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Entomotoxic Effects of Silica Nanoparticles Along with Other Seed Protectants against Pulse Beetle, *Callosobruchus chinensis* (Linnaeus) in Stored Chickpea, *Cicer arietinum* Linn.

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ABSTRACT

The study was carried out at ANDUA&T's Department of Entomology during 2022–2023. The study used a completely randomized design (CRD), had eight treatments, and was replicated three times. The most effective seed protectants were found to be 10 g Kg^{-1} of silica nanoparticles, 2 ppm Kg^{-1} of emamectin benzoate, 5 g Kg^{-1} of silica nanoparticles, and 3 ppm Kg^{-1} of spinetoram. These treatments also had the lowest seed damage and weight loss, the highest germination percentage and seed vigor index, and the highest protein and carbohydrate content of chickpea seeds for up to 90 days of storage while maintaining the IMSCS level. Longer storage times resulted in more seed damage, seed weight loss, and qualitative loss (germination, vigor, carbohydrate, and protein) of chickpea seeds. Thus, the results all of the treatments showed that spinetoram 3 ppm Kg^{-1} seed, Emamectin benzoate 2 ppm Kg^{-1} seed, Silica nanoparticles 5g Kg-1 seed, and Silica nanoparticles 10 g Kg^{-1} seed might be utilized to protect chickpea seeds from *Callosobruchus chinensis* for a long time.

Keywords: Chickpea, silica nanoparticles, seed protectants, *C. chinensis*, management.

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INTRODUCTION

In India, pulses are a major source of protein for vegetarians and provide vital amino acids, proteins, vitamins, minerals, and other nutrients to staple grains. Pulses can help increase the amount of protein consumed in meals because of their high protein content, which is around double that of cereals and several times that of root tubers (FAO, 1968). After the field pea (*Pisum sativum* Linn.) and common bean (*Phaseolus vulgaris* Linn.), the chickpea (*Cicer arietinum* Linn.) is the most widely grown edible legume crop worldwide and the largest in South Asia. One of the primary pulses cultivated and consumed in India is the chickpea, sometimes referred to as gram, Bengal gram, or white gram. More than 65% of the world's pulses are produced in India (FAOSTAT, 2022). With a productivity of 1116 kg/ha, it was cultivated on 10.17 million hectares of land in India, yielding 11.35 million tons (Anonymous, 2021). In comparison to other pulse crops, it is of superior quality and a great source of both protein (18 and 22 percent and carbs (52 to 70 per cent).

In addition, it is a good source of vitamins, minerals (calcium, phosphorus, and iron), fat (4–10%), and energy (416 calories/100 g). Additionally, it lowers cholesterol (Ali & Prasad, 2002). For millions of individuals who are vegetarians by choice or for financial reasons in poor nations, especially in South Asia, chickpeas constitute a vital source of protein. It is also a complete dietary fiber source. India's daily per capita consumption of total pulses is barely 45 g, while the World Health Organization (WHO) recommends 80 g.

Insects are causing both qualitative and quantitative harm to crops that are being grown in the field and stored. Grain losses during storage can be substantial, with insect damage ranging from 5–10% in the temperate zone to 20–30% in the tropical zone. Around 1300 bruchid species have been described worldwide, with many more still pending. Thirty-three plant groups have been identified as bruchid hosts, with the family Leguminosae accounting for about 84% of all known hosts. In India, there are around two hundred insect pests known to infest pulses. Insect attacks during storage cause serious harm to the pulse seed. There are 11 genera and 117 bruchid species known to exist in India. The major genus of Bruchids, which includes *Caryedon*, *Callosobruchus*, *Zabrotes*, *Sulkobruchus*, and *Acanthoscelides*. The most common of them is the genus *Callosobruchus*, which can harm legume seeds by up to 100% while they are being stored. It contains species that severely degrade the grains that are preserved, such as *C. chinensis*, *C. maculatus*, *C. analis*, *C. phaseoli*, and *C. theobromae*. The most prevalent pulse beetle species in India that infest stored legumes are *C. chinensis, C. maculatus*, and *C. analis*, out of the five species that are known to exist.

