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# Effect of biosynthesized vekhand mediated nanoparticles on pulse beetle, *Callosobruchus chinensis* infestation and seed quality parameters in chickpea

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**Abstract**
The present investigation entitled "Effect of biosynthesized vekhand mediated nanoparticles on pulse beetle, *Callosobruchus chinensis* infestation and seed quality parameters in chickpea" was conducted in laboratory condition at Seed Technology Research Unit, Mahatma Phule Krishi Vidyapeeth, Rahuri during 2023-2024 under ambient room condition. The laboratory experiment was carried out in Completely Randomized Design (CRD) with seven treatments and replicated thrice. The objective of the experiment was to study the effect of biosynthesized vekhand mediated silver nanoparticles (Ag NPs @ 200 ppm ($T_1$), Ag NPs @ 400 ppm ($T_2$), Ag NPs @ 600 ppm ($T_3$) and Zinc oxide nanoparticles (ZnO NPs @ 200 ppm ($T_4$), ZnO NPs @ 400 ppm ($T_5$), ZnO NPs @ 600 ppm ($T_6$) on infestation of pulse beetle and seed storability of chickpea during storage. The silver (Ag) and zinc oxide (ZnO) nanoparticles were biosynthesized from vekhand rhizomes. Nanoparticles were characterized by UV-Visible Spectrophotometer and Transmission Electron Microscope (TEM) for confirmation of its size. The characterization of nanoparticles revealed that the maximum absorbance peaks at 420 nm for Ag NPs and 370 nm for ZnO NPs with an average size of 0.1 µm. Seed damage (%), Seed weight loss (%), Seed germination (%), Seed moisture content (%), Seed vigour Index I were recorded at 30 days interval up to 180 days of storage. Results revealed that seed treatment with Ag NPs @ 600 ppm found most effective by recording least seed damage, seed weight loss and seed moisture content, highest seed germination and seedling vigour index I followed by ZnO NPs @ 600 ppm throughout the storage period.

**Keywords:** Chickpea, nanoparticles, pulse beetle, *Callosobruchus chinensis*, vekhand

## Introduction
Chickpea (*Cicer arietinum* L.), a self-pollinating diploid crop (2n=2x=16), is the only cultivated species in the Cicer genus. Chickpea provides a high-quality source of protein (15-22 percent), carbohydrates (40-60 percent), fat (4-8 percent) and vitamins. (Madurapperumage *et al*., 2021) [9].

In India, post-harvest losses in pulses due to stored grain pests are estimated to be around 15 percent (Wazid *et al*., 2020) [20]. Among all stored grain pests, *Callosobruchus chinensis* (Linnaeus) (Coleoptera: Bruchidae) is the most important and major pests of pulses and also considered as a most destructive pest in many tropical and subtropical countries. Females lay eggs on the grain's surface, with pupation occurring inside the grain. Reports indicated that pulse beetles can cause up to 60% weight loss in stored seeds, rendering them unsuitable for both sowing and human consumption. (Jaiswal *et al*., 2018) [6].

The insect pest's management in stored grain primarily relies on chemical insecticides and fumigants. However, extensive use of these chemical insecticides can result in the contamination of grains with pesticide residues. (Malaikozhundan and Vinodhini, 2018) [10]. Moreover, the difficulty in controlling the insect pests in stored grain is the resistance to chemical pesticides. Therefore, it is a growing need to explore alternative management techniques that are highly effective and safe to humans. Nanotechnology, a new and interesting field of science is presently applicable in many areas. It has great application in both agriculture and the field of biotechnology.

*Acorus calamus* is generally known as sweet flag in India. Both leaves and rhizomes of *A. calamus* have shown insecticidal, antimicrobial, antioxidant activities. The principal compounds in the essential oil of *A. calamus* rhizomes were α-asarone (50.09%), (E)-methyl isoeugenol (14.01%) and methyl eugenol (8.59%) (Chau *et al*., 2013) [5], followed by β-asarone (3.51%), α-cedrene (3.09%) and camphor (2.42%).

Green synthesis of nanoparticles refers to the eco-friendly and sustainable production of nanoparticles, typically using natural materials such as plant extracts, microorganisms, or biodegradable substances. This method emphasizes the use of environmentally safe processes. (Abuzeid *et al*., 2023) [2]. The utilization of green synthesized nanoparticles against stored grain pests offers a sustainable and effective solution to pest management in agricultural storage facilities. Synthesis of nanoparticles through green technology is safe, energy efficient, environment friendly.

