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Elevated CO_2 and Nanoparticles for the Management of Pulse Beetle, *Callosobruchus chinensis* L. in Stored Chickpea

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ABSTRACT

Background: Pulse beetle, *Callosobruchus chinensis* L. is a primary pest of stored chickpea which causes 50-60 per cent loss in seed weight and 45.5-66.3 per cent loss in protein content of the seeds and injudicious and indiscriminate use of hazardous synthetic chemicals for preventing storage losses in chickpea may lead to human and animal health issues due to residual hazards. Therefore, the biorational management of the pulse beetle in stored chickpea has been undertaken keeping biology in mind will prevent the loss as well as protect human health hazard.

Methodos: The experiments on various non-chemical biorational approaches like effect of elevated levels of CO_2 and application of nano particles which control the test insect effectively but have less toxicity to non-target organisms and the environment were studied in the Department of Entomology, College of Agriculture, OUAT, Bhubaneswar, Odisha during 2018-2021.

Result: The results showed that elevated levels of CO_2 at 60 and 80 per cent for 150 and 30 minutes respectively resulted in cent per cent mortality of the bruchids. Among the nano particles, nano silica and nano zinc applied @1000 ppm and 750 ppm realized the highest mortality of the bruchids.

Key words: Bio-rational, *Bt* formulation, Desiccant beads, Nano particles, Pulse beetle.

INTRODUCTION

India is the largest producer and consumer of pulses in the world accounting for higher area (33% of the world area), production (25% of the total global production), consumption (27% of world consumption) and importer (14%) of pulses in the world. Gram or chickpea is the most dominant pulse having a major share under area sown 65% and production 72% followed by lentil and field pea (Phadtare *et al*., 2023). Poor storability and lack of improved storage facility is one of the important service constraints leading to post harvest losses in case of pulses to the extent of 25-50 per cent (Jeswani and Baldev, 1990). Pulse beetle, *Callosobruchus chinensis* L. (Coleoptera: Bruchidae) is widely distributed and known as a major destructive insect of stored chickpea (Park *et al*., 2003; Aslam, 2004). The economic loss of this bruchid in various pulses ranged from 30-40 per cent within a period of six months and when left un-attended, losses could be up to 100 per cent (Dongre *et al*., 1996; Akinkurolere *et al*., 2006; Sharma *et al*., 2013). It is reported that the pulse beetle may cause 10-95 per cent loss in the seed weight and 45.5-66.3 per cent loss in protein content of the seeds under normal condition and the severity of damage increases with the duration of storage condition. The germination of pulse seed is also reduced to a great extent (Yadav, 1985). The infestation causes considerable losses both in terms of quality as well as quantity. Both the grubs and adults causes damage and the endosperm were eaten by the grubs leaving only the thin outer covering or thin film of seed coat making them completely unfit for human consumption (Nishad *et al*., 2020; Krishnavedi *et al*., 2020; Dwivedi and Devi, 2019).Therefore, now-a-days, eco-friendly, non-chemical and bio-rational approaches in insect pest management during storage are being considered as effective alternative to the hazardous synthetic chemicals and have assumed greater significance (Balikai and Neenu, 2018; Neenu and Balikai, 2019). Botanicals, plant oils, nano

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emulsions, carbon dioxide treatments etc. are quite effective in keeping the pest damage under control, which possesses no harmful effect on the stored chickpea kept for consumption and seed purposes.

MATERIALS AND METHODS

Effect of elevated levels of CO_2 on *Callosobruchus chinensis*

The experiment on modified atmosphere studies using elevated levels of CO_2 was carried out against *C. chinensis* in the Department of seed science and technology, OUAT, Bhubaneswar in specially designed airtight containers and the required concentration of CO_2 was released into these containers with the help of carbon dioxide cylinder fitted with an outlet tube containing a nozzle and a needle. Five pairs of freshly emerged adults were transferred to airtight plastic containers of 250 g capacity separately and directly exposed to five different concentrations of CO_2 *viz*., 20%, 40%, 50%, 60% and 80% with six different exposure periods *viz*., 30, 60, 90, 120, 150 and 180 minutes and each treatment was replicated thrice (Hasan *et al*., 2020). The chickpea seeds were observed after 2, 4 and 6 months of treatment for each concentration of CO_2 and the data on fecundity, adult emergence, seed damage and weight loss due to damage, moisture content and germination per cent were recorded and analysed statistically. An untreated check was also maintained by following the same procedure adopted for CO_2 studies without exposing the seeds to CO_2 concentrations.