The pulse beetle, *C. chinensis*, is one of the most destructive and widespread pests of stored legumes. The pulse beetle, *C. chinensis,* infestation causes up to 60% weight loss and 45.50 to 66.30% protein loss in stored pulse seeds (Shams, Hasan, & Iman, 2011). During storage, the high moisture content of grains (>12%), higher temperature (25-35 °C), and relative humidity (>60%) create an ideal environment for the spread of insect pests. Infestation causes biochemical changes in seeds, resulting in the loss of numerous seed components. Grubs and grown-ups both cause harm. Grub consumes the endosperm of the grain kernel and forms a hollow. Affected grains have beetle-emergence holes and tiny white eggs adhered to the seed coat. *C. chinensis* was considered a major chickpea storage pest based on its percentage infection. Many insect pests attack post-harvest crops, causing extensive yield loss. Grain damage caused by insect feeding on endosperm and grain embryos increases grain exposure to rot because scratches produce unpleasant odors that humans and animals cannot tolerate (Kalpana, Hajam, & Kumar, 2022). The primary method for controlling stored grain pests is to use broad-action insecticides and fumigants; however, this results in food contamination with harmful pesticide residues.

Thus, it is critical to find new alternative control methods for stored products. Environmentally safe and convenient methods, such as the use of inert dust, plant extract, oils, leaf powders, pressurized carbon dioxide, and temperature management techniques (low and high temperature), are gaining popularity as replacements for synthetic pesticides (Yuya, Tadesse, & Azerefegne, 2009; Talukder & Howse, 1995; Isman, 2006). Nanotechnology has emerged as one of the most promising innovative techniques for pest management in recent years. Nanoparticles represent a new generation of environmental remediation technologies that may give cost-effective solutions to some of the most difficult environmental cleaning issues (Chinnamuthu & Boopathi, 2009).

The treatment of pulse seeds with hydrophobic silica nanoparticles (SNP) against *C. maculatus* infestation revealed a significant reduction in oviposition, adult emergence, and seed damage potential, with no effect on seed germination or root and shoot growth rate (Arumugam, Velayutham, & Shanmugavel, 2016; Debnath, Das & Seth, 2011). Silica and silver nanoparticles, ranging in size from 20 to 60 nm, were significantly more effective on *C. maculatus* larvae than adults. Inorganic nanostructured material may provide a less expensive and more dependable alternative to currently available insecticides for stored product insect pest management. The properties or efficacy of nanoparticles are mostly determined by their size. As a result, fewer nanoparticles cover a larger surface area (Goswami, Roy, & Sengupta, 2010). Given the foregoing, the current study was designed to assess the effectiveness of silica nanoparticles and other seed protectants against *C. chinensis* in chickpeas.

MATERIALS AND METHODS

Experimental site

The experiment took place at the Department of Entomology during 2022-2023 on the campus of the University district headquarters. It is located at 26.47° N latitude and 82.12° E longitude in Uttar Pradesh, India, at an elevation of 113 meters.

Rearing of test insect

Adult bruchids were obtained from the University's seed processing facility godowns in Kumarganj, Ayodhya, and fifty pairs of *C. chinensis* were released into plastic jars containing one kilogram of disinfested chickpea seeds. To conduct the experiment, plastic jar mouths were covered with muslin fabric fastened with a rubber band and placed in a

Biological Oxygen Demand (BOD) incubator at 28±2°C and 75±5% RH. After emergence, the males and females of the pulse beetle, *C. chinensis*, were identified based on physical characteristics. Male (♂) and female (♀) of *C. chinensis* insects have smaller bodies and longer, pectinate antennae compared to females' short, serrate antennae.

Collection of seeds

Chickpea seeds were acquired from the seed processing plant of ANDUA&T, Ayodhya, Uttar Pradesh, India.

Disinfection of seeds

The chickpea seeds for the experiment were fumigated with Aluminium Phosphide (3g/tablet) at a rate of three tablets per ton of seed in an airtight container for seven days before the studies began.

