OPEN ACCESS Plant Protection, 10 (02) 2026. 285-298 DOI:10.33804/pp.010.02.6079

Check for updates

Available Online at EScience Press

Plant Protection

ISSN: 2617-1287 (Online), 2617-1279 (Print)

http://esciencepress.net/journals/PP

Research Article

Biocidal Activity of Biosynthesized Magnesium Oxide Nanoparticles Derived from Ginger (*Zingiber officinale*) Against the Saw-Toothed Grain Beetle, *Oryzaephilus surinamensis* (Coleoptera: Silvanidae)

Eman Emad Rashid Sadoon, Adel Ali Haidar

Department of Biology, College of Education for Pure Sciences, University of Kirkuk, Iraq.

ARTICLE INFO

Article history

Received: 14th January, 2026

Revised: 6th April, 2026

Accepted: 8th April, 2026

Keywords

Magnesium oxide nanoparticles

MgO NPs

Green synthesis

Zingiber officinale

Oryzaephilus surinamensis

Stored grains pest management

ABSTRACT

The growing need for environmentally sustainable pest control has increased interest in green synthesis of nanoparticles using plant extracts. The current study documents the biosynthesis of magnesium oxide nanoparticles (MgO NPs) by using ginger rhizome (*Zingiber officinale*) extract and assesses their physicochemical characteristics and biocidal activity against the saw-toothed grain beetle, *Oryzaephilus surinamensis*. Structural characterization proved successful nanoparticle formation. X-ray diffraction analysis revealed a highly crystalline cubic structure, while transmission electron microscopy showed well-defined cubic and prismatic particles ranging from 40 to 120 nm. UV-Vis spectroscopy showed strong absorption in the ultraviolet region, confirming wide bandgap properties. Fourier-transform infrared spectroscopy confirmed the presence of bioactive compounds responsible for nanoparticle stabilization, and zeta potential analysis (-19.2 mV) showed moderate colloidal stability. Biological tests proved that MgO NPs significantly affected insect growth, development and reproduction in a concentration-dependent manner. Fecundity parameters, including egg production, adult emergence, and productivity, were significantly reduced with increasing nanoparticle concentrations, with minimum values observed at 1500 ppm. Developmental stages, including egg incubation, larval, and pupal durations, were significantly delayed. Adult mortality increased gradually, attaining 100% at higher concentrations. Moreover, MgO NPs reduced seed weight loss by limiting insect feeding and population growth. Seed germination improved at moderate concentrations (500-1000 ppm) but declined at higher levels, indicating possible phytotoxicity. In conclusion, biosynthesized MgO NPs prove strong potential as eco-friendly bio-insecticides, offering an effective and sustainable substitute to conventional hazardous chemical pesticides for stored grain protection.

Corresponding Author: Eman Emad Rashid Sadoon

Email: epbm24006@uokirkuk.edu.iq

© 2026 EScience Press. All rights reserved.

Introduction

Agricultural pests represent a major constraint on agricultural production in the Arab world and are among the key drivers of the food gap, causing both quantitative and qualitative losses that may reach 35-50% in some regions (Hallaq and Al-Samara, 2003). Globally, post-harvest losses due to inadequate storage are estimated at approximately 100 million tons annually (Ahmad et al.,

2021). Although plant agricultural production is influenced by multiple interacting factors, various pests, including insects, plant pathogens, mites, weeds, and rodents, play a significant negative role in reducing both the quantity and quality of crop yields. In developing countries, these losses may sometimes exceed 50% of total production, with insect-related losses alone accounting for approximately 14% (Al-Iraqi and Ramadan, 2010).

Rice (*Oryza sativa* L.), belonging to the family Poaceae, is regarded as an important strategic staple food crop for about half of the world's population (Kazem, 2018; Batool et al., 2026); necessitating its protection during various storage stages as an economic and food security need. Stored grains are susceptible to infestation by numerous insect pests, particularly those belonging to the orders Coleoptera and Lepidoptera (Asbar, 2024). Among the most important of these is the saw-toothed grain beetle, *Oryzaephilus surinamensis* (Coleoptera: Silvanidae), which is globally distributed (Champ and Dyte, 1976). Its small size, high mobility, and strong feeding ability contribute to its success as a pest (Arthur, 2001).

This species causes direct mechanical damage and significant weight loss in grains and their products, including rice, dried fruits, nuts, sugar, confectionery, tobacco, dried meat, and various plant-derived products consumed by humans (Mowery et al, 2002; Lorini, 2005). Moreover, it infests flour products and stored pharmaceuticals. Both larvae and adults can be observed in various types of rice that have been previously exposed to other storage pests or stored under poor conditions. It has also been noted that this insect prefers food products packaged for direct consumption (Ismail, 2014).

The repeated use of chemical pesticides for the control of storage pests has led to the emergence of resistant strains, environmental pollution, and the accumulation of toxic residues in food. This has demanded the search for safer, non-hazardous and more environmentally benign options (Mohammed et al., 2019). Scientific revolutions and innovations have transformed the disciplines of medicine, pharmaceuticals, materials science, energy, and information technology. Nanotechnology has appeared as one of the most important inventions of the 21st century, playing a significant part in knowledge-based economic developments and scientific advances (Ghorab and Ghrissi, 2024).

In this regard, nanotechnology has gained wide acceptance and increasing attention as a recent and innovative strategy to manage pests and diseases due to novel physicochemical properties of nanoparticles, mainly their high surface area, which increases biological activity (Nazir et al., 2019; Al-Qudsi et al., 2021; Shahbaz et al., 2023; Jamil et al., 2025; Hussain et al., 2026; Mehak et al., 2026). Green synthesis of nanoparticles by the use of plant-based extracts has attracted significant attention as a sustainable and eco-friendly strategy, as it reduces the usage of deleterious compounds during the production of stable and effective Nano-materials (Khan et al., 2021; Huston et al., 2021; Jabbar et al., 2022; Patil et al., 2022; Patil and Morbale, 2022). Plant-based secondary metabolites can play a fundamental role in reduction and stabilization processes, consequently affecting the properties and characteristics of synthesized nanoparticles (Radulescu et al., 2023).

Ginger (*Zingiber officinale*) is considered a promising plant source in this field due to its high levels of bioactive compounds, such as gingerol and shogaol. These compounds affect various physiological and metabolic processes in insects, including chitin synthesis, respiratory and nervous system functions, and energy metabolism, in addition to their roles as antifeedants and behavioral inhibitors (Sinha and Ray, 2024).

Despite the growing number of studies on the efficacy of these nanoparticles against stored-product pests, research on the green synthesis of magnesium oxide nanoparticles (MgO NPs) using ginger rhizome extract and on their direct effects against these pests remains limited. Therefore, this study aims to biosynthesize MgO nanoparticles using a green approach from ginger rhizome extract, characterize their physicochemical properties, evaluate their insecticidal activity and effects on seed germination, and ultimately develop safe and sustainable alternatives to chemical pesticides for the protection of stored grains.

Materials and Methods

Rearing of saw-toothed grain beetle

The saw-toothed grain beetle, *Oryzaephilus surinamensis*, was obtained from infested rice seeds collected from three regions in Kirkuk city (Rahim Awa, Baghdad Road, and Domiz) during the period from 28 July to 4 August 2025. The specimens were identified at the Natural History Museum of the University of Baghdad. The infested seeds were placed in 800 ml glass jars containing 200 g of rice seeds and maintained under laboratory conditions (25 ± 2°C and 70 ± 5% relative humidity). After allowing the insects to mate for 10 days, the adults were

removed to obtain the first generation (Omran et al., 2021). The colony was periodically renewed to maintain the required developmental stages for experimentation.