Effect of nano particles against *Callobruchus chinensis* in stored chickpea

The experiment was conducted to evaluate the toxicity of nanoparticles on chickpea pulse beetle using dry dust application. 100 g thoroughly dried chickpea seeds of genotype JG 16 were taken and were treated with the nanoparticles and 5 pairs of freshly emerged pulse beetle adults were released on the treated pods at four different concentrations *viz*., 250 ppm, 500 ppm, 750 ppm and 1000 ppm per kg of seeds (Kawadkar *et al*., 2011). An untreated check was also maintained simultaneously. The study was carried out in a completely randomized design and each treatment was replicated thrice. Adult mortality was observed at 1, 3, 5, 7 and 10 days after exposure to the treated seeds. After studying the adult mortality, the chickpea seeds were placed in the petridishes and kept undisturbed till the emergence of F_1 progeny and the numbers of eggs laid and the number of adults emerged from each treatment were also noted. The observations on the fecundity, adult emergence, seed damage and weight loss due to damage, germination per cent was recorded and statistically analysed after appropriate transformation.

RESULTS AND DISCUSSION

Effect of elevated levels of CO_2 on adult mortality

The mortality of *C. chinensis* adults exposed to various concentrations of CO_2 after 30 minutes of exposure period indicated that low concentration (20%) of CO_2 did not show any effect on adult mortality (Table 1). After 60 minutes of exposure, the mortality was found to be 13.33 per cent which substantially increased with increased exposure time. At 90, 120, 150 and 180 minutes of exposure, the mortality increased to 26.67, 43.33, 50.00 and 56.67 per cent respectively. Further, the elevated levels of CO_2 at 60 and 80 percent for 150 and 30 minutes respectively resulted in cent percent mortality of the bruchids. The present findings are partially in agreement with the results found by earlier researchers (Jyothsna, 2014; Kumar *et al*., 2017; Krishnaveni, 2012; Haile, 2015).

Effect of elevated levels of CO_2 on fecundity and adult emergence of *Callosobruchus chinensis*

It is evident from the results presented in Table 2 that among all the concentrations of CO_2, higher concentrations were very much lethal to the chickpea pulse beetle and exhibited in high mortality and inhibited egg laying during six months of storage. The lowest concentration (20%) of CO_2 was least effective and recorded 5.33, 21.67 and 49.67 eggs after 2, 4 and 6 months of storage respectively while at 20 per cent CO_2 concentration recorded 2.67, 12.33 and 31.67 eggs

Table 1: Effect of different concentrations and exposure periods of CO_2 on adult mortality (%) of *Callosobruchus chinensis.*

CO_2 concentration	Adult mortality (%)						
(%)	30 min.	60 min.	90 min.	120 min.	150 min.	180 min.	Mean
20	0.00 (0.00)	13.33 (21.40)	26.67 (31.13)	43.33 (41.15)	50.00 (44.99)	56.67 (48.85)	31.67 (34.26)
40	16.67 (23.85)	33.33 (34.91)	50.00 (44.99)	60.00 (50.83)	67.33 (55.08)	76.67 (61.20)	50.67 (45.39)
50	36.67(37.21)	43.33 (41.14)	63.33 (52.75)	76.67 (61.20)	86.67 (68.83)	93.33 (77.69)	66.67 (54.79)
60	43.33 (41.14)	66.67 (54.76)	85.00 (67.22)	93.33 (77.69)	100.00 (90.00)	100.00 (90.00)	81.38(64.42)
80	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)
Control	0.00 (0.00)	0.33 (1.91)	0.67 (3.83)	1.33 (6.53)	1.67 (6.53)	1.67(6.53)	0.95(5.57)
		SE m±				**CD (p=0.05)**	
Concentrations (F_1)		0.792				2.23	
Time period (F_2)		0.792				2.23	
Interaction ($F_1 \times F_2$)		1.94				5.47	

Figures in the parentheses are angular transformed values. Min.- Minutes.

after 2, 4 and 6 months after storage respectively. The data pertaining to the effect of elevated levels of CO_2 on adult emergence of *C. chinensis* are presented in Table 3. The results indicates that higher CO_2 concentration of 50 per cent was effective initially for 2 months of storage with 0.67 number of adult emergence but it was further increased to 8.67 after 6 months of treatment. However, the untreated control recorded 41.67, 82.33 and 105.67 adult insects after 2, 4 and 6 months after treatment (MAT), respectively and all the treatments were significantly superior to control. The results are in line with the findings of Krishnaveni (2020) and Rustamani *et al.* (1985), who did not notice any fecundity and adult emergence of *C. chinensis* in pigeonpea seeds treated with 40, 60 and 80 per cent CO_2 during 6 months of storage.