Plan of experiment

The experiment was designed as a Completely Randomized Design (CRD), with three replications and eight treatments. The sample size for each treatment was 500g per cotton bag. The following seed protectants were used in the current study: Silica Nanoparticles (20-60nm) @ 5g/kg of seed; Silica Nanoparticles (20-60nm) @ 10g/kg of seed; Emamectin benzoate (EM-15% SG) @ 2ppm/kg of seed; Deltamethrin (Decis 2.8% EC) @ 1.40ppm/kg of seed; Neem oil @ 10ppm/kg of seed; Spinetoram (Deligate 11.7% SC) @ 3ppm/kg of seed; Wood ash @ 140g/kg of seed; and untreated control.

Methodology of the experiment

For the experiment, 500 g of disinfected chickpea seed was used for each treatment replication. For seed treatment, the required quantity of chemicals was mixed in 2.5 or 5 mL of water to treat 500 g of chickpea seeds. After treatment, seeds were packed in a 1 kg cotton bag and kept in BOD for storage in the laboratory for 90 days.

Observations recorded

For observation in the experiment, the required number of seeds was randomly taken from each cotton bag of each treatment in each replication, and observations were taken as below.

Determination of seed damage

A hundred seeds were randomly picked from each replication of each treatment in the experiment, and healthy and damaged seeds were sorted based on the damage caused by the pulse beetle. The observations were recorded before and after treatment at 30, 60, and 90 days and calculated using the provided method (Kumar, 2008).

$$\text{Per cent seed damage} = \frac{\text{No. of holed seeds in the sample}}{\text{Total No. of seed in the sample}} \times 100$$

Determination of seed weight loss

To determine the percentage weight loss in chickpea seed, one seed from each treatment replication was removed, and the damaged seed was separated. The observations were taken before and after treatment, at 30, 60, and 90 days of storage time. The collected data were utilized to determine seed weight loss per cent using the provided algorithm (Deka, 2000).

$$\text{Per cent weight loss } = \frac{Weight\ of\ damage\ seeds\ in\ sample}{Total\ weight\ of\ seed\ in\ the\ sample} \times 100$$

Determination of seed germination

The germination per cent was recorded after 90 days of storage as per the ISTA procedure by adopting the germination paper (towel paper) method. 50 chickpea seeds were randomly picked from each treatment and replication and placed between two pre-soaked germination papers. The rolled germination paper was covered with butter paper and placed in a seed germinator at 28±2 °C temperature and 70-75% RH for 8 days to ensure optimum germination. The germination paper was opened on the eighth day, and germinated seeds were counted. The germination % for each treatment replication was computed using the formula below:

$$\text{Per cent seed germination } = \frac{No.of\ holed\ seeds\ that\ germinated}{Total\ no.of\ seed\ used} \times 100$$

Determination of seed vigor index

The seed vigor index was calculated using the following formula proposed by Abdul-Baki & Anderson (1973), and it was expressed as whole numbers.

Seed vigour index = Germination (%) × Seedling length (cm)

Determination of carbohydrate content

The Anthrone method obtained Carbohydrate percent before and 90 days after storage (Ludwig & Goldberg, 1956).

Determination of protein content

Protein percent was obtained before and 90 days after storage by the Lowry method (Lowry, Rosebrough, & Farr, 1951).

Statistical analysis

The data from the various studies were statistically analyzed after being transformed under proper settings under CRD with three replications.

RESULTS

Per cent seed damage

The data in Table 1 showed differences in percent seed damage among treatments at different storage periods. All the seed protectants at 30, 60, and 90 days were found to be significantly superior to the control. At 30 days of storage, the percentage of seed damage caused by pulse beetle ranged from 0.55-4.33 per cent within all the tested seed protectants. The percentage of seed damage in the T_8 control was 9.44 per cent. The maximum seed damage was recorded in Wood ash 140g Kg^{-1} seed (4.33%), followed by Neem oil 10mL Kg^{-1} seed (3.33%) and Deltamethrin 1.40 ppm Kg^{-1} seed (1.67%). However, the minimum seed damage was recorded in Silica Nano Particles (SNPs) 10g Kg^{-1} seed (0.55%), followed by Emamectin benzoate 2.0 ppm Kg-1 seed (0.69%), SNPs 5.0 g Kg-1 seed (1.05%), and Spinetoram 3.0 ppm Kg^{-1} seed (1.33%).

