The Pharma Innovation Journal 2023; SP-12(7): 1192-1197

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; SP-12(7): 1192-1197

www.thepharmajournal.com
Received: 25-04-2023
Accepted: 29-05-2023

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Evaluation of biopesticides and newer insecticides on fruit yield to improve the cost-benefit ratio

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Abstract
Brinjal (*Solanum melongena* L.) is a popular solanaceous vegetable that is high in nutrients such as vitamins, phenols, and antioxidants. However, it is vulnerable to a variety of insect pests, with the brinjal fruit and shoot borer inflicting up to 40% loss. To address this issue, we assessed the efficiency of various pesticides, including biopesticides and botanical alternatives, against the insect pest. The data obtained concentrated on fruit yields, and the cost-benefit ratio was determined. Among the insecticides examined, Spinosad had the greatest efficacy in suppressing the brinjal fruit and shoot borer, resulting in the largest yield of marketable fruits. The treatments with *Bacillus thuringiensis* (Bt) had the lowest yield. Biopesticides are being used. Biopesticides, such as Spinosad, provide an environmentally benign method to pest management by avoiding potential harm to beneficial insects and lowering chemical residues on harvested produce. However, the monetary consequences of utilising such insecticides must be considered. As a result, we evaluated the benefit-cost ratio for each treatment to determine its economic feasibility. The results of our research show that applying Spinosad as a brinjal pesticide treatment can provide efficient pest control against the brinjal fruit and shoot borer, resulting in higher yields of marketable fruits. However, more research is required to thoroughly assess the cost-effectiveness and long-term sustainability of these treatments in brinjal agriculture.

Keywords: Bio-pesticides, insecticides, brinjal, benefit-cost ratio, yield

Introduction
Brinjal (*Solanum melongena* L.), also known as eggplant or Aubergine (in Europe), is a highly nutritious solanaceous vegetable cultivated worldwide, rich in vitamins, phenols, and antioxidants (Gur-buz *et al*., 2018) [43]. However, the shoot and fruit borer threatens to cause severe production losses, which is a major pest affecting various vegetable crops globally. Unfortunately, due to their repeated use, this pest has developed resistance to several synthetic insecticides, including organophosphates, pyrethroids, and microbial-derived pesticides (Gur-buz *et al*., 2018) [43]. The brinjal fruit and shoot borer larva pose a regular and severe threat, with a single larva capable of infesting 4-6 fruits. Different insecticides have been evaluated for their efficacy against this pest; however, their frequent and excessive use has given rise to concerns of resistance. Affected shoots dry up, the flowers and developing fruits fall prematurely, and the damaged fruits become unsuitable for human consumption. (Gur-buz *et al*., 2018) [43]. In order to solve this issue as well as avoid resistance, newer chemicals that require lower doses as few as a few grams per hectare—while keeping high toxicity against insect pests should be used in place of older ones. (Gur-buz *et al*., 2018) [43]. Emamectin benzoate, a microbial bio-pesticide, is one among a few viable alternatives. It may be treated separately or in combination. (Islam *et al*., 2016) [11] and Lambda-cyhalothrin, a new class of insecticide, with a novel mode of action that exhibits strong insecticidal activity against lepidopteran pests, including resistant strains (Pawar *et al*., 1986; Mathirajan *et al*., 2000) [19, 15, 20]. It becomes more clear that changing from broad-spectrum chemical pesticides to organic alternatives is required to promote sustainable farming and protect the health of individuals as well as the environment. Finding commercially viable organic alternatives that can protect the environment and prevent the extinction of insect species, which can occur up to 70% faster as a result of climate change, is necessary. (Gur-buz *et al*., 2018) [43]. As a novel alternative to chemical pesticides, bio-pesticide such as microbial bacteria and botanical neem oil may provide benefits like economic effectiveness, reduced adverse effects on the environment, species-specific targeting, and lack of resistance. (Gur-buz *et al*., 2018) [43]. Despite the availability of wildlife-friendly methods, chemical pesticides continue to be widely used in