Effect of elevated levels of CO_2 on chickpea seed damage and weight loss (%) infested by *Callosobruchus chinensis*

The observations pertaining to the studies on the effect of elevated levels of CO_2 on seed damage to stored chickpea subjected to artificial infestation with *C. chinensis* are presented in Table 4. From the data it isclear that higher concentrations of CO_2 *viz*., 60 and 80 per cent did not record any seed damage even after six months of storage, whereas in untreated control the seed infestation was found to be 28.31 per cent after 2 months of treatment and increased to 41.32 per cent after 4 months and further increased to 57.61 per cent at 6 months after treatment. The chickpea seeds subjected to infestation by *C. chinensis* and exposed to different concentrations of CO_2 were observed for weight loss after 2, 4 and 6 months of treatment (Table 5) which exhibited the similar trends as recorded with seed damage.The CO_2 concentration of 80 per cent was found to be lethal to the pulse beetle infestation and did not record any weight loss up to six months of storage. The lower CO_2 concentration of 20 and 40 per cent recorded 4.37 and 2.11 per cent weight loss after 2 months of storage, respectively. It was further increased to 11.63 and 7.22 per cent after 6 months of treatment, respectively which indicated that the lower concentrations of CO_2 were ineffective in protecting the stored chickpea for prolonged period. The results are in conformity with Kumar *et al.* (2017) who stated that high concentrations of CO_2 *viz*., 50, 60, 70 and 80 per cent did not witness any pod damage and weight loss even after 9 months of treatment. Similarly, Divya *et al.* (2016) reported

Table 2: Effect of elevated levels of CO_2 on fecundity of *Callosobruchus chinensis.*

CO_2 concentration	No. of eggs laid/female (100 g of seeds)			
(%)	2 MAT	4 MAT	6 MAT	Mean
20	5.33 (2.31)	21.67 (4.66)	49.67 (7.05)	25.56 (5.06)
40	2.67 (1.63)	12.33 (3.51)	31.67 (5.62)	15.56 (3.94)
50	0.33 (0.57)	5.67 (2.38)	18.33 (4.28)	8.11 (2.85)
60	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
80	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
Control	55.00 (7.42)	102.67 (10.13)	125.33 (11.20)	94.33 (9.71)
	SE m±		**CD (p=0.05)**	
Concentrations (F_1)	0.743		2.13	
Time period (F_2)	0.525		1.51	
Interaction ($F_1 \times F_2$)	1.287		3.69	

Figures in the parentheses are square root transformed values, MAT- Months after treatment.

Table 3: Effect of elevated levels of CO_2 on adult emergence of *Callosobruchus chinensis.*

CO_2 concentration	No. of adults emerged			
(%)	2 MAT	4 MAT	6 MAT	Mean
20	3.00 (1.73)	12.33 (3.51)	32.67 (5.72)	16.00 (4.00)
40	1.33 (1.15)	6.67 (2.58)	19.00 (4.36)	9.00 (3.00)
50	0.67 (0.82)	3.33 (1.82)	8.67 (2.94)	4.22 (2.05)
60	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
80	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
Control	41.67 (6.46)	82.33 (9.07)	105.67 (10.28)	76.56 (8.75)
	SE m±		**CD (p=0.05)**	
Concentrations (F_1)	0.591		1.70	
Time period (F_2)	0.418		1.20	
Interaction ($F_1 \times F_2$)	1.024		2.94	

Figures in the parentheses are square root transformed values, MAT- Months after treatment.

that CO_2 concentration of 50 per cent and more not only checked seed infestation by *C. chinensis* but also reduced the weight loss of seed compared to the normal atmosphere.