At 60 days of storage, the percentage of seed damage varied from 1.96 to 9.17 percent in different treatments. However, the percentage of seed damage in the control was recorded at 19.00 per cent. The maximum seed damage was recorded in Wood ash 140 g Kg^{-1} seed (9.17%), followed by Neem oil 10 mL Kg^{-1} seed (5.91%) and Deltamethrin 1.40 ppm Kg^{-1} seed (4.01%). The minimum seed damage was recorded in SNPs 10g Kg^{-1} seed (1.96%), followed by Emamectin benzoate 2.0 ppm Kg-1 seed (2.22%), SNPs 5.0 g Kg-1 seed (2.92%), and Spinetoram 3.0 ppm Kg^{-1} seed (3.64%).

At 90 days of storage, the percentage of seed damage fluctuated from 5.19 to 14.33 per cent within the tested seed protectants. In contrast, the percentage of seed damage in the control was recorded as 28.44 percent. The maximum seed damage was recorded in Wood ash 140g Kg^{-1} seed (14.33%), followed by Neem oil 10mL Kg^{-1} seed (9.44%), Deltamethrin 1.40 ppm Kg^{-1} seed (7.07%). The minimum seed damage was recorded in SNP 10g Kg^{-1} seed (5.19%), followed by Emamectin benzoate 2.0 ppm Kg^{-1} seed (5.81%), SNP 5.0 g Kg^{-1} seed (6.33%), and Spinetoram 3.0 ppm Kg^{-1} seed (6.73%).

The overall mean percent seed damage of 30, 60, and 90 days after storage revealed that the maximum seed damage was recorded in Wood ash 140 g kg^{-1} (9.26%), followed by Neem oil 10 mL Kg^{-1} (6.23%), Deltamethrin 1.4 ppm Kg^{-1} (4.25%), Spinetoram 3.0 ppm Kg^{-1} (3.97%), SNP 5.0 g Kg^{-1} (3.44%), Emamectin benzoate 2.0 ppm Kg^{-1} (2.91%) and minimum in SNP 10 g Kg^{-1} (2.57%).

Table 1. Effect of silica nanoparticles and other seed protectants on percent seed damage caused by pulse beetle, *C. chinensis* in chickpea.

Tr. No.	Treatment	Dose/Kg seed	Seed damage (%)			
			30 DAT	60 DAT	90 DAT	Mean
T1	Silica Nano Par-ticles	5 g	1.05 (5.89)	2.92 (9.84)	6.33 (14.58)	3.44 (10.68)
T2	Silica Nano Par-ticles	10 g	0.55 (4.25)	1.96 (8.04)	5.19 (13.16)	2.57 (9.22)
T3	Emamectin Benzoate	2 ppm	0.69 (5.67)	2.22 (8.57)	5.81 (13.95)	2.91 (9.81)
T4	Deltamethrin	1.40 ppm	1.67 (7.42)	4.01 (11.55)	7.07 (15.42)	4.25 (11.90)
T5	Neem oil	10 mL	3.33 (10.52)	5.91 (14.07)	9.44 (17.89)	6.23 (14.45)
T6	Spinetoram	3 ppm	1.33 (6.62)	3.64 (11.00)	6.73 (15.03)	3.97 (11.50)
T7	Wood Ash	140 g	4.33 (12.01)	9.17 (17.63)	14.33 (22.24)	9.26 (17.71)
T8	Control	Untreated	9.44 (17.89)	19.00 (25.84)	28.44 (32.33)	18.96 (25.81)
S.E.M ±			(1.63)	(0.40)	(0.45)	(0.43)
CD at 5%			(4.92)	(1.21)	(1.36)	(1.29)

Figures in parenthesis are Arc sine transformed values, DAT= Days after treatment.