## Materials and Methods

The laboratory experiment on synthesis of nanoparticles was carried out at Laboratory of Sorghum Improvement Project, Mahatma Phule Krishi Vidyapeeth, Rahuri and the experiment on effect of nanoparticles on infestation of pulse beetle (*C. chinensis*) and study of seed quality parameters in storage was carried out at Seed Entomology Laboratory, Seed Technology Research Unit, Mahatma Phule Krishi Vidyapeeth, Rahuri. The experiment consists of seven treatments laid out in Completely Randomized Design and replicated thrice.

The initial culture of pulse beetle was obtained from the Seed Entomology Laboratory, Seed Technology Research Unit, Mahatma Phule Krishi Vidyapeeth, Rahuri. Fresh vekhand (*A. calamus*) rhizomes were collected from Medicinal and Aromatic Plant Project, Mahatma Phule Krishi Vidyapeeth, Rahuri. The chemicals used for the synthesis of nanoparticles were include: 1) Zinc acetate dihydrate $Zn(CH_3COO)_2.2H_2O$ (molecular weight: 219.49 g/mol), 2) Silver nitrate (molecular weight: 169.87 g/mol) 3) Distilled water. All the reagents used in the experiments was analytical grade and obtained from Department of Entomology, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri.

### Preparation of vekhand rhizome extract

10 g freshly collected vekhand rhizomes were washed twice with tap water to remove the dust and other impurities followed by distilled water. The rhizomes were cut into fine pieces and ground well using mortar and pestle. The mixture was mixed with 100 ml distilled water and was placed on magnetic stirrer for 15 minutes. The beaker was then kept in hot water bath at a temperature of 80 °C for 20 minutes and allowed to cool at room temperature then filtered using Whatman No.1 filter paper to get clear solution. The supernatant (Light brown color) was collected which was then stored at 4 °C in refrigerator and used for green synthesis of Ag and ZnO nanoparticles.

### Biosynthesis and Characterization of nanoparticles

Biosynthesis of silver nanoparticles was done according to Nakkala *et al*. (2014) [11], Saxena *et al*. (2023) [14], Sudhakar *et al*. (2015) [17] with minor modifications. Biosynthesis of zinc oxide nanoparticles was done according to Shaik *et al*. (2020) [15], Wazid *et al*. (2018) [18] with minor modifications. The powdered form of sample was stored in cool and dark location for further characterization and study.

UV visible spectral analysis was performed by using UV-Visible spectrophotometer, while morphology of nanoparticles was studied by Transmission Electron Microscope.

### Seed treatment with nanoparticles

Freshly harvested certified seeds of chickpea (Variety: Digvijay) was obtained from the Seed Technology Research Unit, Mahatma Phule Krishi Vidyapeeth, Rahuri. Seeds without nanoparticles treatment was served as control. The seeds (1 kg) and the prepared stock solution (Ag and ZnO @ 200, 400, 600 ppm) were mixed thoroughly to achieve equal distribution of nanoparticles on chickpea seeds. The treated seeds were kept for one night for drying. Seed samples were drawn at every 30 days interval up to 180 days and evaluated for pulse beetle infestation and seed quality parameters.

## Results and Discussion

The findings from this investigation are shown under the following subsections:

### Seed damage (%) by *C. chinensis*

Seed treatment with nanoparticles resulted in a significant difference among the treatments with respect to the seed damage. The data presented in Table 1 showed that chickpea seeds treated with Ag NPs @ 600 ppm and ZnO NPs @ 600 ppm was free from seed damage by pulse beetle up to 60 DAS, while the untreated control recorded continuous seed damage throughout the storage period. At 180 DAS, the lowest seed damage was noted in seed treatment with Ag NPs @ 600 ppm (5.67%), which was at par with ZnO NPs at 600 ppm with seed damage 6.33%. Whereas the control recorded the maximum seed damage (61.67%) among all the treatments.

### Seed weight loss (%) due to *C. chinensis*

The data on seed weight loss are presented in Table 2 revealed that at 30 and 60 DAS, no seed weight loss was recorded in any of the nanoparticle treatments, except the untreated control, which recorded seed weight loss 2.57 and 4.88 percent, respectively. Chickpea seeds treated with Ag NPs @ 600 ppm and ZnO NPs @ 600 ppm was found free from seed weight loss up to 90 DAS, while the untreated control recorded continuous seed weight loss throughout the storage period. After 180 days of storage, the seed treatment with Ag NPs @ 600 ppm exhibited the lowest (1.85%) weight loss which was at par with ZnO NPs @ 600 ppm (1.95%). However, the untreated control recorded maximum seed weight loss (31.17%) at the end of storage period.

