Pakistan J. Zool., vol. 58(2), pp 847-855, 2026 DOI: https://dx.doi.org/10.17582/journal.pjz/20241008140626

Toxicity and Repellency Potential of Silver Nano-Formulated Phytoextracts Against Rice Weevil *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae)

Muhammad Salman Saeed[1], Umar Farooq[1], Muhammad Zeeshan Majeed[1]*, Lamya Ahmed Alkeridis[2], Samy Sayed[3], Abu Bakar Muhammad Raza[1] and Asma Akram[1]

[1]*Department of Entomology, College of Agriculture, University of Sargodha, Sargodha 40100, Pakistan*
[2]*Department of Biology, College of Science, Princess Nourah Bint Abdulrahman University, P.O. Box 84428, 11671 Riyadh, Saudi Arabia*
[3]*Department of Economic Entomology and Pesticides, Faculty of Agriculture, Cairo University, Giza 12613, Egypt*

ABSTRACT

Rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae), is one of the most widely distributed destructive pests of stored rice and wheat grains. Synthetic insecticides and fumigants are predominately used to control this pest. However, wide use of these chemicals manifest pesticidal residues and pest resistance necessitating to look for some other environmental-friendly alternatives such as nano-formulated botanical extracts. This study evaluated nano-formulated leaf extracts of some promising plant species against *S. oryzae* adults. Initial screening of the acetone extracts of neem (*Azadirachta indica* A. Juss.), guava (*Psidium guajava* L.), dhraik (*Melia azedarach* L.), tobacco (*Nicotiana tabacum* L.) and eucalyptus (*Eucalyptus camaldulensis* Dehn.) using grain treatment bioassay method showed maximum and significant weevil mortality by the extracts of *A. indica* and *P. guajava i.e.* 98 and 94%, respectively at 120 h post-exposure. These extracts were further nano-formulated using silver nitrate ($AgNO_3$). Toxicity and repellency of different concentrations (*i.e.* 10, 5, 2.5 and 1.25%) of these nano-formulated extracts were determined against *S. oryzae* weevils. Results showed significant mortality of the exposed weevil individuals by all treatments and this mortality response was directly proportional to the extract concentration and exposure time. Nano-formulated *A. indica* extract showed highest mortality (98.7%), followed by *M. azedarach* (97%), *N. tabacum* (96%) and *P. guajava* (84%) at 96 h post-exposure. Probit analysis exhibited minimum LC_{50} for *A. indica* (0.62%), followed by *P. guajava* (0.66%), *N. tabacum* (0.71%) and *M. azedarach* (0.94%) at 96 h post-exposure. In case of repellency, 10% concentration of the nano-formulated *N. tabacum* extract exhibited highest repellency (54%), followed by *M. azedarach* (48%) and *P. guajava* (28%) after 24 h of exposure. Overall study results demonstrated the effectiveness of these nano-formulated phytoextracts against *S. oryzae* advocating their integration in eco-friendly management of stored grain insect pests.

Article Information
Received 08 October 2024
Revised 15 October 2024
Accepted 27 November 2024
Available online 15 May 2025 (early access)
Published 13 February 2026

Authors' Contribution
MZM and ABMR conceived the idea and designed the study. MSS and UF performed experimentation and recorded data. AA and LAA analyzed the data and prepared results. MSS, UF and AA wrote the initial draft of manuscript. SS and ABMR technically proofread the manuscript. MZM and ABMR supervised the research work. LAA and SS provided technical and financial assistance for the study. All authors have read and approved the final version of the manuscript.

Key words
Stored grain pests, Rice weevil, Silver nanoparticles, Nano-formulation, Phytoextracts, Repellency bioassay, *In-vitro* toxicity

INTRODUCTION

Rice (*Oryzae sativa* L. Poaceae) is one of the most imperative and essential staple crops, particularly in Asian countries (Chandio *et al*., 2016). Rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae), is one of the most destructive pests of stored grains worldwide including rice. This pest causes substantial damage to stored rice in tropical and sub-tropical regions with losses reaching up to 40% (Rani *et al*., 2019; Covele *et al*., 2020). Synthetic insecticides and fumigants such as methyl bromide, magnesium and aluminum phosphides are the prime source to control *S. oryzae* infestations both at domestic and commercial levels (Nayak *et al*., 2020; Wakil *et al*., 2021). However, their use and effectiveness in stored grain sector have been limited due to their residual toxicity, health hazards, environmental contamination and problems of pest resistance and resurgence (Chayengia *et*

* Corresponding author: zeeshan.majeed@uos.edu.pk
0030-9923/2026/0002-0847 $ 9.00/0

al., 2010; Hubert *et al*., 2018).

These ecological consequences of extensive and continuous use of synthetic fumigants and other chemicals in stored grain sector necessitate looking for some biorational and environmental-friendly pest control options such as plant-based extracts (Isman, 2020). Phytoextracts can be effective alternatives to synthetic insecticides against stored grain insect pests (Dubey *et al*., 2008). Due to their plant origin, they exhibit low persistency, low mammalian toxicity, high volatility and effective toxicity against stored grain insect pests (Regnault, 1997; Suteu *et al*., 2020).

Moreover, nanotechnology is also being perceived as a promising field of research with a significant potential for future pest management (Muraisi *et al*., 2022). Nano-formulations, particularly silver nanoparticles (AgNPs)-based formulations, have significant impaclications in various agricultural disciplines due to their high surface area to volume ratio, physical and chemical stability, low toxicity and simple surface chemistry (Scrinis and Lyons, 2007; Ale *et al*., 2023). AgNPs synthesized through green methods can be effective carriers to transport agrochemicals to the targeted sites (Sankar and Abideen, 2015; Abbas *et al*., 2024). They have proven to be highly effective against insect pests demonstrating considerable insecticidal, antifungal and antiviral properties (Chandran *et al*., 2006; Srinivasan *et al*., 2023). Therefore, insecticidal phytoextracts formulated with AgNPs could be an efficient strategy against stored grain insect pests including *S. oryzae* weevils.

The present research work aimed to evaluate and compare the nano-formulated phytoextracts against *S. oryzae* weevils under laboratory conditions. Firstly, available promising local phytoextracts were assessed for their effectiveness against *S. oryzae* adults. Secondly, the most effective phytoextracts were nano-formulated using AgNPs and were evaluated against *S. oryzae* adults to determine their LC_{50} and LT_{50} values. Lastly, the repellency of these nano-formulated phytoextracts was also assessed against *S. oryzae* adults.