Per cent weight loss

The data in Table 2 showed the difference in per cent seed weight loss among treatments at different storage periods. All the seed protectants at 30, 60, and 90 days were found to be significantly superior to the control. At 30 days of storage, the percentage weight loss caused by pulse beetle ranged from 0.37-3.02 percent with all the tested seed protectants. In contrast, the percentage weight loss in the control group was recorded at 6.28 percent. The maximum weight loss was recorded in Wood ash 140 g Kg^{-1} seed (3.02%), followed by Neem oil 10mL kg^{-1} seed (2.17%) and Deltamethrin 1.40 ppm Kg^{-1} seed (1.85%). However, the minimum weight loss was recorded in SNPs 10g Kg^{-1} seed (0.37%), followed by Emamectin benzoate 2.0 ppm Kg^{-1} seed (0.82%), SNPs 5.0 g Kg^{-1} seed (1.05%), and Spinetoram 3.0 ppm Kg^{-1} seed (1.80%).

At 60 days of storage, the percentage weight loss caused by pulse beetle ranged from 1.59-6.92 percent with all the tested seed protectants. The percentage weight loss in the control group was recorded at 9.51 percent. The maximum weight loss recorded in Wood ash was 140 g Kg^{-1} seed (6.92%), followed by Neem oil 10 mL kg^{-1} seed (4.05%), Deltamethrin 1.40 ppm kg^{-1} seed (3.09%). However, the minimum weight loss was recorded in SNP 10g Kg^{-1} seed (1.59%), followed by Emamectin benzoate 2.0 ppm Kg^{-1} seed (1.71%), SNP 5.0 g Kg^{-1} seed (1.82%), and Spinetoram 3.0 ppm Kg^{-1} seed (2.87%).

At 90 days of storage, the percent weight loss caused by pulse beetle ranged from 3.53-9.20 percent within all the tested seed protectants. However, the percent weight loss in the control group was recorded at 17.58 percent. The maximum weight loss recorded in Wood ash was 140 g Kg^{-1} seed (9.20%), followed by Neem oil 10mL kg^{-1} seed (6.64%), Deltamethrin 1.40 ppm Kg^{-1} seed (5.24%). However, the minimum weight loss was recorded in SNP 10g Kg^{-1} seed (3.53%), followed by Emamectin benzoate 2.0 ppm Kg^{-1} seed (3.74%), SNP 5.0 g Kg^{-1}seed (4.08%), and Spinetoram 3.0 ppm Kg^{-1} seed (5.03%).

The overall mean percent weight loss of 30, 60, and 90 days after storage revealed that the maximum weight loss was recorded from Wood ash 140 g Kg^{-1} (6.38%) followed by Neem oil 10mL Kg^{-1} (4.09%), Deltamethrin 1.40 ppm Kg^{-1} (3.40%), Spinetoram 3.0 ppm Kg^{-1} (3.24%), SNP 5.0 g Kg^{-1} (2.32%), Emamectin benzoate @ 2.0 ppm Kg^{-1} (2.09%) and minimum in SNP 10 g Kg^{-1} (1.83%).

Table 2. Effect of silica nanoparticles and other seed protectants on seed weight loss caused by pulse beetle, *C. chinensis* in chickpea.

Tr. No.	Treatment	Dose/Kg Seed	Seed weight loss (%)			
			30 DAT	60 DAT	90 DAT	Mean
T1	Silica Nano Particles	5 g	1.05 (5.88)	1.82 (7.75)	4.08 (11.65)	2.32 (8.75)
T2	Silica Nano Particles	10 g	0.37 (3.49)	1.59 (7.24)	3.53 (10.82)	1.83 (7.78)
T3	Emamectin Benzoate	2 ppm	0.82 (5.21)	1.71 (7.51)	3.74 (11.15	2.09 (8.31)
T4	Deltamethrin	1.40 ppm	1.85 (7.82)	3.09 (10.13)	5.24 (13.23)	3.40 (10.62)
T5	Neem oil	10 mL	2.17 (8.47)	4.05 (11.61)	6.64 (14.93)	4.09 (11.66)
T6	Spinetoram	3 ppm	1.80 (7.71)	2.87 (9.75)	5.03 (12.96)	3.24 (10.36)
T7	Wood Ash	140 g	3.02 (10.01)	6.92 (15.25)	9.20 (17.66)	6.38 (17.71)
T8	Control	Untreated	6.28 (14.51)	9.51 (17.96)	17.58 (24.79)	12.46 (20.67)
S.E.M ±			(1.29)	(0.60)	(0.64)	(0.48)
CD at 5%			(3.92)	(1.81)	(1.94)	(1.46)

Figures in parenthesis are Arc sine transformed values, DAT= Days after treatment.