### Seed moisture content (%)

Seed treatment with nanoparticles resulted in a significant difference among the treatments with respect to the moisture content in chickpea seed (Table 3). An increase in seed moisture content was observed with the advancement in storage period due to seed damage by pulse beetle. Maximum moisture content was found in $T_7$ i.e., control throughout the storage period which ranged from 9.28% at 30 DAS to 12.99% at 180 DAS. The seeds treated with Ag NPs @ 600 ppm recorded the lowest moisture content among all the treatments, followed by ZnO NPs @ 600 ppm

during storage. After 30 days of storage, seeds treated with treatment $T_3$ i.e., Ag NPs @ 600 ppm recorded the lowest seed moisture content 8.70 percent followed by ZnO NPs @ 600 ppm (8.75%). At the end of 6 months storage, Ag NPs @ 600 ppm recorded the lowest moisture content (10.68%), which was at par with ZnO NPs @ 600 ppm (10.70%).

**Table 1:** Effect of biosynthesized silver (Ag) and zinc oxide (ZnO) nanoparticles seed treatment on chickpea seed damage (%) by pulse beetle in storage

| Tr. No. | Treatments | Seed damage (%) (DAS) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 30 | 60 | 90 | 120 | 150 | 180 |
| $T_1$ | Ag NPs @ 200 ppm | 0.00 (0.00)* | 2.00 (8.13) | 4.00 (11.54) | 6.33 (14.58) | 8.33 (16.78) | 10.33 (18.75) |
| $T_2$ | Ag NPs @ 400 ppm | 0.00 (0.00) | 1.00 (5.74) | 3.00 (9.97) | 4.67 (12.48) | 7.33 (15.71) | 9.00 (17.46) |
| $T_3$ | Ag NPs @ 600 ppm | 0.00 (0.00) | 0.00 (0.00) | 1.67 (7.42) | 2.00 (8.13) | 3.00 (9.97) | 5.67 (13.77) |
| $T_4$ | ZnO NPs @ 200 ppm | 0.00 (0.00) | 2.00 (8.13) | 5.00 (12.92) | 7.33 (15.71) | 8.67 (17.12) | 11.67 (19.97) |
| $T_5$ | ZnO NPs @ 400 ppm | 0.00 (0.00) | 1.67 (7.42) | 3.67 (11.04) | 5.00 (12.92) | 6.00 (14.18) | 8.33 (16.78) |
| $T_6$ | ZnO NPs @ 600 ppm | 0.00 (0.00) | 0.00 (0.00) | 2.00 (8.13) | 3.33 (10.52) | 4.33 (12.01) | 6.33 (14.58) |
| $T_7$ | Untreated control | 16.33 (23.84) | 24.00 (29.33) | 34.33 (35.87) | 42.33 (40.59) | 49.67 (44.81) | 61.67 (51.75) |
| S.E(m)± | | 0.10 | 0.30 | 0.37 | 0.34 | 0.32 | 0.36 |
| CD @ 1% | | 0.29 | 0.91 | 1.12 | 1.03 | 0.98 | 1.09 |
| CV (%) | | 5.35 | 5.73 | 4.93 | 4.81 | 4.95 | 4.68 |

*Figures in parenthesis are arcsine transformed values. DAS= Days After Storage

**Table 2:** Effect of biosynthesized silver (Ag) and zinc oxide (ZnO) nanoparticles seed treatment on seed weight loss (%) in chickpea in storage