MATERIALS AND METHODS

Rearing of S. oryzae

S. oryzae population was taken from the local grain market of Sargodha, Punjab, Pakistan from stored rice and was maintained in the Laboratory of Entomology, College of Agriculture, University of Sargodha. Culture was feed on clean and disinfected white fine rice (super basmati, unpolished). Fifty adult weevils were released in glass containers (20×30 cm) and the containers were closed with a fine-mesh muslin cloth. These containers were kept in a growth chamber at 28±2°C temperature and 65±5% relative humidity. Weevil culture was reared up to F3 generation until its use in downstream bioassays.

Preparation of phytoextracts

Fresh leaves of neem (*Azadirachta indica* A. Juss.), guava (*Psidium guajava* L.), eucalyptus (*Eucalyptus camaldulensis* Dehn.), dharaik (*Melia azedarach* L.*)* and tobacco (*Nicotiana tabacum* L.) were collected from the plants in the vicinity of College of Agriculture, University of Sargodha during spring 2023. These leaves were washed with tap-water and were air-dried at room temperature (27°C) for two weeks. Shade dried leaves were powdered using an electric bleeder and were put in hermetic plastic bags. Using pure acetone as extraction solvent, the extraction of plant samples was carried out through Soxhlet apparatus (DH.WHM-12393, Daihan Scientific, South Korea) following the protocol described by Majeed *et al*. (2020) and Tayyab *et al*. (2022). Prepared phytoextracts were stored in dark-colored hermetic glass vials in refrigerator at 4 °C until their use in experimentation.

Synthesis and characterization of AgNPs-based nano-formulated phytoextracts

Silver nanoparticles of effective phytoextracts were synthesized using a chemical reduction method. First of all, a solution was prepared by dissolving 0.017g of silver nitrate ($AgNO_3$) in 100 mL of deionized water. The solution was then heated to 80 °C, while continuously stirring. Subsequently, the solution was transferred to a reflux condenser. To this solution, 10 mL of phytoextracts was added using a graduated pipette. The entire solution was heated in an oil bath at 100 °C for duration of 30 min, while maintaining constant stirring. Finally, the solution was allowed to cool to room temperature (27 °C). The formation of silver nanoparticles of both phytoextracts was confirmed and characterized using UV-visible spectrophotometer (UV-Vis, Perkin Elmer, Lambda 35), Raman Spectrometer (Peak Seeker Pro-785; Agiltron, USA) and Scanning Electron Microscope (SEM) (FEI Quanta 250, Hillsboro, OR, USA) following the protocols described by Jafir *et al*. (2021).

Toxicity bioassay against S. oryzae *weevils*

Treated grain bioassay method was used to determine the toxicity of phytoextracts against *S. oryzae* adults. First of all, 10% extracts were screened and then the most effective phytoextracts were formulated with silver ($AgNO_3$) nanoparticles. Experimental design was completely randomized with five replications for each of the four concentrations (*i.e.* 10, 5, 2.5 and 1.25%) of nano-formulated phytoextracts and a control (acetone) treatment. Five grams of raw white fine rice (Super Basmati, unpolished) were treated with one milliliter of each treatment in 60 mm glass Petri plates and 10 individuals of *S. oryzae* (containing both male and female ones) were released in each Petri plate and these plates were incubated in dark in a growth chamber at 28 ± 2°C temperature and 65 ± 5% relative humidity. Mortality of the exposed insect individuals was recorded at 12, 24, 48, 72, 96 and 120 h post-exposure and was corrected using Abbott formula (Abbott, 1925).

Repellency bioassay

Half filter-paper disc method was utilized to assess the repellency potential of nano-formulated phytoextracts. In brief, Whatman filter paper (No.1) discs were cut into two halves according to glass Petri plate (60 cm). One half of each paper was treated with 1 ml of either 10 or 5% concentration of each treatment (phytoextracts) and other half was treated with acetone alone (control). After treating, both halves were placed at room temperature (27°C) for drying up to 10 min and were rejoined in 60 cm glass Petri plate. Ten adults of *S. oryzae* were released in each Petri plate and were covered with lid and were incubated 28±2 ºC temperature and 65±5 % relative humidity. Data regarding the repellency of exposed insect individuals were recorded at 3, 18 and 24 h post-exposure (Elbrense *et al*., 2022).

Statistical analysis

The percent mortality and repellency of tested *S. oryzae* adults are presented graphically. Apart from this graphical representation, factorial analysis of variance (ANOVA) was run to analyze the mortality and repellency data by keeping exposure time and treatment concentration as factors, followed by Honestly significant different (HSD) to compare treatment means at 95% probability level ($P<0.05$). Median lethal concentration (LC_{50}) and median lethal time (LT_{50}) values were calculated by Probit analysis using POLO® statistical regression software. Prior to Probit analyses, data were corrected using Abbott's formula (Abbott, 1925). Percent repellency was determined by using a previously described equation (Elbrense *et al*., 2022). Statistical interpretation of data was done using Statistix 8.1® (Abbott, 1925).

$$PR = \left[\frac{(C-T)}{C+T}\right] \times 100$$

Where PR is percent repellency, C is numbers of insects on control and T is numbers of insects on treatment.

RESULTS

Characteristics of nano-formulated phytoextracts

The most effective phytoextracts *i.e. A. indica*, *M. azedarach*, *P. guajava* and *N. tabacum* were nano-formulated using silver ($AgNO_3$) particles and then the most effective two nano-formulations *i.e. A. indica* and *P. guajava* were further characterized using Raman spectroscopy, ultraviolet-visible (UV-vis) spectroscopy and scanning electron microscopy (SEM) techniques. All these determinations confirmed the formation of silver nanoparticles (AgNPs). The absorption spectra of nano-formulated *A. indica* and *P. guajava* extracts were determined by UV-visible spectroscopy in the wavelength range of 300–800 nm by taking deionized water as blank. Due to surface plasmon resonance, the color of solution was transformed from yellow to dark brown, which is thought to be the most important indicator of synthesis of AgNPs. The maximum absorbance spectrum of synthesized *A. indica* and *P. guajava* AgNPs was observed at 417 and 430 nm, respectively (Figs. 1, 2). Furthermore, the spectral measurement of AgNPs of nano-formulations of both extracts in liquid form was performed with Raman spectrometer (Peak Seeker Pro-785; Agiltron, USA) by a 785 nm laser as a source of excitation transferring a laser power of 50 mW with the help of a 40X objective lens.