Effect of elevated levels of CO_2 on germination (%) of chickpea

Table 6 indicates the chickpea seeds subjected to infestation by *C. chinensis* and exposed to different concentrations of CO_2 and were observed for germination after 2, 4 and 6 months of treatment, which exhibited the similar trends as recorded with seed damage and weight loss. The CO_2 concentration of 60 and 80 per cent were found to be comparatively better treatments and recorded 84.00 and 86.33 per cent germination of chickpea seeds at 2 months of storage. The germination observed in the untreated control was found to be 70.00 per cent after 2 months which further

Table 4: Effect of elevated levels of CO_2 on seed damage (%) infested by *Callosobruchus chinensis.*

CO_2 concentration	Seed damage (%)			
(%)	2 MAT	4 MAT	6 MAT	Mean
20	3.52 (10.78)	6.76 (15.13)	18.51 (25.47)	9.59 (17.99)
40	1.48 (7.01)	4.61 (12.36)	11.83 (20.12)	5.97 (14.06)
50	0.76 (5.11)	1.91 (7.93)	5.03 (12.94)	2.57 (9.26)
60	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
80	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Control	28.31 (31.94)	61.32 (51.54)	86.61 (68.59)	58.75 (50.09)
	SE m±		**CD (p=0.05)**	
Concentrations (F_1)	0.455		1.30	
Time period (F_2)	0.322		0.92	
Interaction ($F_1 \times F_2$)	0.788		2.26	

Figures in parentheses are angular transformation values, MAT- Months after treatment.

Table 5: Effect of elevated levels of CO_2 on weight loss (%) infested by *Callosobruchus chinensis.*

CO_2 concentration	Weight loss (%)			
(%)	2 MAT	4 MAT	6 MAT	Mean
20	4.37 (12.12)	7.08 (15.43)	11.63 (19.94)	7.69 (16.08)
40	2.11 (8.34)	4.39 (12.12)	7.22 (15.55)	4.57 (12.36)
50	1.23 (6.32)	2.05 (8.34)	4.21 (11.83)	2.49 (9.09)
60	0.47 (4.07)	0.96 (5.45)	1.54 (7.01)	0.99 (5.74)
80	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Control	31.45 (34.12)	55.38 (48.07)	76.32 (60.81)	54.35 (47.39)
	SE m±		**CD (p=0.05)**	
Concentrations (F_1)	0.408		1.17	
Time period (F_2)	0.289		0.83	
Interaction ($F_1 \times F_2$)	0.707		2.03	

Figures in parentheses are angular transformation values, MAT- Months after treatment.

Table 6: Effect of elevated levels of CO_2 on germination (%) of chickpea during storage.

CO_2 concentration	Germination (%) of chickpea			
(%)	2 MAT	4 MAT	6 MAT	Mean
20	75.33 (60.20)	72.67 (58.50)	70.00 (56.79)	72.67 (58.50)
40	80.33 (63.65)	76.33 (60.87)	72.67 (58.50)	76.33 (60.87)
50	82.00 (64.90)	78.33 (62.24)	74.67 (59.80)	78.00 (62.03)
60	84.00 (66.42)	80.67 (63.94)	76.00 (60.67)	80.22 (63.58)
80	86.33 (68.28)	83.33 (65.88/)	79.67 (63.22)	83.11 (65.73)
Control	70.00 (56.79)	54.67 (47.70)	42.33 (40.57)	55.67 (48.27)
	S.E m.±		**C.D. (p=0.05)**	
Concentrations (F_1)	1.459		4.18	
Time period (F_2)	1.031		2.96	
Interaction ($F_1 \times F_2$)	2.526		7.25	

Figures in parentheses are angular transformed values, MAT- Months after treatment.

decreased to 54.67 and 42.33 per cent after 4 and 6 months of treatments, respectively. Similar results were also reported by various researchers (Raghupathi *et al*., 2021; Shivaraja *et al*., 2012; Paikaray *et al*., 2022).

Effect of nano particles on adult mortality of *Callosobruchus chinensis*

The data presented in Table 7 reveals that among the nano particle treatments, nano silica @ 1000 ppm was the most effective treatment which registered 72.67 per cent adult mortality after 1 day of treatment and cent per cent mortality was obtained 5 days after treatment (DAT). Likewise, nano zinc oxide @1000 ppm recorded 65.00 per cent mortality 1 DAT and complete adult mortality was observed at 7 DAT. Lower concentration of nano zinc oxide @250 ppm was least effective and recorded 21.93 per cent mortality at 1 DAT which increased to 68.67 per cent after 10 days of treatment. Similarly, nano silica @ 250 ppm recorded 27.33 per cent mortality which was further enhanced to 82.67 per cent at 10 DAT. Treatment with nano silica and nano zinc oxide @750 ppm manifested 95.67 and 90.67 per cent mortality at 7DAT, respectively and both the nano particles exhibited cent per cent mortality at10 DAT. The results are in line with Jyothsna (2014) who recorded nano silica 1000 ppm and 500 ppm to be highly effective and caused cent per cent mortality at 1 day after treatment.