| Tr. No. | Treatments | Seed weight loss (%) (DAS) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 30 | 60 | 90 | 120 | 150 | 180 |
| $T_1$ | Ag NPs @ 200 ppm | 0.00 (0.00)* | 0.00 (0.00) | 0.82 (5.18) | 2.12 (8.37) | 2.66 (9.39) | 3.00 (9.97) |
| $T_2$ | Ag NPs @ 400 ppm | 0.00 (0.00) | 0.00 (0.00) | 0.48 (3.96) | 1.69 (7.47) | 2.41 (8.94) | 2.70 (9.46) |
| $T_3$ | Ag NPs @ 600 ppm | 0.00 (0.00) | 0.00 (0.00) | 0.00 (0.00) | 0.50 (4.05) | 1.62 (7.30) | 1.85 (7.82) |
| $T_4$ | ZnO NPs @ 200 ppm | 0.00 (0.00) | 0.00 (0.00) | 0.84 (5.26) | 2.03 (8.18) | 2.99 (9.96) | 3.30 (10.47) |
| $T_5$ | ZnO NPs @ 400 ppm | 0.00 (0.00) | 0.00 (0.00) | 0.66 (4.66) | 1.85 (7.82) | 2.30 (8.72) | 2.85 (9.72) |
| $T_6$ | ZnO NPs @ 600 ppm | 0.00 (0.00) | 0.00 (0.00) | 0.00 (0.00) | 0.61 (4.47) | 1.71 (7.51) | 1.95 (8.02) |
| $T_7$ | Untreated control | 2.57 (9.23) | 4.88 (12.76) | 10.99 (19.36) | 18.17 (25.23) | 24.04 (29.36) | 31.17 (33.94) |
| S.E(m)± | | 0.01 | 0.02 | 0.03 | 0.08 | 0.09 | 0.11 |
| CD @ 1% | | 0.04 | 0.06 | 0.10 | 0.23 | 0.27 | 0.45 |
| CV (%) | | 3.71 | 3.91 | 1.44 | 2.97 | 3.42 | 4.10 |

*Figures in parenthesis are arcsine transformed values. DAS= Days after Storage

**Table 3:** Effect of biosynthesized silver (Ag) and zinc oxide (ZnO) nanoparticles seed treatment on seed moisture content of chickpea in storage

| Tr. No. | Treatments | Seed moisture content (%) (DAS) | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|
| | | 30 | 60 | 90 | 120 | 150 | 180 | |
| $T_1$ | Ag NPs @ 200 ppm | 8.88 (17.34)* | 9.40 (17.85) | 9.82 (18.26) | 10.09 (18.52) | 10.50 (18.91) | 11.07 (19.43) | 9.96 (18.40) |
| $T_2$ | Ag NPs @ 400 ppm | 8.80 (17.26) | 9.25 (17.70) | 9.67 (18.12) | 9.81 (18.26) | 10.35 (18.77) | 10.82 (19.20) | 9.78 (18.23) |
| $T_3$ | Ag NPs @ 600 ppm | 8.70 (17.16) | 9.05 (17.51) | 9.49 (17.94) | 9.73 (18.17) | 10.16 (18.59) | 10.68 (19.07) | 9.63 (18.08) |
| $T_4$ | ZnO NPs @ 200 ppm | 8.93 (17.39) | 9.45 (17.90) | 9.79 (18.23) | 10.18 (18.61) | 10.58 (18.98) | 11.20 (19.55) | 10.02 (18.45) |
| $T_5$ | ZnO NPs @ 400 ppm | 8.83 (17.29) | 9.33 (17.79) | 9.72 (18.16) | 9.98 (18.41) | 10.42 (18.83) | 10.95 (19.32) | 9.87 (18.31) |
| $T_6$ | ZnO NPs @ 600 ppm | 8.75 (17.21) | 9.11 (17.57) | 9.61 (18.06) | 9.77 (18.21) | 10.21 (18.64) | 10.70 (19.09) | 9.69 (18.13) |
| $T_7$ | Untreated control | 9.28 (17.74) | 9.81 (18.25) | 10.11 (18.54) | 10.76 (19.15) | 12.12 (20.37) | 12.99 (21.13) | 10.85 (19.23) |
| S.E(m)± | | 0.01 | 0.02 | 0.01 | 0.02 | 0.02 | 0.02 | - |
| CD @ 1% | | 0.04 | 0.07 | 0.04 | 0.07 | 0.07 | 0.06 | - |
| CV (%) | | 0.20 | 0.30 | 0.26 | 0.30 | 0.28 | 0.26 | - |

*Figures in parenthesis are arcsine transformed values. DAS= Days After Storage

**Seed germination (%)**

Seed treatment with nanoparticles exhibited significant differences in the germination percentage from 60 DAS presented in Table 4. After 30 days, no significant differences were observed among the treatments. But with progression in storage, significant differences in germination among the different treatments were recorded and yielded a positive result. Seeds treated with Ag NPs @ 600 ppm, ZnO NPs @ 600 ppm were the only treatments whose germination rate was 92 percent even after 180 days of storage. The remaining treatments, including Ag NPs @ 400 ppm (90.58%), ZnO NPs @ 400 ppm (90.00%), Ag NPs @ 200 ppm (87.00%), ZnO NPs @ 200 ppm (86.25%) maintained the seed germination of above IMSC standards up to six months of storage. While in control the germination fell below IMSCS after 120 DAS.