The size and morphology of AgNPs of both nano-formulated extracts were determined by scanning electron microscope (SEM) at 100,000X magnification. The average size of both *A. indica* and *P. guajava* synthesized AgNPs was approximately 19 and 18 nm, respectively (Figs. 1, 2). Energy dispersive X-ray spectroscopy (EXD) related to SEM corroborated the presence of elemental silver by indicating the conversion of silver ions to silver nanoparticles. Furthermore, peaks of carbon, silver and oxygen appeared in case of aqueous extract of *A. indica* (Fig. 1), while the peaks of oxygen, potassium, chlorine, silicon and sodium appeared from the aqueous extract of *P. guajava* extract (Fig. 2).

Toxicity bioassays against S. oryzae *adults*

In preliminary screening, acetone extracts of five indigenous plant species were tested for their insecticidal potential against *S. oryzae* adults. Results of this bioassay in which weevils were exposed to 10% extracts of the plants showed that all extracts exhibited significant mortality ($F_{4,20} = 6.68$; $P = 0.0014$) of exposed weevils as compared to the control treatment (Supplementary Table I). Maximum mortality of *S. oryzae* adults was observed in case of extracts of *A. indica* (98%) and *P. guajava* (89%), followed by *M. azedarach* (87%) and *N. tabacum* (84%). Minimum weevil mortality (74%) was recorded for the extract of *E. camaldulensis* (Fig. 3A) Weevil mortality remained less than 5% in control treatment.

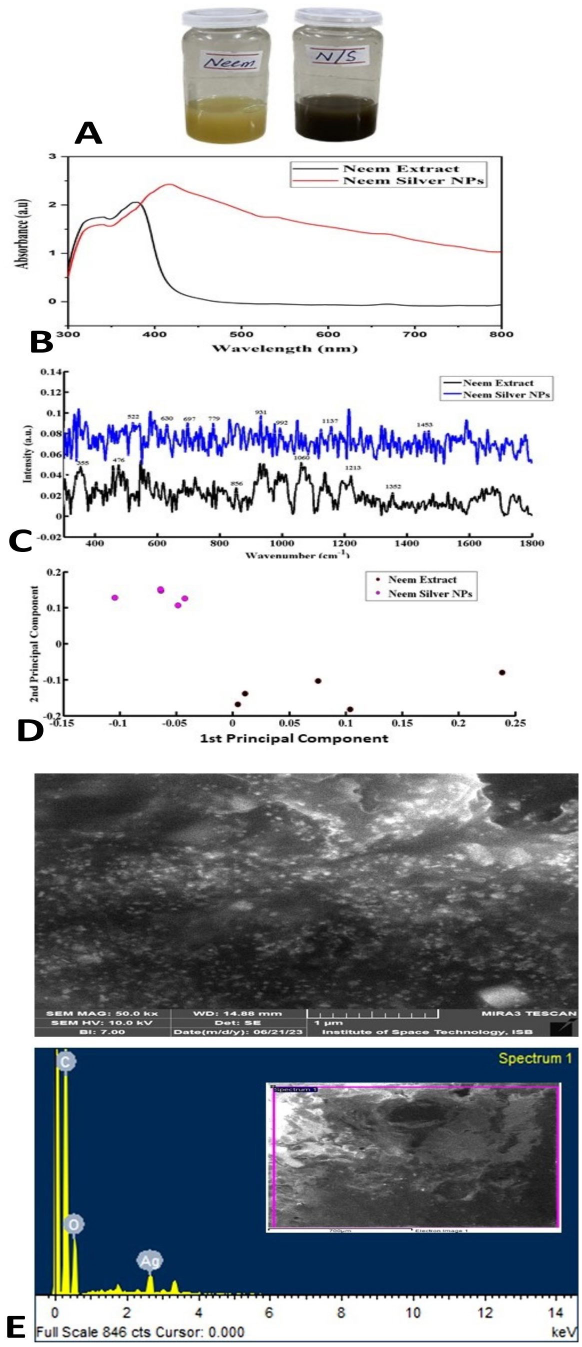

Fig. 1. Acetone extract of neem (*Azadriachta indica* L.) and its silver nanoparticles-based formulation (A) (aqueous solution of 1.0 mM $AgNO_3$ before (neem) and after (N/S) adding the botanical extract) and their Raman UV spectra (B), mean plots (C) and scatter plots (D) and (E) Scanning electron microscopic (SEM) image and energy dispersive x-ray spectroscopic (EDX) spectra and surface morphology (at 700 µm resolution) of silver nanoparticles of acetone extract of neem (*Azadriachta indica* L.).