Ginger extraction

Fresh *Z. officinale* rhizomes (40 g) were boiled in 500 ml of distilled water for 30 min, with the container covered with plastic wrap to minimize evaporation, yielding an aqueous extract with a final concentration of 80 mg/ml. The solution was then cooled to room temperature and filtered through Whatman No. 1 filter paper to remove solid residues (Yasin et al., 2025).

Green synthesis of MgO nanoparticles

MgO NPs were synthesized using ginger rhizome extract as a natural reductant. After that, 20 ml of plant extract was added to a 0.1 M aqueous solution of magnesium sulfate, and the mixture was stirred using a magnetic stirrer at 100°C for 1 h. To remove residual impurities, the developed supernatant was shaken at 5000 rpm for 10 min, washed repeatedly with distilled water, and dried overnight. The resulting product was dried at 70°C to obtain the respective hydroxide precursor. The obtained precipitate was repeatedly washed with deionized water and calcined at 450°C for 2 h to form MgO NPs (More and Jamra, 2021). The same process was continuously repeated until the appropriate load was reached.

Characterisation of nanoparticles

Several characterization techniques were employed to characterize the synthesized MgO NPs. The crystalline structure was confirmed by standard X-ray diffraction (XRD), while particle formation was assessed by UV-Vis spectrophotometry, and FTIR determined the functional groups of the particles. The size and morphology were determined by transmission electron microscopy (TEM), and zeta potential characterization assessed colloidal stability.

Preparation of nanoparticle solutions

The synthesized magnesium oxide nanoparticles (MgO NPs) were prepared as a 1500 ppm stock solution, with a final volume of 100 ml, by dissolving 1.5 g in 1 L of deionized water. The solution was subsequently sonicated for 10 min at 1000 rpm using a Silent Crusher Homogenizer to create a homogeneous suspension, thereby limiting particle agglomeration. Using the equation $C_1V_1 = C_2V_2$, final concentrations of 500, 1000, and 1500 ppm were prepared (Ibrahim et al., 2022). Prior to the experiment, the nanoparticles were characterized (size, surface area, zeta potential) to determine whether uniform reproducibility has been achieved.

Experimental design

The biological experiment aimed to study the effects of MgO NPs on the saw-toothed grain beetle, *O. surinamensis*, at three concentrations (500, 1000, and 1500 ppm) compared with an untreated control. All life stages of the insect (i.e., eggs, larvae, and pupae) were incorporated and evenly distributed among the treatments. Three replicates of 10 g of seeds in Petri dishes were used for each treatment. For each dish, 10 newly emerged adults (5 females + 5 males) were added. All plates were sealed with breathable covers and kept under controlled laboratory conditions at 25 ± 2°C and 78 ± 5% relative humidity. Mortality and weight loss in seeds were recorded every second day of the experimental period. With this design, the treated and control groups were comparable, and the effects of MgO NPs on different insect life stages were reproducible.

Fecundity (productivity)

Healthy rice seeds were sterilized at -20 °C for 24 h to assess the effect of nanoparticles on the fecundity of adult saw-toothed grain beetles. The seeds were then soaked in 10 ml of each nanoparticle solution at its specific concentration and placed on filter paper to dry at room temperature. Afterwards, they were transferred to Petri dishes at a rate of 10 g per dish, with three replicates per concentration, plus a control treatment. Each dish contained five pairs (5 ♀ + 5 ♂) of newly emerged adults, and small holes were made in the lids to allow ventilation. The total number of eggs laid was recorded, along with the mortality of both control and treated insects. Abbott's formula was applied to correct mortality (Abbott, 1925). The adult emergence rate was estimated (Al-Bakr, 1999), and the percentage of productivity and reduction in the first-generation population were calculated (Tabu et al., 2012) using the following equation:

$$\text{Productivity (\%)} = \frac{\text{Number of emerged adults}}{\text{Number of eggs laid}} \times 100$$

The egg incubation period and the larval and pupal durations of *O. surinamensis*

For each replicate, 10 g of broken rice seeds were placed in Petri dishes to provide suitable conditions for larval and pupal development. Each dish was then supplied with five pairs of newly emerged adults (5 ♀ and 5 ♂). Petri dishes were sealed with small holes for ventilation and incubated at 25 ± 2°C and 70 ± 5% relative humidity, with daily observation. Adults were removed from the dishes after oviposition. All eggs were removed, except 10 per dish,

after which the dishes were returned to the incubator. Egg color was monitored, and the durations of egg hatching, larval development, and pupation were recorded.

Measurement of adult mortality of saw-toothed grain beetle

In this study, the adult mortality of the saw-toothed grain beetle was evaluated using two approaches. Petri dishes containing 10 g of rice seeds treated with the nanoparticle solutions were prepared, with three replications for each treatment and control. Ten newly emerged adults (5 ♀ + 5 ♂) were introduced into each dish. The dishes were maintained under controlled laboratory conditions of temperature and humidity. Dead insects were counted every other day for 16 days. Mortality (%) was initially calculated using Hill's formula (Hill, 2002):

$$\text{Mortality percentage (\%)} = \frac{\text{Number of dead insects}}{\text{Total number of eggs}} \times 100$$

To account for the natural mortality observed in the control group, the corrected mortality was also calculated using Abbott's formula (Abbott, 1925):

$$\text{Corrected mortality (\%)} = \frac{t-c}{100-c} \times 100$$

Where t = percent mortality in the treatment; c = percent mortality in the control. Thus, both direct and corrected mortality rates were used to provide an accurate assessment of the nanoparticle effects on adult beetles.

Calculation of percentage of weight loss of seeds due to saw- toothed grain beetle

Healthy rice seeds (10 g per Petri dish) were treated, with three replicates for each treatment and the control group. Ten freshly emerged adults (5 females + 5 males) of *O. surinamensis* were introduced into each dish. The Petri dishes were sealed with a small breathable cover and incubated at 25 ± 2°C with a relative humidity of 70 ± 5%. Seed weight loss percentage was determined at 7, 14, 21, 28, 35, 42, and 49 days after planting, following the method described by Keita et al. (2001).

$$\text{Seed weight loss (\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

Statistical analysis

The experiment was conducted using a Completely Randomised Design (CRD). The data were analyzed using one-way analysis of variance (One-Way ANOVA) to determine the significance of differences between treatments. When significant differences were detected, means were compared using the Least Significant Difference (LSD) test at a 0.05 probability level. Finally, the coefficient of variation (CV%) was calculated to assess experimental precision. Statistical analyses were performed following routine procedures (Al-Rawi and Khalaf, 1980).

Results and Discussion

Various structural characterization techniques confirmed the successful biosynthesis of MgO NPs using ginger rhizome extract, locally known as Abshi.

X-Ray diffraction (XRD) analysis

The structural properties of biosynthesized magnesium oxide nanoparticles were studied using X-ray diffraction (XRD). The clear, intense peaks observed in the 2θ range of 10-80° for Cu-Kα radiation (λ = 1.5406 Å) in the diffraction patterns indicate that the nanoparticles are crystalline. Figure 1 shows the main peaks in the X-ray diffraction patterns of MgO NPs at 2θ = 36.9°, 42.9°, 62.3°, 74.7°, and 78.6°, corresponding to the 111, 200, 220, 311, and 222 crystal planes, respectively. The observed peaks are consistent with the cubic rock-salt phase (Fm-3m symmetry), indicating the formation of a pure crystalline phase without secondary phases. The peaks with full width at half maximum (FWHM) values indicate that the particles are in the nanoscale range. The average crystallite size, estimated using the Scherrer equation, indicates that the MgO NPs exhibit high crystallinity and well-ordered structures. The nanoparticles synthesized had the potential for high crystallinity and homogeneity, which is associated with the bioactive compounds (phenolic compounds and flavonoids) in the ginger extract, which might have been involved in reduction, aiding in controlling crystal growth, stabilizing nanoparticles, and governing the crystalline structure of the resultant nanoparticles.