**Table 4:** Effect of biosynthesized silver (Ag) and zinc oxide (ZnO) nanoparticles seed treatment on seed germination of chickpea in storage

| Tr. No. | Treatments | Seed germination (%) (DAS) | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|
| | | 30 | 60 | 90 | 120 | 150 | 180 | |
| $T_1$ | Ag NPs @ 200 ppm | 98.00 (81.87)* | 95.83 (78.22) | 93.00 (74.66) | 91.83 (72.71) | 89.42 (71.02) | 87.00 (68.87) | 92.51 (74.12) |
| $T_2$ | Ag NPs @ 400 ppm | 97.67 (81.21) | 97.25 (80.45) | 96.33 (78.96) | 93.00 (74.66) | 91.70 (73.26) | 90.58 (72.13) | 94.42 (76.34) |
| $T_3$ | Ag NPs @ 600 ppm | 98.67 (83.37) | 98.00 (81.87) | 97.17 (80.31) | 96.00 (78.46) | 94.33 (76.23) | 92.50 (74.11) | 96.11 (78.63) |
| $T_4$ | ZnO NPs @ 200 ppm | 97.67 (81.21) | 95.67 (77.99) | 94.08 (75.92) | 90.50 (72.05) | 88.08 (69.81) | 86.25 (68.23) | 92.04 (73.61) |
| $T_5$ | ZnO NPs @ 400 ppm | 98.00 (81.87) | 97.17 (80.31) | 96.00 (78.46) | 92.00 (73.57) | 90.75 (72.29) | 90.00 (71.57) | 93.99 (75.80) |
| $T_6$ | ZnO NPs @ 600 ppm | 98.33 (82.58) | 97.58 (81.06) | 97.00 (80.03) | 94.75 (76.75) | 93.17 (74.85) | 92.00 (73.57) | 95.47 (77.71) |
| $T_7$ | Untreated control | 96.33 (78.96) | 90.83 (72.38) | 88.08 (69.81) | 86.75 (68.65) | 81.92 (64.83) | 58.00 (49.99) | 83.65 (66.15) |
| S.E(m)± | | 0.98 | 0.68 | 0.23 | 0.25 | 0.48 | 0.39 | - |
| CD @ 1% | | NS | 2.07 | 0.71 | 0.76 | 1.46 | 1.18 | - |
| CV (%) | | 2.09 | 1.49 | 0.53 | 0.58 | 0.79 | 0.99 | - |

*Figures in parenthesis are arcsine transformed values. DAS= Days After Storage

**Seedling vigour index I**

The silver and zinc oxide nanoparticles exerted a significant influence on seedling vigour I of chickpea seedlings during storage period (Table 5). After 30 days of storage, the seed treatments $T_3$ i.e., Ag NPs @ 600 ppm (3608.02), $T_6$ i.e., ZnO NPs @ 600 ppm (3486.94), $T_2$ i.e., Ag NPs @ 400 ppm (3340.60), $T_5$ i.e., ZnO NPs @ 400 ppm (3264.05), $T_1$ i.e., Ag NPs @ 200 ppm (3161.09), $T_4$ i.e., ZnO NPs @ 200 ppm (3095.68) showed statistically similar results to each other. Whereas, the lowest (2316.48) seedling vigour index I observed in control. At 180 DAS, among all the treatments, seeds treated with Ag NPs @ 600 ppm (2974.50) recorded the highest seedling vigour index I which was at par with the treatment of ZnO NPs @ 600 ppm (2896.74). While the least seedling vigour index I (1385.80) among all the treatments was recorded in the untreated control.

The similar findings reported by Yerragopu *et al*. (2019) [21], who noted that biologically synthesized Ag NPs resulted in minimal seed damage (38.67%), minimal seed weight loss (0.78%) and complete mortality (100%) of *Callosobruchus chinensis* at a concentration of 70 ppm on the seventh day after treatment. Abid *et al*. (2020) [1] noted the least seed damage and seed weight loss in seeds treated with biologically synthesized Ag NPs by *Callosobruchus*