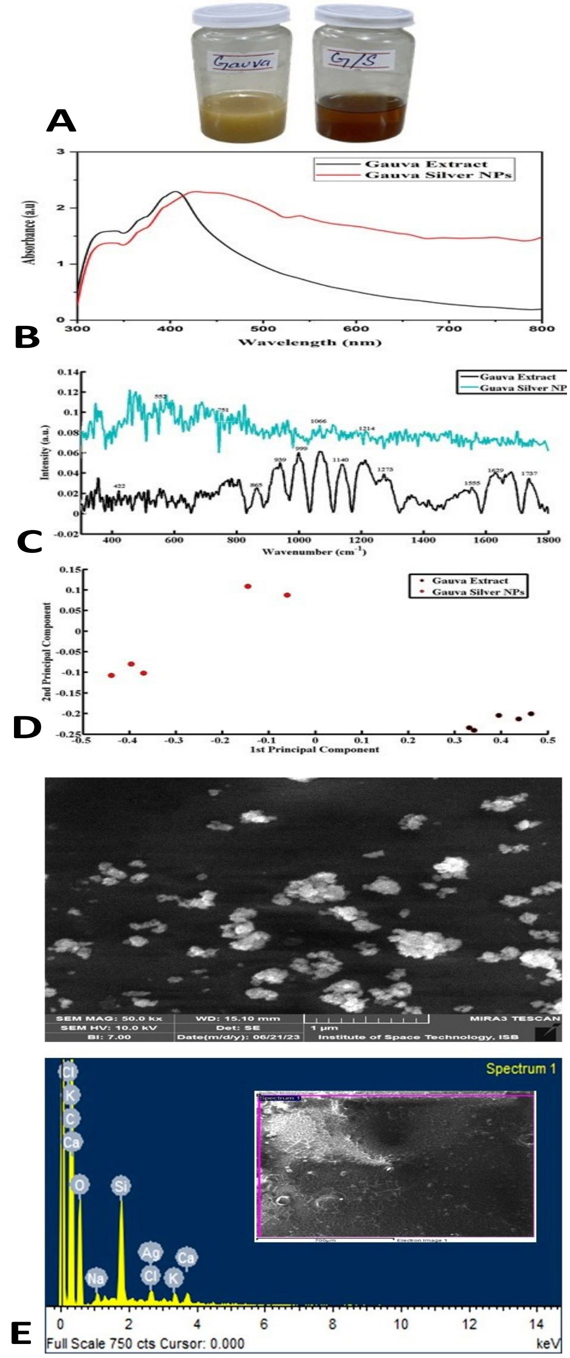

Fig. 2. Acetone extract of guava (*Psidium guajava* L.) and its silver nanoparticles-based formulation (A) (aqueous solution of 1.0 mM $AgNO_3$ before (guava) and after (G/S) adding the botanical extract) and their Raman UV spectra (B), mean plots (C) and scatter plots (D) and (E) Scanning electron microscopic (SEM) image and nergy dispersive x-ray spectroscopic (EDX) spectra and surface morphology (at 700 µm resolution) of silver nanoparticles of acetone extract of guava (*Psidium guajava* L.).

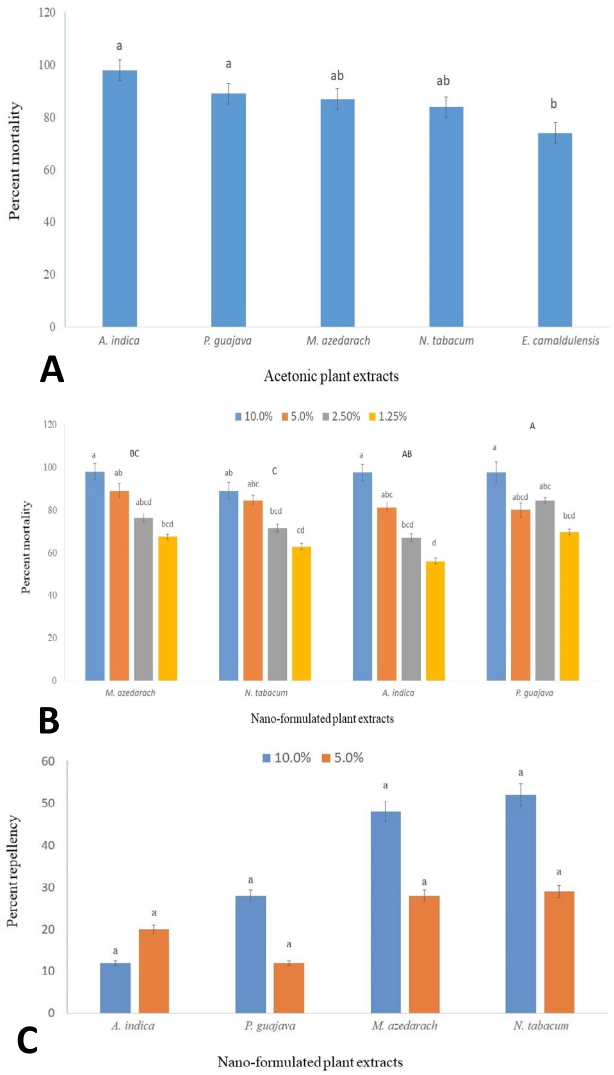

Fig. 3. Cumulative percent morality (mean±SE; n = 5) of adult individuals of rice weevil (*S. oryzae*) exposed to 10% acetone phytoextracts (A) different concentrations of nano-formulated acetone phytoextracts recorded at 96 h (B) and 24 h (C) post-exposure. Different small and capital letters at column tops indicate statistical difference between all treatments (one-way ANOVA; Tukey's HSD test at α= 0.05) and overall among the treatments (factorial ANOVA; Tukey's HSD test at α= 0.05), respectively.

In detailed toxicity bioassay, four phytoextracts (*i.e. A. indica*, *P. guajava*, *M. azedarach* and *N. tabacum*) which showed maximum and significant mortality of *S. oryzae* weevils were further formulated with silver nanoparticles (AgNPs) and were tested against *S. oryzae* adults using same protocol as done for previous bioassay. In this bioassay, different concentrations of the nano-formulated phytoextracts were used. Results of this bioassay clearly demonstrated a significant effect on the mortality of *S. oryzae* adults by the treatments ($F_{3, 64}$ = 7.53, P < 0.001), their concentrations ($F_{3, 64}$ = 39.70, P < 0.001) and by their interaction ($F_{9, 64}$ = 2.32, P= 0.0248) (Supplementary Table II). On overall basis, nano-formulated extracts of *A. indica* and *P. guajava* exhibited highest weevil mortality (*i.e.* 98%) at 96 h post-exposure and were statistically different from other two extracts (Fig. 3B).

Probit analysis of the weevil mortality data demonstrated almost similar trend of toxicity of nano-formulated phytoextracts against *S. oryzae* and this trend was directly proportional to concentration of the extract and exposure time (Tables I and II). According to probit analysis, *A. indica, P. guajava* and *N. tabacum* appeared to be the most toxic extracts exhibiting minimum LC_{50} and LT_{50} values *i.e.* 0.60, 0.66 and 0.71% at 96 h of exposure, and 4.97, 7.57 and 13.7 h for 10% concentration of extracts, respectively (Tables I and II). While, minimum LC_{50} and LT_{50} values were recorded for the extract of *M. azedarach.*

Table I. Median lethal concentration (LC_{50}) values of nano-formulated acetone leaf extracts of indigenous plant species evaluated against adults of rice weevil *S. oryzae* under laboratory conditions.