Effect of nano particles on the fecundity and adult emergence

The data presented in Table 8 revealed that the higher concentrations (1000 and 750 ppm) of both the silica and zinc nano particles resulted in complete mortality of the adults within 2 to 6 months after treatment (MAT). The egg laying and emergence of adults were not observed from the above treatments. The lower concentrations of nano silica and nano zinc @ 250 ppm resulted in very few eggs laying (6.00 and 5.00 eggs respectively) by the pulse beetle at 2 months after treatment which further enhanced to 10.67 and 13.33 eggs at 6MAT respectively. The eggs laid by the test insect also could not properly develop in to adults. Treatment with nano silica @ 500 ppm recorded 4.67 eggs, whereas nano zinc oxide at the same concentration registered 6.00 eggs during 6 months of storage. Both the nano particles at 500 ppm were also found to be effective in preventing the development of the insect thus reducing the adult emergence at 6 MAT. These nano treatments were significantly superior

Table 7: Effect of nanoparticles on adult mortality of *C. chinensis* L.

Treatments	1 DAT	3 DAT	5 DAT	7 DAT	10 DAT	Mean
Nano zinc oxide @ 250 ppm	21.93 (27.90)	30.00 (33.23)	45.67 (42.53)	54.33 (47.48)	68.67 (55.99)	44.12 (41.61)
Nano zinc oxide @ 500 ppm	29.00 (32.62)	41.33 (40.02)	58.33 (49.82)	72.67 (58.54)	87.67 (69.39)	57.80 (49.46)
Nano zinc oxide @ 750 ppm	38.33 (38.24)	54.33 (47.48	75.67 (60.46)	90.67(72.18)	100.00 (90.00)	71.80 (57.89)
Nano zinc oxide @ 1000 ppm	65.00 (53.71)	80.33 (63.64)	95.67 (77.96)	100.00(90.00)	100.00(90.00)	88.20(69.88)
Nano silica @ 250 ppm	27.33 (31.47)	45.00(42.14)	55.67 (48.25)	73.33 (58.87)	82.67 (65.37)	56.80 (48.94)
Nano silica @ 500 ppm	43.67 (41.38)	58.33 (49.82)	71.00 (57.45)	83.67 (66.21)	90.33 (71.81)	69.40 (56.41)
Nano silica @ 750 ppm	56.00 (48.42)	72.67 (58.54)	83.33 (65.92)	95.67(77.96)	100.00 (90.00)	81.53 (64.56)
Nano silica @ 1000 ppm	72.67 (58.53)	91.33 (72.94)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	92.80 (74.37)
Control	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
SE m±	1.833	1.956	2.317	2.585	2.769	2.227
CD (p=0.05)	5.45	5.81	6.88	7.68	8.22	6.62

Figures in parentheses are angular transformed values, DAT: Days after treatment.

Table 8: Effect of nanoparticles on fecundity and adult emergence of *C. chinensis* L.

Dosages	Number of eggs laid/female (100 g of seeds)			Number of adults emerged		
	2 MAT	4 MAT	6 MAT	2 MAT	4 MAT	6 MAT
Nano zinc oxide @ 250 ppm	5.00 (2.23)	10.67 (3.27)	13.33 (3.65)	4.33 (2.08)	8.00 (2.83)	10.67 (3.27)
Nano zinc oxide @ 500 ppm	2.67 (1.63)	4.33 (2.08)	6.00 (2.45)	1.67 (1.29)	2.67 (1.63)	4.33 (2.08)
Nano zinc oxide @ 750 ppm	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
Nano zinc oxide @ 1000 ppm	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
Nano silica @ 250 ppm	6.00 (2.45)	8.33(2.89)	10.67 (3.27)	4.00 (2.00)	6.67 (2.58)	8.33 (2.89)
Nano silica @ 500 ppm	1.33 (1.15)	2.67 (1.63)	4.67 (2.16)	0.67 (0.82)	1.33 (1.15)	3.00 (1.73)
Nano silica @ 750 ppm	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
Nano silica @ 1000 ppm	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
Control	63.00 (7.94)	87.67 (9.36)	112.67 (10.61)	40.00 (6.32)	67.33 (8.21)	91.67 (9.57)
SE m±	0.751	0.994	1.236	0.540	0.798	1.031
CD (p=0.05)	2.23	2.95	3.67	1.60	2.37	3.06

Figures in parentheses are square root transformed values, MAT- Months after treatment.