*maculatus*. Silica nanoparticles (SNPs) applied to the seeds of *Cajanus cajan*, *Macrotyloma uniflorum*, *Vigna mungo*, *Vigna radiata*, *Cicer arietinum* and *Vigna unguiculata* significantly reduced oviposition, adult emergence, and potential seed damage caused by the pulse beetle, *C. maculatus* (Arumugam *et al*., 2016) [4]. Khandaitaray *et al*. (2024) [8] reported that higher concentration of nano silica and nano zinc both at 1000 ppm and 750 ppm, there was no seed weight loss observed for up to 6 months of storage. No evidence of seed infestation or damage, egg laying, adult emergence was noticed. Biosynthesized nanoparticle treated seeds demonstrated the highest mortality, lowest egg count, minimal seed damage and least seed weight loss due to pulse beetles in chickpea seeds, as observed by Wazid *et al*. (2018) [18] using ZnO nanoparticles (1500 ppm) and Wazid *et al*. (2019) [19] using Cu nanoparticles (1500 ppm) for up to one month of storage.

Anandaraj and Natarajan (2017) [3] in onion seeds, Smitha *et al*. (2019) [16] in groundnut seeds, Rose *et al*. (2023) [12] in groundnut seeds, Kademani *et al*. 2023 in groundnut seeds proved that silver nanoparticles enhanced the seed quality characters such as germination percent, shoot length, root length, etc. of the respective seeds. Sandeep *et al*. (2019) [13] conducted study using treatment Fe NPs @ 500 ppm which recorded higher seedling growth characteristics in soybean. In the current investigation, least percent seed moisture recorded in seed treatment with nanoparticles at high concentrations (600 ppm) it might be due to the less seed damage by pulse beetles. Based on both previous studies and current findings, it was concluded that there is a direct relationship between damage and moisture content, as seed coat boring likely allowed greater absorption of atmospheric moisture into the cotyledon. Maximum seed germination and Seed vigour index I in seed treatment with Ag NPs @ 600 ppm was due to minimum seed damage and seed weight loss in these treatment.

**Table 5:** Effect of biosynthesized silver (Ag) and zinc oxide (ZnO) nanoparticles seed treatment on seedling vigour index I of chickpea in storage

| Tr. No. | Treatments | Seedling vigour index I (DAS) | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|
| | | 30 | 60 | 90 | 120 | 150 | 180 | |
| $T_1$ | Ag NPs @ 200 ppm | 3161.09 | 3067.52 | 2871.22 | 2755.36 | 2556.68 | 2419.09 | 2805.16 |
| $T_2$ | Ag NPs @ 400 ppm | 3340.60 | 3243.61 | 3097.53 | 2945.31 | 2812.13 | 2704.02 | 3023.87 |
| $T_3$ | Ag NPs @ 600 ppm | 3608.02 | 3511.01 | 3382.00 | 3257.31 | 3109.64 | 2974.50 | 3307.08 |
| $T_4$ | ZnO NPs @ 200 ppm | 3095.68 | 3037.74 | 2828.04 | 2639.01 | 2441.94 | 2248.67 | 2715.18 |
| $T_5$ | ZnO NPs @ 400 ppm | 3264.05 | 3246.97 | 3122.63 | 2924.33 | 2708.60 | 2661.02 | 2987.93 |
| $T_6$ | ZnO NPs @ 600 ppm | 3486.94 | 3416.36 | 3283.77 | 3105.23 | 2975.33 | 2896.74 | 3194.06 |
| $T_7$ | Untreated control | 2844.98 | 2637.47 | 2464.99 | 2316.48 | 2094.63 | 1385.80 | 2290.72 |
| S.E(m)± | | 57.55 | 28.90 | 37.11 | 26.95 | 29.89 | 44.63 | - |
| CD @ 1% | | 174.57 | 87.65 | 112.57 | 81.76 | 90.67 | 135.38 | - |
| CV (%) | | 3.06 | 1.58 | 2.14 | 1.64 | 1.94 | 3.13 | - |

DAS = Days After Storage

## Conclusion

Based on the findings from the current investigation, it could be concluded that biosynthesized nanoparticles, especially at optimal concentrations can effectively reduce the pulse beetle infestations and enhance the overall quality of chickpea seeds during storage. Chickpea seeds treated with Ag NPs @ 600 ppm was found to be most effective followed by ZnO NPs @ 600 ppm in reducing the infestation of pulse beetle up to 180 days of storage period. In regards to seed quality parameters such as seed moisture content, seed germination and seedling vigour index I, seed treatment with Ag NPs @ 600 ppm was most effective in maintaining the seed quality and storability of chickpea during storage followed by ZnO NPs @ 600 ppm. Additionally, seed germination maintained above the IMSC standards (<85%) even after six months of storage.

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