Effect of seed protectants on seed quality parameters of chickpea

Seed germination percentage

The data presented in Table 3 showed differences in percent seed germination at different storage periods. All the seed protectants at 90 days were found to be significantly superior. At 90 days of storage, the per cent seed germination among tested seed protectants ranged from 94.33-82.62 per cent within all the tested seed protectants. The percentage of seed germination in the control was recorded at 77.67 percent. The maximum seed germination was recorded in SNPs 10g Kg-1 seed (94.33%), followed by Emamectin benzoate 2.0 ppm Kg-1 seed (92.67%), SNPs 5.0 g Kg-1 seed (91.67%), and Spinetoram 3.0 ppm Kg-1 seed (90.67%). However, the minimum seed germination was recorded in Wood ash 140 g kg-1 seed with (82.62%), followed by Neem oil 10mL kg-1 seed with (86.67%), and Deltamethrin 1.40 ppm Kg-1 seed (89.33%).

Table 3. Effect of seed protectants on seed quality parameters on seed germination and seed vigor index at 90 days of storage.

Tr. No.	Treatments	Dose/Kg seed	Germination (%)	Seed vigor index
T1	Silica Nano Particles	5 g	91.67 (73.22)	6537.33
T2	Silica Nano Particles	10 g	94.33 (76.22)	7223.10
T3	Emamectin Benzoate	2 ppm	92.67 (74.29)	6644.60
T4	Deltamethrin	1.40 ppm	89.33 (70.94)	5521.50
T5	Neem oil	10 mL	86.67 (68.58)	5261.10
T6	Spinetoram	3 ppm	90.67 (72.21)	6371.04
T7	Wood Ash	140 g	82.62 (68.58)	4933.74
T8	Control	Untreated	77.67 (61.80)	3663.50
S.E.M ±			(1.04)	160.38
CD at 5 %			(3.17)	484.96

Figures in parenthesis are Arc sine transformed values.

Seed vigor index

At 90 days of storage, the seed vigor index ranged from 7223.10- 4933.74 within all the tested seed protectants. However, the seed vigor index in the control was recorded at 3663.50. The maximum seed vigor index was recorded in SNP 10 g Kg^{-1} seed (7223.10), followed by Emamectin benzoate 2.0 ppm Kg-1 seed (6644.60), SNP 5.0 g Kg^{-1}seed (6537.33), and Spinetoram 3.0 ppm Kg^{-1} seed (6371.04). However, the minimum seed vigor index was recorded in Wood ash 140 g Kg^{-1} seed (4933.74), followed by Neem oil 10mL Kg^{-1} seed with (5261.10) and Deltamethrin 1.40ppm Kg^{-1} seed (5521.50).

Carbohydrate content

The data in Table 4 indicated a difference in carbohydrate content in chickpeas after 90 days of storage. All the seed protectants at 90 days were found to be significantly superior to the control. At 90 days after storage, the Carbohydrate content ranged from 33.27-18.25 µg g-1 within the tested seed protectants. The carbohydrate content in the control was recorded at 15.38 µg g-1. The maximum carbohydrate content was observed in SNP 10g Kg-1 seed (33.27 µg g-1), followed by Emamectin benzoate 2.0 ppm kg-1 seed (29.26 µg g-1), SNP 5.0 g Kg-1 seed (28.45 µg g-1), and Spinetoram 3.0 ppm Kg-1 seed (24.38 µg g-1). However, the minimum carbohydrate content was recorded in Wood ash 140 g Kg-1 seed with (18.25 µg g-1) recorded in followed by Neem oil 10mL Kg-1 seed (19.84 µg g-1) and Deltamethrin 1.40 ppm Kg-1 seed (21.97 µg g-1).

Table 4. Effect of seed protectants on seed quality parameters on carbohydrate and protein at 90 days of storage.