TEM examination

The shape of MgO NPs was well-defined. Both cubic and prismatic forms were observed. Some semi-spherical particles also appeared in the TEM images. This might be due to the formation of smaller particles (< 20 nm) (Figure 2). These findings are consistent with the pure crystalline nature of the synthesized MgO NPs. The morphology agrees with XRD results, which confirm the cubic rock-salt ordering. Particle sizes ranged from 40 to 120 nm, and some aggregation was observed, likely due to the high surface energy and strong van der Waals forces between nanoparticles. Nevertheless, the particles retained well-defined crystalline edges, indicative of good crystal growth and structural quality.

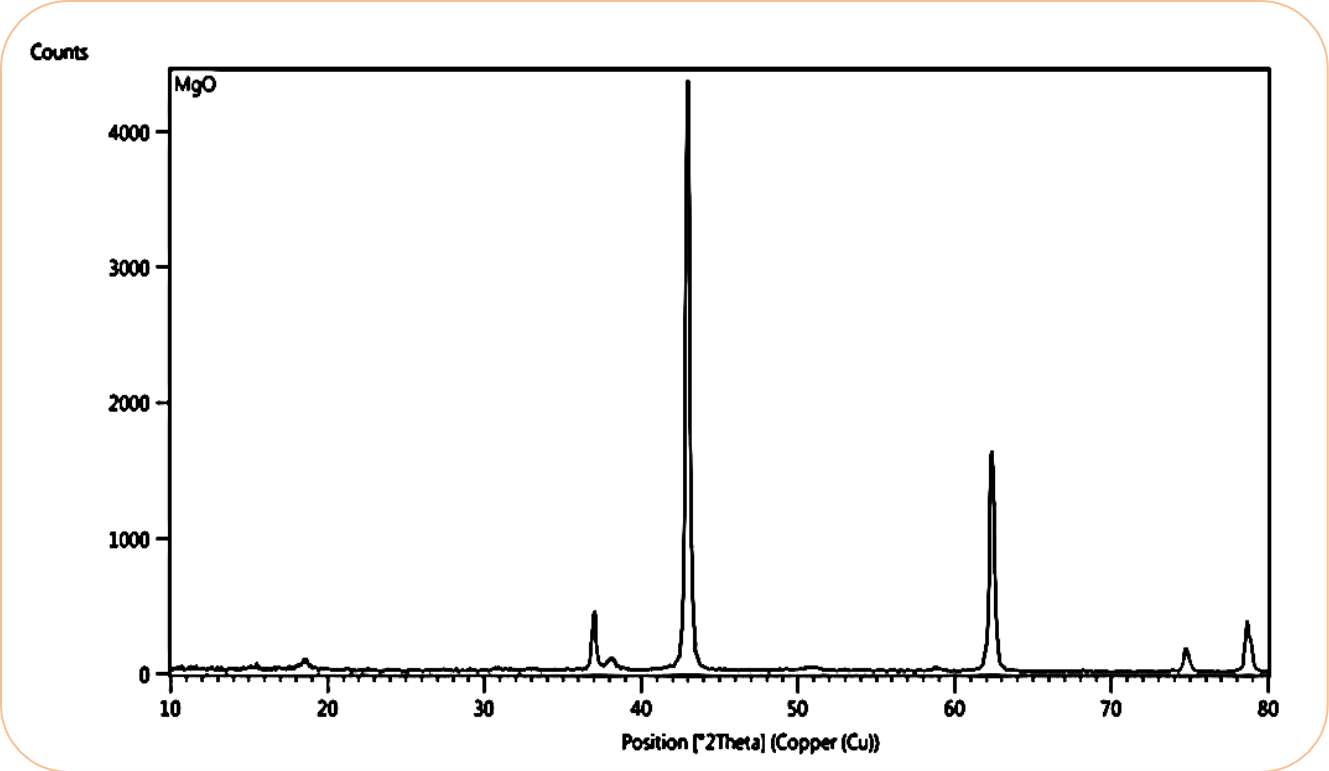


Figure 1. X-Ray diffraction (XRD) pattern of magnesium oxide nanoparticles.



Figure 2. TEM Images of biosynthesized magnesium oxide nanoparticles.

UV-Visible Spectroscopy (UV-Vis) analysis

The UV-Vis absorption spectrum of magnesium oxide nanoparticles shows a distinct absorption peak in the ultraviolet region at $\lambda < 220$ nm (Figure 3). The presence of this absorption edge corresponds to electronic transitions from the valence band to the conduction band, thereby indicating that magnesium oxide is a wide-bandgap semiconductor. The high absorbance in the UV region corroborates its electronic structure, which makes it useful for UV-active applications.

Fourier-transform infrared (FTIR) spectroscopy

The FTIR spectrum of the magnesium oxide nanoparticles biosynthesized using ginger rhizome extract is shown in Figure 4. The wide band at 3419 cm^{-1} was assigned to O–H stretching vibrations and water adsorbed on the surface. The absorption band at 1643 cm^{-1} is attributed to the bending vibrations of H_2O molecules or carbonyl groups. The absorption bands between 2910 and 2980 cm^{-1} and between 1425 and 1550 cm^{-1} could be assigned to organic functional groups such as C–H, C=C, and COO^-. The bands observed in the region of 1045-1174 cm^{-1} are due to C–O stretching vibrations of phenolic compounds and sugars. These spectral features indicate the likely presence of bioactive substances on the nanoparticle surfaces, which might facilitate nanoparticle formation and prevent agglomeration by stabilizing the nanoparticles in solution. Following the FTIR analysis, additional characterization was performed using zeta potential analysis to evaluate the nanoparticles' surface charge and stability.