Table 9: Effect of nanoparticles on seed damage (%) and weight loss (%) due to *C. chinensis* L. Infestation.

Dosages	Seed damage (%)			Weight loss (%)		
	2 MAT	4 MAT	6 MAT	2 MAT	4 MAT	6 MAT
Nano zinc oxide @ 250 ppm	5.00 (12.94)	7.67 (16.08)	11.33 (19.63)	3.34 (10.49)	5.96 (14.06)	9.44 (17.88)
Nano zinc oxide @ 500 ppm	2.00 (8.11)	4.33 (11.95)	5.44(13.41)	1.32 (6.55)	2.82 (9.61)	3.70 (11.07)
Nano zinc oxide @ 750 ppm	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Nano zinc oxide @ 1000 ppm	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Nano silica @ 250 ppm	3.67 (11.07)	5.96 (14.06)	9.67(18.12)	2.34 (8.74)	3.77 (11.24)	7.96 (16.32)
Nano silica @ 500 ppm	1.33 (6.55)	2.87(9.79)	4.33 (11.95)	0.93 (5.45)	1.33 (6.55)	3.67(11.07)
Nano silica @ 750 ppm	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Nano silica @ 1000 ppm	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Control	28.31 (31.94)	61.32 (51.54)	86.61 (68.59)	31.45 (34.12)	55.38 (48.07)	76.32 (60.81)
SE m±	0.446	0.747	0.992	0.461	0.681	0.889
CD (p=0.05)	1.33	2.22	2.95	1.37	2.02	2.64

Figures in parentheses are angular transformed values, MAT- Months after treatment.

to control where the adult emergence at 2, 4 and 6 MAT was 40.00, 67.33 and 91.67 adults, respectively. Jyothsna (2014) reported the superiority of nano silica and nano zinc @ 1000 ppm and 500 ppm concentrations in reducing the fecundity and adult bruchid emergence.

Effect of nano particles on the seed damage (%) and weight loss (%) in chickpea seeds

It is evident from the data presented in Table 9 that nano silica and nano zinc oxide @ 1000 and 750 ppm did not record any seed damage even after 6 months of storage. Among the different nano particle treatments, nano zinc oxide at 250 ppm was comparatively less effective which recorded 5.00 per cent seed damage at 2 MAT followed by nano silica treatment (3.67%) at the same concentration. Nano zinc oxide at 500 ppm recorded 2.00 per cent seed damage which was at par with nano silica treatment at the same concentration (1.33%) at 2 MAT. Nano zinc oxide at 500 ppm resulted in 5.44 per cent seed damage which was at par with nano silica at 500 ppm (4.33%) after 6 months of storage. Similarly, higher concentration of nano silica and nano zinc both at 1000 ppm and 750 ppm did not exhibit any loss in seed weight up to 6 months of storage as no seed infestation or damage was noticed. Among the different nano particle treatments, nano zinc oxide at 250 ppm resulted in 9.44 per cent of seed weight loss after six months of storage which was at par with nano silica at the same concentration (7.96%). Malaikozhundan and Vinodhini (2018) reported minimum per cent pod damage by *Caryedon serratus* (4.34) with nano ZnO particle treatment.

CONCLUSION

The exposure of adult pulse beetle to 60% and 80% CO_2 for 180 minutes resulted in a complete mortality of adults within one or two days of treatment. Exposing the chickpea seeds to a higher concentration of CO_2 not only checked seed infestation but also prevented the progeny development up to 6 months of treatment but did not affect the seed germination. Management of pulse beetle by nanoparticles @ 250, 500, 750 and 1000 ppm per kg of seeds showed the superior performance of the higher concentrations (1000 ppm and 750 ppm) of nano silica and nano zinc over other treatments which completely protected the chickpea seeds from oviposition, development and damage by *C. chinensis*.

Conflict of interest: None.

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