Tr. No.	Treatments	Dose/Kg Seed	Carbohydrate (μg g-1)	Protein (μg g-1)
T1	Silica Nano Particles	5 g	28.45	44.75
T2	Silica Nano Particles	10 g	33.27	52.81
T3	Emamectin Benzoate	2 ppm	29.26	46.59
T4	Deltamethrin	1.40 ppm	21.97	28.09
T5	Neem oil	10 mL	19.84	20.15
T6	Spinetoram	3 ppm	24.38	41.91
T7	Wood Ash	140 g	18.25	19.05
T8	Control	Untreated	15.38	16.84
	S.E.M ±		0.006	0.005
	CD at 5%		0.002	0.002

Initial carbohydrate content in seeds was 34.54 μg g-1; Initial protein content in seeds was 52.52 μg g-1.

Protein content

At 90 days after storage, the protein content ranged from 52.81-19.05 μg g^{-1} within the tested seed protectants (Table 4). In contrast, the control protein content was recorded at 16.84 μg g^{-1}. The maximum protein was recorded in SNPs 10g Kg^{-1} seed (52.81 μg g^{-1}), followed by Emamectin benzoate 2.0 ppm Kg^{-1} seed (46.59 μg g-1), SNPs 5.0 g Kg^{-1} seed (44.75 μg g-1), and Spinetoram 3.0 ppm Kg^{-1} seed (41.91 μg g^{-1}). The minimum Protein was recorded in Wood ash 140 g Kg^{-1} seed (19.05 μg g^{-1}), followed by Neem oil 10mL kg^{-1} seed (20.15 μg g^{-1}) and Deltamethrin 1.40 ppm Kg^{-1} seed (28.09 μg g^{-1}).

DISCUSSION

Inert dust, particularly silica dust, is increasingly being employed as a stored grain protectant (Golob, 1997). Nanomaterials are still in their early stages of usage in agriculture. Stadler, Butelerb, & Weaver (2010) used nano alumina to successfully control two stored grain pests, *S. oryzae* and *Rhyzopertha dominica* (Fab.). However, Yang & Watts (2005) discovered that nano alumina in groundwater affects the growth of carrots, cabbage, cucumber, corn, and soybeans. The present work examined the entomotoxic potential of SNPs on the *C. chinensis*, in stored chickpea seeds. SNPs treatment resulted in insect mortality at dosages that were nearly identical to currently available DE formulations, ranging from 500 to 5,000 mg kg^{-1}. Even at the greatest dose, SNPs had no effect on grain mass looseness or bulk density like DE does (Korunik, 1997). Our findings clearly demonstrated that all seed protectants resulted in significantly less seed damage than theuntreated control during various storage periods. Among the tested seed protectants, SNPs 10g Kg^{-1} seed with 0.55, 1.96, and 5.19 percent seed damage, respectively, at 30, 60, and 90 days after seed treatment, followed by Emamectin benzoate 2.0 ppm Kg^{-1} seed with 0.69, 2.22 and 5.81 per cent damage, respectively at 30, 60 and 90 days after seed treatment which was at par with SNP 5g Kg^{-1} seed with 1.95, 2.92 and 6.33 per cent seed damage, respectively at 30, 60 and 90 days after seed treatment. Insect mortality could be attributed to digestive tract impairment (Smith, 1969) or integument surface enlargement caused by dehydration or spiracle and trachea blockage. Arumugam, Velayutham, & Shanmugavel (2016) reported similar results, finding that applying hydrophobic SNPs significantly reduced seed damage potential in all treatments compared to the control. It was very clearly shown that there was no adult development and seed damage except the laying of very few number of eggs at the lowest concentrations of SNPs-treated seeds. The present findings are also in conformity with Wazid, Prabhuraj, & Naik, (2020), who reported that SNPs proved to be superior by recording the highest mortality, lowest number of eggs, and least seed damage (sorghum and chickpea) up to five months of storage, showed superiority in preventing the adult emergence of rice weevil *S. oryzae* and *C. analis*.