Botanical extracts	Observation time (h)	LC_{50} (%)	95% upper and lower fiducial limits	X^2-value	P value*
A. indica (Neem)	12	13.96	7.29-158.81	83.27	< 0.05
	24	4.32	6.64 -7.65	109.18	< 0.05
	48	1.16	0.64-1.63	94.17	< 0.05
	72	0.72	0.28-1.13	93.22	< 0.05
	96	0.62	0.38-1.03	72.85	< 0.05
M. azedarach (Dhraik)	12	3.78	2.83-5.06	117.32	< 0.05
	24	2.11	1.33- 2.86	161.44	< 0.05
	48	1.41	0.83 -1.91	148.40	< 0.05
	72	1.30	0.66 -1.84	211.82	< 0.05
	96	0.94	0.26 -1.49	242.40	< 0.05
N. tabacum (Tobacco)	12	3.49	1.99-6.06	122.91	< 0.05
	24	1.81	0.72- 2.77	146.35	< 0.05
	48	1.33	0.57-1.97	168.11	< 0.05
	72	0.93	0.29-1.49	196.05	< 0.05
	96	0.71	0.29-1.27	324.11	< 0.05
P. guajava (Guava)	12	5.83	3.43 -7.63	148.54	< 0.05
	24	4.11	2.53-7.65	147.20	< 0.05
	48	1.40	0.13-2.53	76.57	< 0.05
	72	0.79	0.29-1.27	74.44	< 0.05
	96	0.66	0.12- 1.14	117.10	< 0.05

*Since the significance level is less than 0.05, a heterogeneity factor is used in the calculation of confidence limits α denotes water used as solvent.

Table II. Median lethal time (LT_{50}) values of nano-formulated acetone leaf extracts of indigenous plant species evaluated against adults of rice weevil *S. oryzae* under laboratory conditions.

Botanical extracts	Concentration (%)	LT_{50} (h)	95% upper and lower fiducial limits	X^2-value	P value*
A. indica (Neem)	10	4.97	42.61-66.31	83.27	< 0.05
	5	19.74	15.73-37.47	109.18	< 0.05
	2.5	26.69	12.01-26.67	94.17	< 0.05
	1.25	52.15	7.3-19.61	93.22	< 0.05
M. azedarach (Dhraik)	10	14.85	0.82-9.39	270.41	< 0.05
	5	12.90	2.69-23.61	300.85	< 0.05
	2.5	14.10	3.48-19.78	197.07	< 0.05
	1.25	36.85	27.69-48.13	94.19	< 0.05
N. tabacum (Tobacco)	10	13.75	3.79-11.02	168.77	< 0.05
	5	12.15	2.79-23.94	306.13	< 0.05
	2.5	14.10	3.47-19.78	197.07	< 0.05
	1.25	36.85	27.68-48.13	94.19	< 0.05
P. guajava (Guava)	10	7.57	7.34-19.61	180.56	< 0.05
	5	21.44	12.01-26.67	178.74	< 0.05
	2.5	34.69	15.73-37.47	162.15	< 0.05
	1.25	55.15	42.61-66.31	87.250	< 0.05

*Since the significance level is less than 0.05, a heterogeneity factor is used in the calculation of confidence limits α denotes water used as solvent.

Repellency bioassay against S. oryzae *weevils*

Analysis of variance (ANOVA) performed on the results of repellency bioassay revealed that the treatments (phytoextracts) ($F_{3,32}$ = 3.50; P= 0.0509) and exposure time ($F_{1, 32}$ = 3.21; P= 0.0225) exhibited a significant effect on weevils repellency, while the interaction of both these factors exerted a non-significant effect ($F_{3,32}$= 1.90; P= 0.4521) on the repellence property of *S. oryzae* adults (Supplementary Table III). High concentration (10%) of nano-formulated *N. tabacum* extract exhibited the highest repellency effect (52%), followed by *M. azedarach* (48%), *P. guajava* (24%) and *A. indica* (12%). While, about 29, 28, 20 and 12% repellency was exhibited by the 5% extracts of *N. tabacum*, *M. azedarach*, *P. guajava* and *A. indica*, respectively (Fig. 3C).

DISCUSSION

Rice weevil *S. oryzae* has been a challenging stored products' pest being primarily controlled by the extensive applications of synthetic fumigants and other insecticides. Pest resistance, environmental contamination and health hazards are being manifested by this approach necessitating to look for other alternate pest control methods which would be safe and environment-friendly such as using pesticidal phytoextracts (Isman, 2020; Wakil *et al*., 2021).

This study therefore aimed to determine the insecticidal and repellency potential of some selected phytoextracts against *S. oryzae* adults. As nano-formulations of pesticidal compounds is being focused as a novel and effective approach (Fraceto *et al*., 2016), the effective phytoextracts were further nano-formulated using silver nanoparticles. Results of preliminary bioassay with 10% of acetone phytoextracts demonstrated a significant mortality of *S. oryzae* adults by the extracts of *A. indica*, *P. guajava*, *N. tabacum* and *M. azedarach* causing considerable weevil mortality as compared to control. These results are in accordance with the findings of Chayengia *et al*. (2010), Khani *et al*. (2011) and Hashim *et al*. (2017) who reported considerable mortality of *S. oryzae* weevils by these phytoextracts. Particularly, neem (*A. indica*) and guava (*P. guajava*) appeared to be the most toxic to *S. oryzae* in our bioassays. *A. indica* is a well-known plant species with insecticidal properties (Chaudhary *et al*., 2017; Ferreira and Alves, 2021).

Later on, AgNPs-based formulations of these phytoextracts were synthesized by green-route chemistry which is an eco-friendly and promising approach for stored grains insect pest management (Rehman *et al*., 2021; Jasrotia *et al*., 2022). The results of bioassay with nano-formulated phytoextracts against *S. oryzae* adults revealed a significant increase in percent mortality with the increase of concentration and exposure time. Our findings are consistent with many previous research reports (Debnath *et al*., 2011; Stadler *et al*., 2012; Zahir *et al*., 2012; Rouhani *et al*., 2013; Carbone *et al*., 2020; Srinivasan *et al*., 2023; Abdel-Megeed *et al*., 2024). Stadler *et al*. (2012) evaluated nano-structured alumina (NSA) against *S. oryzae* and *Rhyzopertha dominica* and reported high mortality of *S. oryzae* adults 3 days post-treatment to NSA-treated wheat. Goswami *et al*. (2010) reported the toxicity of different surface functionalized hydrophilic nanoparticles *i.e.* silver (AgNPs), silica (SNPs), aluminum oxide (ANPs), zinc oxide (ZNPs) and titanium dioxide (TNPs) nanoparticles against *S. oryzae*. Insect mortality due to AgNPs treatment was about 85%, obtained at dose rates of almost 10 ml/kg of grain. Similarly, Rani *et al*. (2019) and Adnan *et al*. (2022) reported a significantly high mortality of adults of *S. oryzae* and other sorted product insect pests with green-synthesized AgNPs mediated with the leaf extracts of *Moringa oleifera* (Moringaceae) and *Withania somnifera*, respectively.