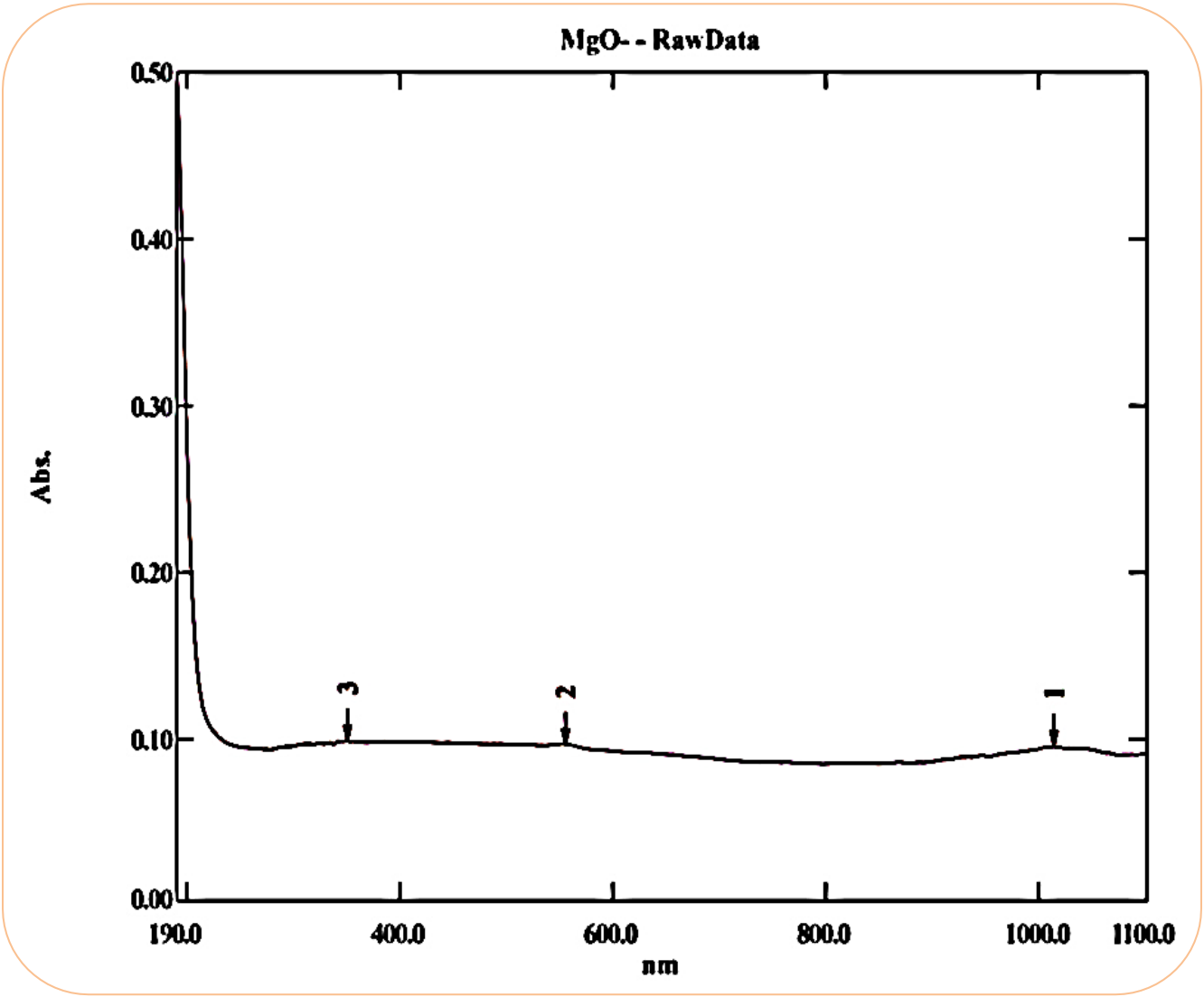


Figure 3. UV-Visible absorption spectrum of magnesium oxide nanoparticles.

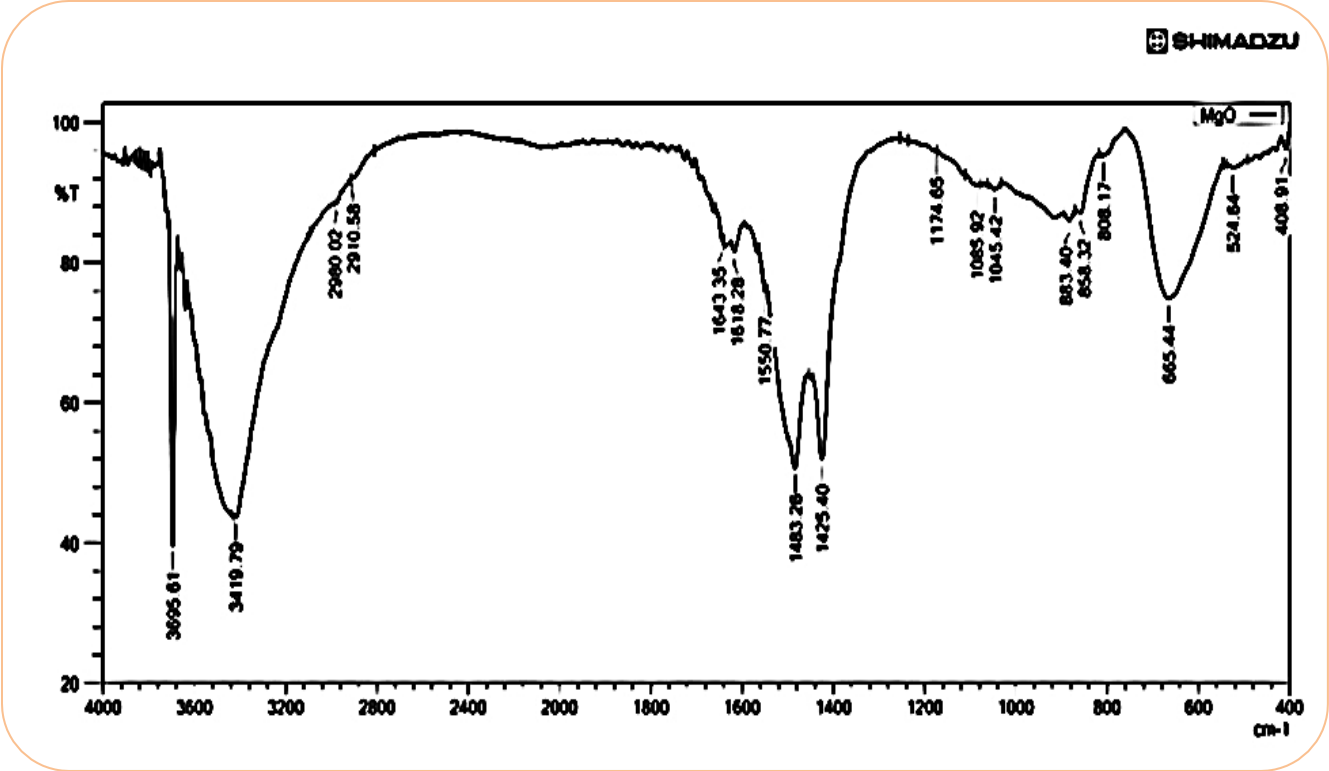


Figure 4. FTIR spectrum of magnesium oxide nanoparticles.

Zeta potential analysis

The zeta potential of ginger rhizome extract-stabilized biosynthesized magnesium oxide nanoparticles was −19.2 mV, and the electrophoretic mobility at 25.5°C was −0.000149 $cm^2/V{\cdot}s$ (Figure 5). The surface charge was overall negative, indicating limited colloidal stability and potentially allowing some aggregation of nanoparticles. This negative surface potential, likely due to the ionization of hydroxyl (–OH) groups on the nanoparticle surface, can help maintain nanoparticle dispersion in suspension, thereby slightly increasing stability despite the tendency for some aggregation.

Impact of nanoparticles on fecundity of the saw-toothed grain beetle

Our results indicated that the effect of MgO NPs on the fecundity of *O. surinamensis* was characterized by a higher rate of fecundity when MgO NPs were not present (control) in comparison to the other treatment groups (Table 1). The decrease was apparent in egg production, adult emergence, and general productivity. The control group's reproductive performance resulted in the highest numbers of eggs (389.67), adults emerged (312.33), and productivity (80.15%). In contrast, these values decreased progressively with increasing concentrations of nanoparticles, culminating in the minimum values of 97.67 eggs, 41.33 adults, and 42.32% productivity at 1500 ppm of MgO NPs. These results suggest that an increase in nanoparticle concentration directly impairs the insect's reproductive capacity. This decrease in fecundity might be caused by damage to reproductive tissues, disruption of embryo development, or nanoparticles entering the egg chorion. Moreover, MgO NPs might induce oxidative stress by generating reactive oxygen species (ROS), further impairing fertility and adult emergence. Although previous studies have suggested potential mechanisms such as ROS generation, interference with chitin synthesis, and cuticle disruption, the primary mode of action of MgO NPs appears to be physical desiccation through interaction with the insect cuticle, rather than systemic metabolic toxicity (Kumar et al., 2018a; Alghuthaymi et al., 2021; Abdullah and Haider, 2025). Comparatively, these findings are consistent with other recent studies indicating that MgO and biosynthesized metal oxide nanoparticles substantially reduce fecundity and reproductive success in stored-product insects. For instance, Alghuthaymi et al. (2021) reported that MgO NPs significantly decreased egg-laying and adult emergence in *Tribolium castaneum*.