farming areas due to their cost, accessibility, and farmers' mistrust of natural pesticides' capacity to effectively combat persistent insect infestations. However, a change to safer and more efficient insecticides is required, especially in vegetable crops that need frequently harvesting, to ensure the safe use of pesticides. (Gur-buz *et al*., 2018) [43]. In major parts of Nepal, brinjal is the second most widely grown vegetable after tomatoes within the Solanaceae family, and it is highly consumed in India, Nepal, and other South Asian countries (Singh and Bhandari, 2015) [32]. *L. orbonalis* remains a significant constraint, affecting the quantity and quality of the brinjal harvest (Rahman *et al*., 2017) [5]. India holds a prominent position in the cultivation of eggplant, ranking second in yield and productivity globally, with West Bengal leading in brinjal production (Anonymous, 2021) [2]. Insect pest infestation poses a major obstacle to increasing vegetable crop production worldwide, with brinjal being plagued by numerous pests, including the brinjal shoot and fruit borer (*Leucinodes orbonalis*), jassid (*Biguttula biguttula*), Epilchna beetle (*Hinosepilachna vigintiopunctata*), whitefly (*Bemisia tabaci*), and aphid (*Aphis gossypii*) as major damaging pests (Gur-buz *et al*., 2018) [43]. Among these, *L. orbonalis* is South Asia's most notorious and destructive pest, causing extensive damage to eggplant shoots and fruits throughout the growing season. In addition to direct damage, the pest's excreta oozing holes on the fruits result in a filthy appearance, reducing their market value. Sucking pests further exacerbate crop damage by weakening plants through sap-sucking, reducing photosynthesis and indirectly transmitting viral diseases (Gur-buz *et al*., 2018) [43]. Insecticides are essential for pest control, especially while producing brinjal because frequent harvesting is required. Successful pest management techniques, however, place a premium on the proper and safe use of insecticides. Finding safer and more effective insecticides to protect crops is therefore crucial. (Gur-buz *et al*., 2018) [43].

Materials and Methods

The field experiment was conducted in 2019 and 2020 at Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, U.P., India, using the high-yielding variety Pusa Purple Long. The crop received proper maintenance throughout the growing period, and the objective was to evaluate the impact of biopesticides and newer insecticides on fruit yield to improve the cost-benefit ratio. The percentage of fruit infestation at different stages of the crop will be calculated, focusing on the infestation that occurred during the fruiting stage. To record fruit yield, the healthy fruits of brinjal in each treatment were measured in quintal/ha, considering the cumulative fruit production in each plot. To observe the increase in yield in the treated plot compared to the controlled plot, as well as the percentage increase in yield over the control plot, the following formula was utilized.

$$\% \text{ Fruit yield (q/ha)} = \frac{\text{Fruit yield (kg/plot) X 1000(m2)}}{\text{plot size (m2)} \times 100}$$

$$\text{Increase Yield (q/ha)} = \frac{\text{Yield of treated plot} - \text{Yield of untreated plot}}{\text{Yield of untreated plot}}$$

Result and Discussion

Evaluation of biopesticides and newer insecticides on fruit yield to improve the cost benefit ratio during the crop season of Zaid 2019

The statistically analysed data on fruit yield under different treatments, including the biopesticides and newer insecticides, yielded higher and superior over control during Zaid, 2019. The maximum fruit yield 257.32 q/ha was recorded in the plots treated with Spinosad 45% SC @ 150 ml/ha, Emamectin benzoate 5% SG @ 250 gm/ha was second best treatment which recorded fruit yield of 252.71 q/ha. The next treatments in order were Indoxacarb 14.5 SC @ 500 ml/ha, Profenophos 50 EC @ 1000 ml/ha, Lambda-cyhalothrin 5% EC @ 500 ml/ha, Quinalphos 25% EC@ 1000 ml/ha, Neem oil (1500 ppm) @ 2500 ml/ha and *Bacillus thuringiensis* @ 1000 gm/ha and with fruit yield of 238.43, 193.86, 186.63, 181.36, 174.87 and 168.23 q/ha, respectively. The lowest brinjal yield, 156.97 q/ha, was observed in the untreated control.