The results of repellency bioassay revealed that all botanicals exhibited significant repelling effect to *S. oryzae* adults. In the present study, all nano-formulated phytoextracts showed moderate repellency at minimum exposure time of 3 h, while high repellency as recorded at

24 h post-exposure. These results are consistent with the findings of previous studies (Nerio *et al*., 2009; Jayakumar *et al*., 2017; Yeguerman *et al*., 2022; Arafah *et al*., 2023). The order of the repellency of phytoextracts at 10% was *N. tabacum* > *M. azedarach* > *P. guajava* > *A. indica* after 24 h of exposure time. Our results are in line with those of Kanmani *et al*. (2021) who reported 100% repellent effects of nano-formulated *N. tabacum* to *S. oryzae* and *C. maculatus* at 100 ppm of concentration. Zia-ul-Haq *et al*. (2014) reported that the repellent effect *of N. tabacum* and *M. azedarach* may be due to metabolic activities and sensitivity of insects to these botanicals. Similarly, Reeba and Helen (2021) and Shahzadi *et al*. (2019) reported highest repellency against *S. oryzae* and *T. castaneum* by plant mediated AgNPs prepared by aqueous extract of grapefruit (*Citrus paradisi*) and acetone essential oil of clove (*Syzygium aromaticum*), respectively.

CONCLUSION

On the basis of overall study results, it is concluded that silver nitrate ($AgNO_3$) based nano-formulated extracts of all tested plant species, particularly of neem (*A. indica*) and guava (*P. guajava*), exhibited a significant mortality of adults of rice weevil *S. oryzae*, while nano-formulated extracts of dhraik (*M. azedarach*) and tobacco (*N. tabacum*) caused considerable repellency of *S. oryzae* weevils as compared to control. These findings suggest that the commercial formulations of green nanoparticles could be developed to manage *S. oryzae* and other coleopterous stored grain pests. Moreover, the characterization of active components of phytoextracts and the validation of these phyto-formulations at large scale constitute the future perspectives of the study.

DECLARATIONS

Acknowledgments

Authors are grateful to Dr. Muhammad Irfan Majeed (Department of Chemistry, University of Agriculture, Faisalabad, Pakistan) for his valuable assistance in the fabrication and characterization of nano-formulations of phytoextracts. The authors are also grateful to Princess Nourah Bint Abdulrahman University, Riyadh, Saudi Arabia for supporting this study.

Funding

The authors are thankful to the Princess Nourah Bint Abdulrahman University Researchers Supporting Project number (PNURSP2025R82).

Data availability

All data taken and analyzed in this study are available in the published manuscript.

Supplementary material

There is supplementary material associated with this article. Access the material online at: https://dx.doi.org/10.17582/journal.pjz/20241008140626

Statemen of conflict of interest

The authors have declared no conflict of interest.

REFERENCES

Abbas, U., Majeed, M.Z., Alkherb, W.A.H., Alshehri, M.A., Alkeridis, L.A., Sayed, S., Majeed, M.I. and Riaz, M.A., 2024. Evaluation of silver nanoformulated plant extracts against larvae of fall armyworm *Spodoptera frugiperda* (J.E. Smith) under laboratory and field conditions. *Ent. Res.*, **11**: 1–11. https://doi.org/10.1111/1748-5967.70003

Abbott, W.S., 1925. A method of computing the effectiveness of an insecticide. *J. econ. Ent.*, **18**: 265–267. https://doi.org/10.1093/jee/18.2.265a

Abdel-Megeed, A., Abdel-Rheim, K.H., Kordy, A.M., El-Ghannam, S.A., Salem, M.Z. and Adel, M.M., 2024. Duckweed (*Lemna minor*) biomass aqueous extract-mediated synthesis of silver nanoparticles as a novel formulation era for long-term efficacy against *Tribolium castaneum* and *Sitophilus oryzae* adults on wheat seeds. *Biomass Convers. Biorefin.*, **1**: 1–18. https://doi.org/10.1007/s13399-024-05356-0

Adnan, M., Akbar, A., Mussarat, S., Murad, W., Hameed, I., Begum, S., Khan and S.N., 2022. Phytoextract-mediated synthesis of silver nanoparticles (AgNPs) and their biological activities. *Biomed. Res. Int.*, 9845022. https://doi.org/10.1155/2022/9845022

Ale, A., Andrade V.S., Gutierrez, M.F., Bacchetta C, Rossi, A.S., Santo, O.P., Desimone, M.F. and Cazenave J., 2023. Nanotechnology-based pesticides: Environmental fate and ecotoxicity. *Toxicol. appl. Pharm.*, **471**: 116560. https://doi.org/10.1016/j.taap.2023.116560

Arafah, N.S.M., Jun, C.Y., Shariff, S.S.M., Noor, N.Q.I.M. and Zaharudin, N., 2023. Effects of selected plants against rice weevil (*Sitophilus oryzae*). *Malay. appl. Biol.*, **52**: 113-118. https://doi.org/10.55230/mabjournal.v52i4.d044

Carbone, K., Santangelo, E., De Angelis, A., Micheli, L., Frosinini, R., Gargani, E. and Mazzucato, A., 2020. Green synthesis of silver nanoparticles from hyperpigmented tomato skins and preliminary evaluation of the insecticidal activity. *In: 28th Eur. Biom. Conf. Exhib.*, pp. 6–9.

