيد الزنك النانوية. لكل تركيز، أُجريت أربع مكررات، بإجمالي 100 يرقة. الكنترول كان باستخدام الماء المقطر. تم حساب عدد اليرقات الباقية بعد 24 ساعة من الحضانة. أظهرت النتائج أن التركيز المميت 10، والتركيز المميت 50، والتركيز المميت 90 كانت 0.08، و1.00، و12.9 مجم/مل على التوالي. وشهدت مستويات البروتين الكلي زيادة ملحوظة، بينما انخفضت مستويات الألبومين انخفاضاً ملحوظاً. ولوحظ نمط تناقص ملحوظ في مستويات إنزيمات الإجهاد التأكسدي لدى مجموعات اليرقات المختلفة، بما في ذلك إنزيم سوبر أكسيد ديسميوتاز، وإنزيم الكاتالاز، وإنزيم الجلوتاثيون ريدكتاز. من ناحية أخرى، أظهرت مستويات إنزيمات تلف الخلايا زيادة ملحوظة في مستويات إنزيم بيروكسيداز الدهون وأكسيد النيتريك. وفي الختام، أظهرت نتائج هذه الدراسة أن ZnONPs تُظهر فعالية قاتلة لليرقات ضد ذباب المنزل، مما يقلل من نشاط إنزيمات الإجهاد التأكسدي ويزيد من مستويات تلف الخلايا.

الكلمات المفتاحية: الذبابة المنزلية- الجسيمات النانوية المعدنية- أكسيد الزنك النانوية (ZnONPs)- ثاني أكسيد التيتانيوم النانوية (TiO_2NPs)