Evaluation of biopesticides and newer insecticides on fruit yield to improve the cost-benefit ratio during the crop season of Zaid 2020

The recorded fruit yield during Zaid, 2020 indicated that all the treatments of biopesticides and newer insecticides gave significantly higher yields than the control. The maximum fruit yield was observed in the treatment Spinosad 45% SC @ 150 ml/ha with 264.86 q/ha and followed by Emamectin benzoate 5% SG @ 250 gm/ha, Indoxacarb 14.5SC @ 500 ml/ha, Profenophos 50 EC @ 1000 ml/ha, Lambda-cyhalothrin 5 EC @ 500 ml/ha, Quinalphos 25 EC @ 1000 ml/ha, Neem oil (1500 PPM) @ 2500 ml/ha and *Bacillus thuringiensis* @ 1000 gm/ha with fruit yield of 264.86, 242.31, 198.67, 190.18, 184.57, 177.08 and 172.63 q/ha, respectively. However, the lowest fruit yield was recorded in the untreated control with 163.73 q/ha.

Evaluation of treatments on the incremental cost-benefit ratio

When each treatment, the expenses of labour and spray were equal, but there were differences in the total amount of workers needed, the cost of bio-pesticides, and the cost of newer insecticides for spraying a single hectare of crops. The cost of all treatments required for spraying on one hectare of land was calculated to determine the economics of the applied treatments. Table-1

It was clear from the table that the treatment Lambda-cyhalothrin 5% EC @ 500 ml/ha, showed the minimum cost of Rs 2970 Rs./ha. It followed by Quinalphos 25% EC @ 1000 ml/ha, *Bacillus thuringiensis* @ 1000 gm/ha, Profenophos 50 EC @ 1000 ml/ha, Neem oil (1500 PPM) @ 2500 ml/ha, Emamectin benzoate 5% SG @ 250 gm/ha, Indoxacarb 14.5% SC @ 500 ml/ha and Spinosad 45% SC @ 150 ml/ha with cost of Rs 3330, 3525, 3678, 6825, 7200 and 7950 per hectare, respectively. Whereas the maximum cost of treatment (Rs 9450/ha) was recorded with Spinosad 45% SC @ 150 ml/ha.

The data recorded on net profit revealed that the highest net profit of Rs 110970/ha was obtained with the treatment spinosad 45% SC @ 150 ml/ha during Zaid, 2019 and followed by Emamectin benzoate 5% SG @ 250 gm/ha, Spinosad 45% SC @ 150 ml/ha, Indoxacarb 14.5% SC @ 500 ml/ha, Profenophos 50 EC @ 1000 ml/ha, Lambda-cyhalothrin 5% EC @ 1000 ml/ha, Quinalphos 25% EC @ 1000 ml/ha, Neem oil (1500 ppm) @ 2500 ml/ha and *Bacillus thuringiensis* @ 1000 gm/ha of with net profit of Rs 107688, 89802, 40590, 32622, 25938 and 14655 per hectare, respectively. Among all the bio-pesticides and newer insecticides the lowest net profit (Rs. 9987 /ha) was calculated from the treatment water during Zaid, 2019.

During Zaid, 2020 the highest net profit Rs. 111906/ha was observed with the treatment Spinosad 45% SC @ 150 ml/ha. The net profit of other effective treatments were found Emamectin benzoate 5% SG @ 250 gm/ha, Spinosad 45% SC @ 150 ml/ha, Indoxacarb 14.5% SC @ 500 ml/ha, Profenophos 50 EC @ 1000 ml/ha, Lambda-cyhalothrin 5% EC @ 500 ml/ha, Quinalphos 25% EC @ 1000 ml/ha, Neem oil (1500 ppm) @ 2500 ml/ha and *Bacillus thuringiensis* @ 1000 gm/ha with net profit of Rs 106068, 86346, 38250, 28770, 21678 and 9155 per hectare, respectively. Among all the bio-pesticides and newer insecticides the lowest net profit (Rs 7155 /ha) was calculated from the treatment water during Zaid, 2020.