Chandio, A.A., Yuansheng, J. and Magsi, H., 2016. Agricultural sub-sectors performance: An analysis of sector-wise share in agriculture GDP of Pakistan. *Int. J. econ. Fin.*, **8**: 156–162. https://doi.org/10.5539/ijef.v8n2p156

Chandran, S.P., Chaudhary, M., Pasricha, R., Ahmad, A. and Sastry, M., 2006. Synthesis of gold nanotriangles and silver nanoparticles using aloe-vera plant extract. *Biotechnol. Prog.*, **22**: 577–583. https://doi.org/10.1021/bp0501423

Chaudhary, S., Kanwar, R.K., Sehgal, A., Cahill, D.M., Barrow, C.J., Sehgal, R. and Kanwar, J.R., 2017. Progress on *Azadirachta indica* based biopesticides in replacing synthetic toxic pesticides. *Front. Plant Sci.*, **8**: 610. https://doi.org/10.3389/fpls.2017.00610

Chayengia, B., Patgiri, P., Rahman, Z. and Sarma, S., 2010. Efficacy of different plant products against *Sitophilus oryzae* (Linnaeus) (Coleoptera: Curculionidae) infestation on stored rice. *J. Biopest.*, **3**: 604. https://doi.org/10.57182/jbiopestic.3.3.604-609

Covele, G., Gulube, A., Tivana, L., Ribeiro-Barros, A. I., Carvalho, M. O., Ndayiragije, A. and Nguenha, R., 2020. Effectiveness of hermetic containers in controlling paddy rice (*Oryza sativa* L.) storage insect pests. *J. Stored Prod. Res.*, **89**: 101710. https://doi.org/10.1016/j.jspr.2020.101710

Debnath, N., Das, S., Seth, D., Chandra, R., Bhattacharya, S.C. and Goswami, A., 2011. Entomotoxic effect of silica nanoparticles against *Sitophilus oryzae* (L.). *J. Pest Sci.,* **84**: 99–105. https://doi.org/10.1007/s10340-010-0332-3

Dubey, N.K., Srivastava, B. and Kumar, A., 2008. Current status of plant products as botanical pesticides in storage pest management. *J. Biopest.*, **1**: 182–186. https://doi.org/10.57182/jbiopestic.1.2.182-186

Elbrense, H., El-Husseiny, I., Abo El-Makarem, H.A., Arab, A. and El-Kholy, S., 2022. Insecticidal, antifeedant and repellent efficacy of certain essential oils against adult rust-red flour beetle, *Tribolium castaneum*. *Egypt. J. Chem.*, **65**: 167–178. https://doi.org/10.21608/ejchem.2021.79263.3897

Ferreira, L.S. and Alves, S.N., 2021. Neem (*Azadirachta indica*): Larvicidal properties. A review. *Rev. Conex. Ciên.* **16**: 49–63. https://doi.org/10.24862/cco.v16i1.1287

Fraceto, L.F., Grillo, R., de Medeiros, G.A., Scognamiglio, V., Rea, G. and Bartolucci, C., 2016. Nanotechnology in agriculture: which innovation potential does it have? *Front. environ. Sci.*, **4**: 20. https://doi.org/10.3389/fenvs.2016.00020

Goswami, A., Roy, I., Sengupta, S. and Debnath, N., 2010. Novel applications of solid and liquid formulations of nanoparticles against insect pests and pathogens. *Thin Solid Films,* **519**: 1252–1257. https://doi.org/10.1016/j.tsf.2010.08.079

Hashim, N.A., Samsuddin, N., Saad, K.N. and Thanh, V.T., 2017. Effects of several plant leaves on rice weevil, *Sitophilus oryzae* (Coleoptera: Curculionidae) productivity and stored rice qualities. *Asian J. Agric. Fd. Sci.*, **5**: 2321–1571.

Hubert, J., Stejskal, V., Athanassiou, C.G. and Throne, J.E., 2018. Health hazards associated with arthropod infestation of stored products. *Annu. Rev. Ent.*, **63**: 553–573. https://doi.org/10.1146/annurev-ento-020117-043218

Isman, M.B., 2020. Botanical insecticides in the twenty-first century: Fulfilling their promise? *Annu. Rev. Ent.*, **65**: 233–249. https://doi.org/10.1146/annurev-ento-011019-025010

Jafir, M., Ahmad, J.N., Arif, M.J., Ali, S. and Ahmad, S.J.N., 2021. Characterization of *Ocimum basilicum* synthesized silver nanoparticles and its relative toxicity to some insecticides against tobacco cutworm, *Spodoptera litura* Feb. (Lepidoptera: Noctuidae). *Ecotoxicol. environ. Saf.*, **218**: 112278. https://doi.org/10.1016/j.ecoenv.2021.112278

Jasrotia, P., Nagpal, M., Mishra, C.N., Sharma, A.K., Kumar, S., Kamble, U. and Singh, G.P., 2022. Nanomaterials for postharvest management of insect pests: Current state and future perspectives. *Front. Nanotechnol.*, **3**: 811056. https://doi.org/10.3389/fnano.2021.811056

Jayakumar, M., Arivoli, S., Raveen, R. and Tennyson, S., 2017. Repellent activity and fumigant toxicity of a few plant oils against the adult rice weevil, *Sitophilus oryzae* Linnaeus 1763 (Coleoptera: Curculionidae). *J. Ent. Zool. Stud.*, **5**: 324–335.

Kanmani, S., Kumar, L., Raveen, R., Tennyson, S., Arivoli, S. and Jayakumar, M., 2021. Toxicity of tobacco *Nicotiana tabacum* Linnaeus (Solanaceae) leaf extracts to the rice weevil *Sitophilus oryzae* Linnaeus 1763 (Coleoptera: Curculionidae). *J. Basic appl. Zool.*, **82**: 1–12. https://doi.org/10.1186/s41936-021-00207-0

Khani, M., Awang, R.M., Omar, D., Rahmani, M. and Rezazadeh, S., 2011. Tropical medicinal plant extracts against rice weevil, *Sitophilus oryzae* L. *J. med. Pl. Res.*, **5**: 259–265.