HORIBA Scientific

HORIBA SZ-100 for Windows [Z Type] Ver2.20

SZ-100

Measurement Results

14040918-Ebrahimzadeh-3499AA-MgO-zeta_003.nzt

Measurement Results

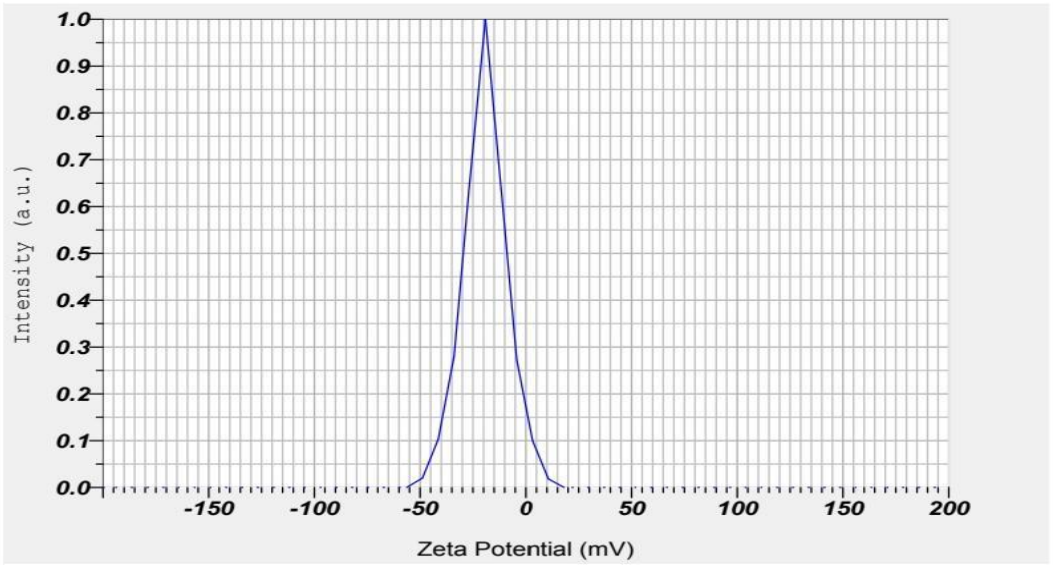
Date	: Tuesday, December 09, 2025 10:12:35 AM
Measurement Type	: Zeta Potential
Sample Name	: 14040918-Ebrahimzadeh-3499AA-MgO-zeta
Temperature of the Holder	: 25.2 °C
Dispersion Medium Viscosity	: 0.891 mPa·s
Conductivity	: 0.191 mS/cm
Electrode Voltage	: 3.4 V

Calculation Results

Peak No.	Zeta Potential	Electrophoretic Mobility
1	-19.2 mV	-0.000149 cm2/Vs
2	--- mV	--- cm2/Vs
3	--- mV	--- cm2/Vs

Zeta Potential (Mean) : -19.2 mV

Electrophoretic Mobility Mean : -0.000149 cm^2/Vs



Explore the future Automotive Test Systems | Process & Environmental | Medical | Semiconductor | Scientific HORIBA

Figure 5, Zeta potential of magnesium oxide nanoparticles.

Table 1. Effect of nanoparticles on the fecundity of the saw-toothed grain beetle.

Treatments	Concentration (ppm)	Mean number of eggs laid	Number of emerged adults	Productivity (%)
MgO	500	273.33^{b}	191.67^{b}	70.12^{b}
	1000	194.33^{d}	98.67^{d}	50.76^{d}
	1500	97.67^{f}	41.33^{f}	42.32^{e}
LSD (0.05)		6.41	4.82	2.11
F		185.32	162.47	148.76
CV%		1.98	2.34	2.87

* Significant at P≤0.05.

Influence of nanoparticles on egg incubation period of western saw-toothed grain beetle

As shown in Table 2, MgO NPs significantly increased the egg incubation period of the saw-toothed grain beetle. In the same context, the calculated F value at the 0.05 level of significance was significant (F = 21.64, P ≤ 0.05), indicating differences between treatments. Longer incubation times were observed at higher nanoparticle concentrations. At 1500 ppm, the longest incubation period (7.00 days) was found, whereas the shortest (5.33 days) was found in the control treatment. This effect might be attributed to the nanoparticles' ability to induce oxidative stress in developing eggs, thereby impairing key biological functions, such as cell division. Moreover, MgO NPs may alter the permeability of the egg chorion, potentially slowing embryonic development by reducing the efficiency of nutrient and gas transport. The toxic effects of nanoparticles may also be related to their high surface area, which allows greater interaction with biological membranes (Zhang, 2014), as well as to the possible release of metal ions from the nanoparticles. In conclusion, MgO NP treatment extended egg incubation and may stress reproduction and development in the insect, consistent with previous studies on nanoparticle effects.

Table 2. Effect of nanoparticles on the egg incubation period of the saw-toothed grain beetle.

Material	Egg incubation period (days) at			
	Control	500	1000	1500
MgO NPs	5.33^{c}	5.67^{c}	6.00^{c}	7.00^{b}
LSD (0.05)	2.05			
F value	2			
%CV	17.92			

* Significant at P ≤ 0.05.

Duration of the saw-toothed grain beetle larval stage under the influence of nanoparticles

The larval period of the saw-toothed grain beetle was highly influenced by MgO NPs (Table 3). The statistical differences among the treatments were confirmed by the calculated F-value (F = 34.18, P ≤ 0.05). Larval duration increased progressively with increasing nanoparticle concentration. The minimum duration (14.67 days) was recorded in the control treatment, and the maximum (20.67 days) was observed at 1500 ppm. This phenomenon may result from physiological stress induced by nanoparticles, possibly via ROS induction and oxidative stress. This stress can affect metabolism (e.g., digestive enzymes) and hormonal regulation of molting and metamorphosis (ecdysteroids), leading to reduced growth rate and prolonged development (Zahran and Sayed, 2021).These findings are consistent with previous research showing that when nanoparticles are used, larval duration increases due to impairment of various physiological and metabolic processes.

Table 3. Effect of nanoparticles on the larval stage duration of the saw-toothed grain beetle.

Material	Larval stage duration (days) at			
	Control	500	1000	1500
MgO NPs	14.67^{c}	16.00^{bc}	17.67^{a}	20.67c
LSD (0.05)	2.84			
F value	34.18			
%CV	8.66			

* Significant at P≤0.05.

Influence of nanoparticles on duration of pupal stage

As illustrated in Table 4, the mean duration of the pupal stage of the saw-toothed grain beetle was significantly prolonged in MgO NPs treatment compared to the control, in a dose-dependent manner. In addition, the duration at the pupal stage level was also significantly affected, with increasing values from 4.00 days in the control to 5.67 days at 1500 ppm MgO NPs revealing a clear concentration-dependent effect.