The outcomes showed that all seed protectants caused the least weight loss at a significant level over the untreated control at different storage periods. Among tested seed protectants, SNPs 10 g Kg^{-1} seed with 0.37, 1.59, and 3.53 percent weight loss, respectively, at 30, 60, and 90 days after seed treatment, followed by Emamectin benzoate 2.0 ppm Kg^{-1} seed with 0.82,1.72 and 3.74 per cent weight loss, respectively at 30, 60 and 90 days after seed treatment and par with SNPs 5.0 g Kg^{-1} seed with 1.05, 1.82 and 4.08 percent weight loss, respectively at 30, 60, and 90 days after seed treatment. The present findings agree with the findings of Jayanth (2021), who indicated the superior performance of amorphous silica gel @ 500 ppm kg^{-1} seed over other treatments. Amorphous silica gel @ 500 ppm kg^{-1} seed resulted in a minimum seed weight loss of 0.34 percent, indicating its efficacy in protecting the seed. Debnath (2011) hypothesized that surface-functionalized SNPs might be a viable alternative to conventional pesticides. Entomotoxicity of SNPs was tested against rice weevil *S. oryzae*, and its efficacy was compared with bulk-sized silica (individual particles larger than 1 µm). Amorphous SNPs were highly effective against this insect pest, causing more than 90% mortality, indicating the effectiveness of SNPs in controlling insect pests. It is clear from the results that all seed protectants significantly affected seed germination over the control. Among tested seed protectants, SNP 10g Kg^{-1} seed (94.33%) at 90 days after seed treatment, followed by Emamectin benzoate 2ppm kg^{-1} seed (92.67%) at 90 days after seed treatment. The all-seed protectants resulted in the least seed vigor index at a significant level over the control at different storage periods. Among tested seed protectants, SNP, 10g kg^{-1} seed, showed the highest seed vigor (7223.10) at 90 days after seed treatment, followed by Emamectin benzoate 2.0 ppm kg^{-1} seed (6644.60) at 90 days after seed treatment. The present findings are confirmed by the findings of Kumar, Yadav, & Yadav (2023), who reported that seeds treated with dry formulations of nano-form ZnO nanoparticles at a concentration of 250 ppm, dry formulations of nano-form ZnO nanoparticles at a concentration of 500 ppm, and dry formulations of nano-form TiO2 nanoparticles at a concentration of 100 ppm recorded the highest radicle emergence percentage, germination percentage, seedling length, vigor index-I, and vigor index-II.

All seed protectants resulted in high carbohydrate content at a significant level over the control at different storage periods. Among tested seed protectants, SNPs 10 g Kg^{-1} seed (33.27 µg g^{-1}) carbohydrate at 90 days after seed treatment, followed by Emamectin benzoate 2.0 ppm kg^{-1} seed (29.26 µg g^{-1}) carbohydrate at 90 days after seed treatment. Seed protectants resulted in high Protein content at a significant level over control at different storage periods (Pandey & Agrawal, 2020; Joshi, Gupta & Shashank 2022; Pandey, Agrawal, & Agrawal, 2022). Among tested seed protectants, T_2 SNPs 10 g Kg^{-1} seed (52.81 µg g^{-1}) protein at 90 days after seed treatment, followed by T_3-Emamectin benzoate 2.0 ppm Kg^{-1} seed (46.59 µg g^{-1}) protein at 90 days after seed treatment. The findings reported by Das & Dutta (2022) revealed that 9 months of storage positively affected biochemical parameters in ZnO NPs primed seed.

It may be established that the SNPs 10 g kg^{-1} seeds and Emamectin benzoate 2.0 ppm Kg^{-1} seeds were completely successful at controlling *C. chinensis*. As a result, these could be useful components in building an integrated pest management approach for *C. chinensis*. Both SNPs and Emamectin benzoate are readily available. The persistence of the treatment suggests that the treated grains are not acceptable for human eating; nonetheless, such treated grain is ideal for planting.

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Authors' contributions

Ashish Rathore: Writing-original draft, Methodology, Investigation, Formal analysis, Conceptualization. Sameer Kumar Singh: Writing-original draft, Methodology, Investigation, Formal analysis, Conceptualization. Kamal Ravi Sharma: Writing-review & editing, Supervision, Conceptualization. Vinod Kumar Dubey: Writing-review & editing, Supervision, Conceptualization. Umesh Chandra: Writing-review & editing, Supervision, Conceptualization.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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