Majeed, M.Z., Afzal, M., Riaz, M.A., Ahmed, K.S., Luqman, M., Shehzad, M.Z. and Wahid, S., 2020. Comparative toxicity of phyto-extracts of indigenous flora of Soone Valley against some insect pests of agricultural and urban importance. *Punjab Univ. J. Zool.*, **35**: 239–253. https://doi.

org/10.17582/journal.pujz/2020.35.2.239.253
Muraisi, L., Hariyadi, D.M., Athiyah, U. and Pathak, Y., 2022. Eco-friendly Nanotechnology in Agriculture: Opportunities, toxicological implications, and occupational risks. In: *Sustainable nanotechnology: strategies, products, and applications*. pp. 287–296. https://doi.org/10.1002/9781119650294.ch18

Nerio, L.S., Olivero-Verbel, J. and Stashenko, E.E., 2009. Repellent activity of essential oils from seven aromatic plants grown in Colombia against *Sitophilus zeamais* Motschulsky (Coleoptera). *J. Stored Prod. Res.*, **45**: 212–214. https://doi.org/10.1016/j.jspr.2009.01.002

Nayak, M.K., Daglish, G.J., Phillips, T.W. and Ebert, P.R., 2020. Resistance to the fumigant phosphine and its management in insect pests of stored products: a global perspective. *Ann. Rev. Entomol.,* **65**: 333-350. https://doi.org/10.1146/annurev-ento-011019-025047

Rani, S.S., Justin, C.G.L., Gunasekaran, K. and Joyce, S.S., 2019. Efficacy of green synthesized silver nanoparticle, plant powders, and oil against rice weevil, *Sitophilus oryzae* L. (Coleoptera: Curculionidae) on sorghum seeds. *J. Pharmacogn. Phytochem.*, **8**: 38–42.

Reeba, C.V. and Helen, S.M., 2021. Insecticidal and larvicidal activities of silver nanoparticles synthesized using plant bio-materials. *Annls Roman. Soc. Cell Biol.*, **25**: 5255–5261.

Regnault-Roger, C., 1997. The potential of botanical essential oils for insect pest control. *Integr. Pest Manage. Rev.*, **2**: 25–34. https://doi.org/10.1023/A:1018472227889

Rehman, H.U., Majeed, B., Farooqi, M.A., Rasul, A., Sagheer, M., Ali, Q. and Akhtar, Z.R., 2021. Green synthesis of silver nitrate nanoparticles from *Camelina sativa* (L.) and its effect to control insect pests of stored grains. *Int. J. Trop. Insect Sci.*, **1**: 1–9. https://doi.org/10.1007/s42690-021-00495-7

Rouhani, M., Samih, M.A. and Kalantari, S., 2013. Insecticidal effect of silica and silver nanoparticles on the cowpea seed beetle, *Callosobruchus maculatus* F. (Col.: Bruchidae). *J. entomol. Res.*, **4**: 297–305.

Sankar, M.V. and Abideen, S., 2015. Pesticidal effect of green synthesized silver and lead nanoparticles using *Avicennia marina* against grain storage pest *Sitophilus oryzae*. *Int. J. Nanomater. Biostruct.*, **5**: 32–39.

Scrinis, G. and Lyons, K., 2007. The emerging nano-corporate paradigm: Nanotechnology and the transformation of nature, food and agri-food systems. *Int. J. Soc. agric. Fd.*, **15**: 22–44.

Shahzadi, K., Bashir, F., Nazir, K., Seemab, S., Shaker, M.A.A., Waheed, I. and Fatima, K., 2019. Impacts of green synthesized silver nanoparticles against *Tribolium castaneum* (Coleoptera: Tenebrionidae). *Int. J. ent. Res.*, **4**: 114–117.

Srinivasan, A., Manickavasagam, K., Malaichamy, K., Arunachalam, L., Sundaram, P., Kolanthasamy, E. and Kasivelu, G., 2023. Impact of silver nanoparticles against stored product pest *Sitophilus oryzae* (L.) and effect on agromorphological characteristics of *Zea mays* (maize seeds). *Proc. Saf. Environ. Prot.*, **177**: 1336–1350. https://doi.org/10.1016/j.psep.2023.07.074

Stadler, T., Buteler, M., Weaver, D.K. and Sofie, S., 2012. Comparative toxicity of nanostructured alumina and a commercial inert dust for *Sitophilus oryzae* (L.) and *Rhyzopertha dominica* (F.) at varying ambient humidity levels. *J. Stored Prod. Res.*, **48**: 81–90. https://doi.org/10.1016/j.jspr.2011.09.004

Suteu, D., Rusu, L., Zaharia, C., Badeanu, M. and Daraban, G.M., 2020. Challenge of utilization vegetal extracts as natural plant protection products. *Appl. Sci.*, **10**: 8913. https://doi.org/10.3390/app10248913

Tayyab, M.B., Majeed, M.Z., Riaz, M.A., Aqueel, M.A., Ouedraogo, S.N., Luqman, M. and Tanvir, M., 2022. Insecticidal potential of indigenous flora of Soon Valley against Asian citrus psyllid *Diaphorina citri* Kuwayama and cotton aphid *Aphis gossypii* Glover. *Sarhad J. Agric.*, **38**: 26–39. https://doi.org/10.17582/journal.sja/2022/38.1.26.39

Wakil, W., Kavallieratos, N. G., Usman, M., Gulzar, S. and El-Shafie, H.A., 2021. Detection of phosphine resistance in field populations of four key stored-grain insect pests in Pakistan. *Insects*, **12**: 288. https://doi.org/10.3390/insects12040288

Yeguerman, C.A., Urrutia, R.I., Jesser, E.N., Massiris, M., Delrieux, C.A., Murray, A.P. and González, J.O.W., 2022. Essential oils loaded on polymeric nanoparticles: bioefficacy against economic and medical insect pests and risk evaluation on terrestrial and aquatic non-target organisms. *Environ. Sci. Pollut. Res.*, **29**: 71412–71426. https://doi.org/10.1007/s11356-022-20848-0

Zahir, A.A., Bagavan, A., Kamaraj, C., Elango, G. and Rahuman, A.A., 2012. Efficacy of plant-mediated synthesized silver nanoparticles against *Sitophilus oryzae*. *J. Biopest.*, **5**: 95–102.

Zia-ul-Haq, M., Afzal, M., Khan, A.A., Raza, A.M., Irfanullah, M., Khan, A.M. and Kamran, M., 2014. Impact of phytopesticides on *Trogoderma granarium* Everts (Coleoptera: Dermestidae) in stored wheat. *World appl. Sci. J.*, **31**: 1722–1733.