Table 4, Effect of nanoparticles on the pupal stage duration of the saw-toothed grain beetle.

Material	Pupal stage duration (days) at			
	Control	500	1000	1500
MgO NPs	4.00^{b}	4.33^{b}	5.00^{ab}	5.67^{a}
LSD (0.05)		0.85	0.90	0.95
%CV		9.2	11.1	12.0

* Significant at P≤0.05.

The low coefficient of variation (9.2-12.0%) indicates high data reliability. The extension is a consequence of the oxidative stress induced by reactive oxygen species (ROS) produced by MgO NPs, which can disrupt cell membranes, metabolic pathways, and enzyme activity, and may also interfere with hormonal regulation of molting and metamorphosis. Alternatively, nanoparticles could disrupt gut physiology, limiting nutrient absorption and the

energy available for development. The lack of clear evidence for direct metabolic toxicity suggests that the observed effects are physiologically mediated via stress mechanisms, a possibility consistent with previous studies that identified prolonged and altered biochemical signaling, providing a mechanistic understanding (Wang et al., 2012; Park et al., 2016).

Impact of nanoparticles on the mortality rate of adult saw-toothed grain beetles

Table 5 shows the effect of MgO NPs on the mortality percentage of adult *O. surinamensis* exposed to different conditions of locomotion and temperature under laboratory conditions. Mortalities at the earliest exposure time (day 2) were generally low, with 0% mortality in the control and 16.67% at 500 ppm. In a time- and concentration-dependent manner, mortality increased significantly; at the highest concentrations, this reached 100% mortality between days 12 and 16. The control group, on the other hand, did not exceed 43.33% mortality by day 16. Differences between treatments were significant ($P \leq 0.05$). This indicates strong cumulative toxicity of MgO NPs on the adult beetles. This work describes different biological pathways that might be responsible for such toxicity. The ROS generated likely caused oxidative stress and damage to proteins, lipids, and nucleic acids in beetle cells, especially at higher concentrations, resulting in 100% mortality (Kumar et al., 2018b). The extensive leakage of intracellular fluids caused by MgO NPs, possibly strengthening permeability and weakening cell membrane stability, may also have contributed to the increased mortality, confirming the dose-response relationship (Siddiqi and Husen, 2017). As these particles are at the nanoscale, they likely disrupted cuticle integrity and ingestion, leading to structural damage consistent with the prolonged developmental stages observed in this study (Rai et al., 2014). The findings of this research align with technological advances in nanoparticles for managing stored-product pests. Similarly, biomass-synthesized nanoparticles such as SeNPs and TiO_2NPs reduced the survival and development of bean beetle pests and represent small-scale, more affordable pest control methods (Helmy et al., 2023). Compared to previous studies, we reported that MgO NPs produced >100% lethality at high concentrations within 30 min, demonstrating approximately 10 times higher toxicity than other tested metal oxide nanoparticles. In summary, these findings not only highlight the potential of MgO NPs as safe and effective insecticidal agents but also provide novel insights into their putative mode of action across insect species, including direct effects on adult mortality and the relationship between cellular-level and phenotype-level mechanisms at the population level. These results highlight the potential of MgO NPs as an important alternative to chemical pesticides against *O. surinamensis*.

Table 5. Mortality percent of adult saw-toothed grain beetle due to the effect of magnesium oxide nanoparticles.

Material	Concentrations (ppm)	2	4	6	8	10	12	14	16
MgO NPs	500	16.67^{e}	35.55^{e}	50.00^{e}	65.47^{e}	72.62^{d}	85.71^{c}	89.68^{c}	95.24^{b}
	1000	30.00^{d}	46.66^{d}	68.98^{d}	82.74^{c}	91.07^{c}	94.44^{c}	100^{a}	100^{a}
	1500	43.33^{c}	64.44^{c}	77.31^{c}	87.50^{bc}	95.83^{b}	100^{a}	100^{a}	100^{a}
Control		0.00^{f}	6.67^{f}	13.33^{f}	23.33^{f}	26.67^{e}	33.33^{d}	36.67^{d}	43.33^{c}
LSD(0.05)		8.92	12.47	11.32	9.85	8.11	7.02	6.11	5.84
%CV		12.84	14.63	13.11	10.92	9.34	8.27	7.45	6.92

* Significant at P≤0.05.

Influence of nanoparticles on percentage weight reduction of infected rice seeds

In this study, the overall weight loss of rice seeds, as influenced by MgO NPs on *O. surinamensis* feeding and population parameters was significantly reduced. On the other hand, the highest concentration of MgO NPs (1500 ppm), as evident from the recorded data, produced the greatest inhibition in insect activity, as reflected by the lowest weight loss (Table 6). Our findings agree with earlier reports showing that nanoparticles (Al_2O_3 and ZnO NPs) minimize pest-related losses by inhibiting insect feeding and progeny production post-harvest (Elbeshehy et al., 2018; Khatami et al., 2019). Nevertheless, the decrease in weight loss observed in the

present study appears higher than that reported for other nanoparticles, which could be attributed to the intrinsic physicochemical properties of MgO NPs, including high surface reactivity, small particle size, and high insecticidal activity. Similarly, the loss of seed weight observed here is directly associated with MgO NP-induced adult mortality and prolonged developmental stages. This demonstrates a clear dose-dependent effect, strengthening the prospect of using MgO NPs as novel bio-insecticides, greener than conventional insecticides. Also, nanoparticles can form a thin external layer on the seeds, acting as a physical barrier that reduces feeding efficiency, in accordance with previously reported mechanisms (Rai et al., 2014). In summary, this study shows that MgO NPs not only enhance insect mortality but also significantly reduce the economic impact on seeds. More specifically, this is the first direct evaluation of MgO NPs against the saw-toothed grain beetle on rice seeds as a laboratory model to provide stronger evidence of their dual mode of action (toxic + physical barrier) compared to previously studied nanoparticles.

Table 6. Effect of magnesium oxide nanoparticles on percentage weight loss at different stages of saw-toothed grain beetle infested rice seeds.

Material	Concentrations (ppm)	7	14	21	28	35	42	49
MgO NPs	500	2.23^{e}	3.20^{e}	3.50^{e}	4.40^{e}	4.87^{e}	5.10^{e}	5.97^{e}
	1000	1.70^{d}	2.50^{d}	3.10^{d}	3.80d	3.93^{d}	4.40^{d}	5.20^{d}
	1500	1.20^{c}	1.73^{b}	2.20^{b}	2.73^{b}	3.20^{b}	3.47^{b}	4.33^{b}
Control		3.90^{a}	4.53^{a}	4.93^{a}	5.20^{a}	5.67^{a}	6.13^{a}	6.80^{a}
LSD(0.05)		0.35	0.38	0.41	0.42	0.45	0.48	0.50
%CV		8.5	7.9	8.2	8.0	8.6	8.3	8.1

* Significant at P≤0.05.

