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Nanoparticle-based approaches for the control and management of fall armyworm (Spodoptera frugiperda)

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ABSTRACT

The fall armyworm, or *Spodoptera frugiperda*, is a serious crop pest that reduces crop yields significantly. Creating environmentally friendly and efficient fall armyworm (FAW) pest management techniques is essential for sustainable agriculture. In order to protect against these insects and maintain the nation's food security, pesticides are used indiscriminately. Nonetheless, as part of eco-friendly management, new methods for managing these insect pests have been introduced, with the usage of nanotechnology being promoted, due to the dangerous consequences of chemical pesticides. Nanotechnology plays a vital role in designing and preparing target-oriented and controlled-release pesticides. Chemical alteration is one way to accomplish this, and this new technology holds enormous promise for developing innovative formulas. This article explores the use of certain nanomaterials in the management of fall armyworm, emphasising their benefits, drawbacks, and how they work. It is possible to significantly increase crop protection and productivity by integrating nanotechnology into pest management methods.

INTRODUCTION

The Global menace, Fall armyworm (*Spodoptera frugiperda)*: *Spodoptera frugiperda* J.E. Smith (Lepidoptera), sometimes known as fall armyworm (FAW), is a major global pest of maize crops and a member of the Noctuidae family. After being discovered for the first time in America, this pest then moved to Asia-Pacific and Africa. It has grown to be a major worldwide concern since 2018 (Deshmukh *et al.,* 2021). Fall armyworms feed on wheat, maize, barley, cotton, soybeans, sorghum, and tomatoes. It results in significant crop losses, which have an impact on economies around the globe. Its favourite plant is maize, and it can reduce yields by 15–73%. It attacks the maize plant from the time it is a seedling until the beginning of ear growth. There are two types of FAW: the rice strain and the maize strain. The maize strain is more common and damages different areas of the crop, which is problematic for the farmer. (Sun *et al.,* 2021).

Common pesticides used to control FAW populations include organophosphates, carbamates, and pyrethroids. The two most important aspects influencing this control are the stage of development and the time of administration. However, the use of these chemicals has caused harm to the environment, stays in the environment, and causes pest resistance to chemical control; their applications are typically limited. As a result, scientists are currently concentrating on sustainable alternatives to the toxic pesticides that have been used for many years.

The use of nanotechnology in contemporary agriculture is a relatively new idea. In this context, monodisperse, analogous, and morphologically identical particles with diameters ranging from 10 to 100 nm are referred to as nanoparticles. When compared to other pesticides, their exceptional stability and great water solubility are noteworthy. Fortunately, in contrast to conventional chemical pesticides, nanoparticles do not provide health risks to the environment or the general public. Since nanoparticles typically penetrate plant cells, they transform into nanocarriers, which makes them effective at capturing pests.

Nano particles in action: Tracking their journey in fall armyworm management

Many attempts have been made to manage insects which provide effectiveness and are at the same time eco-friendly in nature. Nanoparticles have been widely used in modern agricultural pest management systems. Other advantages of the use of nanoparticle insecticides are the possibility of preparing formulations that contain insoluble compounds that can be more readily dispersed in solution. It reduces the problems associated with drifting and leaching, due to its solid nature, and leads to a more effective interaction with the target insect. These features enable the use of a smaller amount of active compound per area, as long as the formulation may provide an optimal concentration delivery for the target insecticide for longer times. Hence, nanotechnology can be applied in several ways in order to enhance the efficacy of insecticides in crops.

The NPs, zinc oxide (ZnO-NPs) and silicon dioxide (SiO_2-NPs) nanoparticles, caused visible damage such as a reduction in larvae body length, alterations in their morphology, especially in the dorsal and ventral regions because interfere with the developmental physiology of the insect and, at high concentrations, cause its mortality. Pink and dark spots, generalised malformations, body necrosis, and mummified bodies (death). The ZnO-NPs and SiO_2-NPs nanoparticles present an efficient and innovative solution for the control of *S. frugiperda*. (Ruiz-Aguilar *et al*., 2025). Exposure to ZnO NPs caused body deformities in all stages of the lifecycle from larvae to adults, body malformations instigated after the ingestion of baby corn dipped in ZnONPs (Pittarate *et al*., 2021). The study conducted by Mashood *et al.* (2021) concluded that green-synthesised ZnO nanoparticles can regulate the population of S. *frugiperda* by causing larval mortality and structural deformations, making it a promising tool in integrated pest management program.

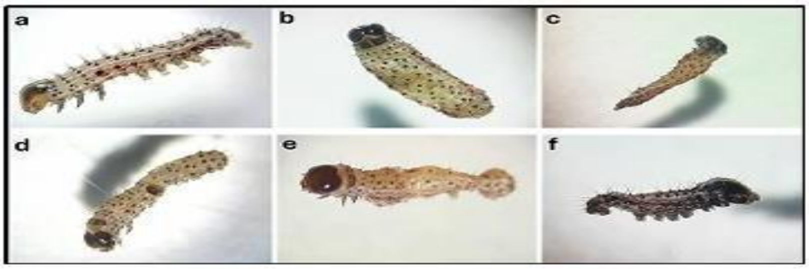

Fig. 1: Mortality of *S. frugiperda* on 2nd larval instar where (a) denotes control and (b) to (f) shows deformed larvae treated with different concentrations of SiNPs (Ruiz-Aguilar *et al*., 2025)

a) Control and malformed pupae

b) Control and malformed adult

Fig. 2: Deformities of pupal and adult stages of *S. frugiperda* on 2nd larval instar treated with green synthesized zinc oxide nanoparticles from *Calotropis procera* (Masood *et al*., 2024)

Advantages of Nanotechnology in pest management:

Because of their huge surface area, nanoparticles can interact with pests more effectively and deliver active chemicals to the target site exactly. Their efficacy can be extended and the frequency of applications decreased by engineering them for a delayed or stimuli-responsive release. Higher efficacy necessitates lower application rates, and nanoparticles can be engineered to cause less runoff or leaching and collateral damage to non-target species. At lesser dosages, nanoparticles can increase insecticides' ability to enter the bodies of pests and raise fatality rates.

Disadvantages of Nanotechnology in pest management:

There is still a chance of negative impacts on beneficial insects, birds, and aquatic life, even if some studies have shown that they are less toxic than traditional pesticides. As with traditional pesticides, there is a chance that pests will become resistant to nanopesticides. The cost of developing and implementing some nano-based pest control techniques can be high.

Conclusion

Nanotechnology plays a vital role in designing and preparing target-oriented and controlled-release pesticides in the modern agricultural pest management system. The use of nanoparticle insecticide formulations containing insoluble compounds can be more readily dispersed in solution, thereby reducing the drifting and leaching losses due to their solid nature, and leads to a more effective interaction with the target insect. These features enable the use of a smaller amount of active compound per area delivery for the target insecticide for longer times.

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