The data regarding net profit in data of both years revealed that the highest net profit (Rs 111438/ha) was obtained with the treatment Spinosad 45% SC @ 150ml/ha water. The net profit of other effective treatments were found Emamectin benzoate 5% SG @ 250 gm/ha, Spinosad 45% SC @ 150 ml/ha, Indoxacarb 14.5% SC @ 500 ml/ha, Profenophos 50 EC @ 1000 ml/ha, Lambda-cyhalothrin 5% EC @ 500 ml/ha, Quinalphos 25% EC@ 1000 ml/ha, Neem oil (1500 ppm) @ 2500 ml/ha and *Bacillus thuringiensis* @ 1000 gm/ha with net profit of Rs. 106068, 86346, 38250, 28770, 21678 and 9155 per hectare, respectively. Among all the bio-pesticides and newer insecticides, the lowest net profit (Rs. 7155 /ha) was calculated from the treatment water during Zaid, 2020.

The maximum incremental cost-benefit ratio of 1:14.96 during Zaid, 2019 and 1:14.73 during Zaid, 2020 was recorded in the treatment of Emamectin benzoate 5% SG @ 250 gm/ha (Table -2) and followed by Spinosad 45%SC @ 150 ml/ha water, Indoxacarb 14.5 SC @ 500 ml/ha, Profenophos 50 EC @ 1000 ml/ha, Lambda-cyhalothrin 5% EC @ 500 ml/ha, Quinalphos 25% EC @ 1000 ml/ha, *Bacillus thuringiensis* @1000 gm/ha and Neem oil (1500 ppm) 2500 ml/ha with an incremental cost-benefit ratio of 1:11.74, 1:11.30, 1:11.04, 1:10.98, 1:2.83 and 1:2.15 during the first year, *i.e.* Zaid, 2019 and 1:11.84, 1:10.86, 1:10.40, 1:9.69, 1:6.51 and 1:2.03 during second year *i.e.* Zaid, 2020, respectively. Whereas the minimum ICBR of 1:2.15 during Zaid, 2019 and 1:1.35 during Zaid, 2020 was observed in neem oil treatment (1500 ppm) @ 2500 ml/ha water.

Table 1: Effect of various treatments on yield and incremental cost benefit ratio of brinjal against infestation caused by brinjal shoot and fruit borer, *L. orbonalis,* during Zaid, 2019

S. No.	Treatments	Dose (gm/ml)/ha	Yield (q/ha)	Increased yield over control (q/ha)	Value of increased yield (Rs./ha) [A]	*Cost of treatments (Rs./ha) [B]	Net profit (Rs./ha) [A-B]	ICBR (A-B) / B
1	Indoxacarb 14.5SC	500 ml/ha	238.43	81.46	97752	7950	89802	11.30
2	Lambda – cyhalothrin 5% EC	500 ml/ha	186.63	29.66	35592	2970	32622	10.98
3	Emamectin benzoate 5%SG	250 gm/ha	252.71	95.74	114888	7200	107688	14.96
4	Spinosad 45% SC	150 ml/ha	257.32	100.35	120420	9450	110970	11.74
5	Profenophos 50EC	1000 ml/ha	193.86	36.89	44268	3678	40590	11.04
6	*Bacillus thuringiensis*	1000 gm/ha	168.23	11.26	13512	3525	9987	2.83
7	Neem oil (1500 PPM)	2500 ml/ha	174.87	17.9	21480	6825	14655	2.15
8	Quinalphos 25% EC	1000 ml/ha	181.36	24.39	29268	3330	25938	7.79
9	Untreated control	-	156.97	-	-	-	-	-

The market cost of brinjal = Rs. 1200/q; Sprayer rent = Rs. 50/spray; Labour charge = Rs. 300/day, and two labour for one spray were used. *Plant protection cost includes insecticides/botanicals, labour charges for spraying and rent of sprayer.