Impact of nanoparticles on the germination percentage of rice seeds

The effect of MgO NPs on saw-toothed grain beetle infested rice seeds is represented in Table 7, where P ≤ 0.05 indicates that magnesium oxide nanoparticles have a significant effect on the germination percentage of rice seeds. The germination (G) rate percentage in the control treatment was 88.33%, showing that seed viability was reduced in beetle-infested seeds. MgO NPs were applied at concentrations of 0, 250, 500, and 1000 ppm, considering maximum germination. Among all nanoparticle treatments, MgO NPs showed the highest germination rates, reaching 96.67% at 500 ppm and 93.33% at 1000 ppm. At 1500 ppm, the germination percentage decreased to 86.67%, indicating potential phytotoxicity at higher concentrations. These results were significantly different between treatments (LSD = 6.0, P = 0.002) and showed low variability (CV = 3.2%) These results can be attributed to numerous mechanisms. The presence of MgO NPs might ameliorate insect-feeding-induced damage, thereby increasing seed viability and germination. Moreover, previous work indicates that nanoparticle treatment might enhance water uptake and may activate early germination enzymatic activities, leading to improved germination percentage and overall seed physiological performance (Alhammad et al., 2023). Nevertheless, these effects become phytotoxic at higher concentrations (1500 ppm). In general, these findings indicate a dual function of MgO NPs in agriculture: at high concentrations, they may be beneficial for pest control, where high concentrations are required for insect mortality, while at recommended concentrations; they appear to act as positive stimulators of germination, thereby improving the agricultural quality of infested seedlings.

Table 7. Effect of magnesium oxide nanoparticles on germination percent of rice seeds infested with saw-toothed grain beetle.

Material	Concentrations (ppm)	Germination percentage (%)
MgO NPs	500	96.67^{a}
	1000	93.33^{a}
	1500	86.67^{bc}
Control		88.33^{b}
LSD(0.05)		6.0
%CV		3.2

* Significant at P≤0.05.

Conclusions

In this study, MgO NPs were successfully biosynthesized using ginger (*Zingiber officinale*), yielding well-stabilized MgO NPs with desirable physicochemical properties. On adult saw-toothed grain beetles (*Oryzaephilus surinamensis*), the nanoparticles showed a significant effect. They killed the tested insects completely within a very short time at higher concentrations. The nanoparticles also affected insect life-history traits, including reduced oviposition, decreased adult emergence, and prolonged developmental stages. These effects led to lower weight loss in treated rice seeds, confirming the activity of MgO NPs at both the individual and population levels. This study is significant as it presents novel understandings that are different from earlier findings documented in the literature. Earlier studies assessed biosynthesized MgO NPs for their insecticidal properties. The present findings observe and compare the effects of nanoparticles on the life cycle and other traits of insect pests and seed germination and protection. It also provides data on their efficacy in a concentration-dependent manner. The findings also reveal that MgO NPs are not phytotoxic to seed germination when used at their low to moderate concentrations. This offers practically feasible solutions to protect stored grains from pests. On the whole, biosynthesized MgO NPs are an innocuous, eco-friendly, and effective substitute to detrimental chemical pesticides. They offer strong insecticidal activity and maintain seed viability, making them an attractive and sustainable strategy for post-harvest pest management.

Author's contributions

EERS carried out the experimental work, analyzed the data, and drafted the manuscript. AAH conceptualized and supervised the study, designed the experiments, and critically revised the manuscript for important intellectual content. Both EERS and AAH contributed to the critical assessment of the research, participated in editing and refining the manuscript, and enhanced its scientific clarity and presentation. All authors reviewed and approved the final version of the manuscript.

Research Funding

This research did not receive any grant from funding agencies.

Conflict of Interest

The authors declare no conflict of interest.

Sustainable Development Goals Targeted

SDG 2: Zero Hunger
SDG 3: Good Health and Well-being
SDG 12: Responsible Consumption and Production

Policy Reference

Promotion of Integrated Pest Management (IPM) and Eco-friendly Nanotechnology-based Alternatives for Sustainable Stored Grain Protection.

Publisher's Note

The publisher remains neutral regarding jurisdictional claims and institutional affiliations. The views and data presented are solely those of the authors and do not necessarily reflect those of *Plant Protection* or its publisher, who assumes no responsibility for errors or consequences arising from the use of this information.

References

Abbott, W.S., 1925. A method of computing the effectiveness of an insecticide. Journal of Economic Entomology 18(2), 265-267.

Abdullah, A.S., Haider, A.A., 2025. Evaluation of nanopesticides in controlling sub-adult stages of the great wax moth, Journal of Nanostructures 15(3), 1279-1286.

Ahmad, R., Hassan, S., Ahmad, S., Nighat, S., Devi, Y.K., Javeed, K., Usmani, S., Ansari, M.J., Erturk, S., Alkan, M., Hussain, B., 2021. Stored grain pests and current advances for their management. IntechOpen. https://doi.org/10.5772/intechopen.101503.

Al-Bakr, A.A.M.H., 1999. Effect of *Melia azedarach* L. on the biology of the cowpea weevil. Master's thesis, University of Mosul, Iraq.

Alghuthaymi, M., Khan, S., Siddiqi, R., 2021. Toxicity of magnesium oxide nanoparticles on stored-product insects. Journal of Stored Products Research 92, 101792.

Alhammad, B.A., Ahmad, A., Seleiman, M.F., Tola, E., 2023. Seed priming with nanoparticles improved germination. Plants 12(4), 690.

Al-Iraqi, R.A., Ramadan, N.A., 2010. Applied picture guide to agricultural pest control. Al-Yazouri Scientific Publishing and Distribution, Amman, Jordan.

Al-Qudsi, Y., Al-Khadr, A., Al-Gharib, I., Al-Salem, H.S., Ali, M., Al-Manoufi, A., 2021. Role of nanotechnology in enhancing cereal crop productivity and supporting the agricultural economy. International Journal of

Scientific Research and Sustainable Development 4(1), 1-17.

Al-Rawi, K.M., Khalaf Allah, A.A.M., 2000. Design and analysis of agricultural experiments. University of Mosul Press.

Arthur, F.H., 2001. Immediate and delayed mortality of *Oryzaephilus surinamensis* (L.) exposed on wheat treated with diatomaceous earth: effect of temperature, relative humidity and exposure interval. Journal of Stored Products Research 37, 13-21.

Asbar, R., 2024. Efficacy of some plant extracts against adults of rice weevil (*Sitophilus oryzae* L.) under laboratory conditions. Arab Journal of Plant Protection 42(3), 368-376.

Batool, M., Raja, M.U., Mukhtar, T., Hassan, M.U., Ahsan, R., Ullah, S., Zakria, M., 2026. Phenotypic and molecular assessment of bacterial blight resistance genes in elite rice germplasm of Pakistan. Archives of Phytopathology and Plant Protection. 1-13. https://doi.org/10.1080/03235408.2026.2627616

Champ, B.R., Dyte, C.E., 1976. Report of the FAO global survey of pesticide susceptibility of stored grain pests. FAO Plant Production and Protection Series No. 5. Food and Agriculture Organization.

Elbeshehy, E.K.F., Elshikh, M.S., Fouda, A., 2018. Insecticidal effect of ZnO and Al_2O_3 nanoparticles. Environmental Science and Pollution Research 25(11), 11292-11301.

Ghorab, K., Ghrissi, K., 2024. Green biosynthesis of copper oxide nanoparticles using aqueous extract of *Artemisia herba-alba* and studying their antibacterial and antioxidant activity. Master's thesis, Kasdi Merbah University, Ouargla, Algeria.

Hallaq, F.H., Al-Samara, M., 2003. Stored product pests and their control. Directorate of University Books and Publications, Faculty of Agriculture, University of Aleppo.

Helmy, E.A.M., San, P.P., Zhang, Y.Z., Adarkwah, C., Tuda, M., 2023. Entomotoxic efficacy of nanoparticles against pests. Scientific Reports 13(1), 8508.

Hill, D.S., 2002. Pests of stored foodstuffs and their control. Kluwer Academic Publishers.

Hussain, S., Younas, Z., Abasi, F., Nazik, M., Ahmad, F., Raja, N.I., Mukhtar, T., Manzoor, Z., Khan, R., Mashwani, Z.U.R., 2026. Deciphering the potential of silver-selenium nanocomposites on growth metrics, physiological attributes, and antioxidant profiles in cotton (*Gossypium hirsutum* L.). Plant Nano Biology 16, 100271. https://doi.org/10.1016/j.plana.2026.100271

Huston, M., DeBella, M., DiBella, M., Gupta, A., 2021. Green synthesis of nanomaterials. Nanomaterials 11(8), 2130.

Ibrahim, F.I.K., Hasan, A.A., Mustafa, Z.M., 2022. Evaluation of some nanoparticles as insecticides on the biology of saw-toothed grain beetle. Master's thesis, University of Kirkuk, Iraq.

Ismail, A.Y.H., 2014. Pests of stored materials. College of Education for Pure Sciences, University of Mosul, Iraq, 400 pp.

Jabbar, A., Tariq, M., Gulzar, A., Mukhtar, T., Zainab, T., 2022. Lethal and sub lethal effects of plant extracts and green silver nanoparticles against *Culex pipiens* mosquitoes. Pakistan Journal of Zoology 54(3), 1259-1267.

Jamil, Z., Mukhtar, T., Raja, M.U., Shahbaz, M., Seelan, J.S.S., Tatar, M., Ali, A., Fatima, N., Bejaoui, R., Usanmaz Bozhüyük, A., 2025. Utilization of phytogenic silver nanoparticles and bacterial agents for the management of citrus canker disease. Turkish Journal of Agriculture and Forestry 49, 998-1008.

Kazem, A.H.J., 2018. Agricultural geography of the Arab world. Dar Al-Safa Publishing and Distribution.

Keita, S.M., Vincent, C., Schmit, T.P., Arnason, J.T., Belanger, A., 2001. Efficacy of essential oils as insecticidal fumigants. Journal of Stored Product Research 37, 339-349.

Khan, H.S., Tariq, M., Mukhtar, T., Gulzar, A., 2021. Insecticidal toxicity of plant extracts and green silver nanoparticles against *Aedes albopictus*. Pakistan Journal of Zoology 53(6), 2123-2128.

Khatami, M., Jahan, M.S., Nazari, M., Ghasemi, S., 2019. Impact of metal oxide nanoparticles on stored-product pests. Journal of Stored Products Research 82, 1-11.

Kumar, A., Bhanjana, G., Sharma, A., Sidhu, M.C., Dilbaghi, N., 2018b. Structural damage in insect cuticle by nanoparticles. Journal of Insect Physiology 107, 38-47.

Kumar, A., Singh, P., Sharma, V., 2018a. Impact of metal oxide nanoparticles on reproductive physiology. Journal of Insect Physiology 105, 45-53.

Lorini, I., 2005. Manual técnico para manejo de pragas. Embrapa Trigo, Passo Fundo, RS.

Mehak, A., Akram, A., Ali, A., Raja, N.I., Mukhtar, T.,

Sathiya Seelan, J.S., Shahbaz, M., 2026. Titanium dioxide nanoparticles as a sustainable strategy to control root-knot nematodes (RKNs) in tomato (*Solanum lycopersicum* L.). Physiological and Molecular Plant Pathology 143, 103122. https://doi.org/10.1016/j.pmpp.2026.103122

Mohammed, A.A., Kadhim, J.K., Hasan, A.M., 2019. Laboratory evaluation of entomopathogenic fungi for the control of khapra beetle and their effects on fecundity and longevity. Journal of Agricultural and Urban Entomology 35, 1-11.

More, R.D., Jamra, D.M., 2021. Eco-friendly green synthesis of MgO nanoparticles from *Zingiber officinale* root extract and its antibacterial application. International Journal of Rosh Applied Science Engineering Technology 9(6).

Mowery, S.V., Mullen, M.A., Campbell, J.F., 2002. Mechanisms underlying saw-toothed grain beetle (*Oryzaephilus surinamensis* L.) infestation of consumer food packaging materials. Journal of Economic Entomology 95(6), 1333-1336.

Nazir, K., Mukhtar, T., Javed, H., 2019. *In vitro* effectiveness of silver nanoparticles against root-knot nematode (*Meloidogyne incognita*). Pakistan Journal of Zoology 51(6), 2077-2083.

Omran, I.M., Hassan, K.S., Mansour, A.L.N.A.A., 2021. Evaluation of plant extracts on mortality and development of saw-toothed grain beetle. Indian Journal of Ecology 48(SI), 160-164.

Park, E.-J., Kim, H., Kim, Y., Choi, K., Park, K., 2016. Oxidative stress and toxicity of nanomaterials. Nanotoxicology 10(1), 1-23.

Patil, S.D., Morbale, S.T., 2022. Biogenic synthesis of manganese nanoparticles: a review. International Journal of Biological, Pharmaceutical and Applied Sciences 11(11), 5578-5586.

Patil, S.P., Chaudhari, R.Y., Nemade, M.S., 2022. *Azadirachta indica* leaves mediated green synthesis of metal oxide nanoparticles: a review. Talanta Open 5, 100083.

Radulescu, D.-M., Surdu, V.-A., Ficai, A., Ficai, D., Grumezescu, A.-M., Andronescu, E., 2023. Green synthesis of metal and metal oxide nanoparticles: principles and biomedical applications. International Journal of Molecular Sciences 24(20), 15397.

Rai, M., Ingle, A.P., Gade, A.K., Duran, N., 2014. Nanoparticles as new generation insecticides. Applied Microbiology and Biotechnology 98(10), 4497-4505.

Shahbaz, M., Akram, A., Raja, N.I., Mukhtar, T., Mehak, A., Fatima, N., Ajmal, M., Ali, K., Mustafa, N., Abasi, F. 2023. Antifungal activity of green synthesized selenium nanoparticles and their effect on physiological, biochemical, and antioxidant defense system of mango under mango malformation disease. PLoS ONE 18(2): e0274679. https://doi.org/10.1371/journal.pone.0274679

Siddiqi, K.S., Husen, A., 2017. Plant-mediated nanoparticles and their applications. Journal of Trace Elements in Medicine and Biology 40, 10-23.

Sinha, N., Ray, S., 2024. The potential of ginger (*Zingiber officinale* Rosc.) extracts as a bio-pesticide. Journal of Entomology and Zoology Studies 12(3), 38-45.

Tabu, D., Selvaraj, T., Singh, S.K., Mulugeta, N., 2012. Management of adzuki bean beetle using botanicals and oils. Journal of Agricultural Technology 8(3), 881-902.

Wang, Q., Li, W., Sun, Y., Zhao, Y., 2012. Oxidative stress as mediator of nanoparticle effects. Plos One 7(12), e52625. https://doi.org/10.1371/journal.pone.0052625.

Yasin, Q.U.A., Sattar, R., Amin, M., 2025. Green synthesis of silver oxide nanoparticles using *Zingiber officinale* extract: catalytic and antibacterial potentials. Conclusions in Engineering 8(1).

Zahran, N.F., Sayed, R.M., 2021. Protective effect of nanosilica against saw-toothed grain beetle. Journal of Stored Products Research 92, 101799.

Zhang, W., 2014. Nanoparticle aggregation: principles and modeling. In: Nanomaterials: Impacts on cell biology and medicine, pp. 19-43.