Table 2: Effect of various treatments on yield and incremental cost benefit ratio of brinjal against infestation caused by brinjal shoot and fruit borer, *L. orbonalis* during Zaid, 2020

S. No.	Treatments	Dose (gm/ml)/ha	Yield (q/ha)	Increased yield over control (q/ha)	Value of increased yield (Rs./ha) [A]	*Cost of Treatments (Rs./ha) [B]	Net profit (Rs./ha) [A-B]	ICBR (A-B) / B
1	Indoxacarb 14.5SC	500 ml/ha	242.31	78.58	94296	7950	86346	10.86
2	Lambda – cyhalothrin 5 EC	500 ml/ha	190.18	26.45	31740	2970	28770	9.69
3	Emamectin benzoate 5% SG	250 gm/ha	258.12	94.39	113268	7200	106068	14.73
4	Spinosad 45% SC	150 ml/ha	264.86	101.13	121356	9450	111906	11.84
5	Profenophos 50EC	1000 ml/ha	198.67	34.94	41928	3678	38250	10.40
6	*Bacillus thuringiensis*	1000 gm/ha	172.63	8.9	10680	3525	7155	2.03
7	Neem oil (1500 PPM)	2500 ml/ha	177.08	13.35	16020	6825	9195	1.35
8	Quinalphos 25% EC	1000 ml/ha	184.57	20.84	25008	3330	21678	6.51
9	Untreated control	-	163.73	-	-	-	-	-

Market cost of brinjal = Rs. 1200/q; Sprayer rent = Rs. 50/spray; Labour charge = Rs. 300/day and two labour for one spray were used. *Plant protection cost includes insecticides/botanicals, labour charges for spraying and rent of sprayer.

Discussion

The present findings with the Sunder Pal (2018) [17] study agree to some extent. Table 1 shows the statistically examined data on fruit yield under different treatments, with larger yields being produced by bio-pesticide along with more newer insecticides. They were found to be superior over control during Zaid, 2019. The maximum fruit yield of 257.32 q/ha was recorded in the plots treated with Spinosad 45 SC @ 150 ml/ha, and Emamectin benzoate 5 SG @ 250 gm/ha was the secondbest treatment which recorded a fruit yield of 252.71 q/ha. The next treatments in order were Indoxacarb 14.5SC @ 500 ml/ha, Profenophos 50 EC @ 1000 ml/ha, Lambda cyhalothrin 5 EC @500 ml/ha, Quinalphos 25 EC @ 1000 ml/ha, Neem oil (1500 PPM) @ 2500 ml/ha and *Bacillus thurnigiensis* @ 1000 gm/ha and with fruit yield of 238.43, 193.86, 186.63, 181.36, 174.87 and 168.23 q/ha, respectively.

The lowest fruit yield, 156.97 q/ha, was observed in the untreated control. The data table-2 recorded on fruit yield during Zaid, 2020 indicated that the treatments of bio-pesticides and newer insecticides gave significantly higher yields than the control. The maximum fruit yield was observed in the treatment Spinosad 45 SC @ 150 ml/ha with 264.86 q/ha and followed by Emamectin benzoate 5 SG @ 250 gm/ha, Indoxacarb 14.5SC @ 500 ml/ha, Profenophos 50 EC @ 1000 ml/ha, Lambda-cyhalothrin 5 EC @ 500 ml/ha, Quinalphos 25 EC @ 1000 ml/ha, Neem oil (1500 PPM) @ 2500 ml/ha and *Bacillus thuringiensis* @ 1000 gm/ha with fruit yield of 264.86, 242.31, 198.67, 190.18, 184.57, 177.08 and 172.63 q/ha, respectively. However, the lowest fruit yield was recorded in the untreated control with 163.73 q/ha. The labour charges and charges of spray were uniform for each treatment, but there was a difference between the number of labour used, the cost of bio-pesticides and newer insecticides for spray treatment in one hectare of crop. The economics of the used treatments were assessed cost of all treatments required for spray in one hectare of land, shown in Table-2. It was clear from the table that the treatment Lambda-cyhalothrin 5 EC @ 500 ml/ha showed the minimum cost of Rs. 2970 Rs./ha. It followed by Quinalphos 25 EC @ 1000 ml/ha, *Bacillus thuringiensis* @ 1000 gm/ha, Profenophos 50 EC @ 1000 ml/ha, Neem oil (1500 PPM) @ 2500 ml/ha, Emamectin benzoate 5 SG @ 250 gm/ha, Indoxacarb 14.5 SC @ 500 ml/ha and Spinosad 45 SC @ 150 ml/ha with cost of Rs 3330, 3525, 3678, 6825, 7200 and 7950 per hectare, respectively. Whereas the maximum cost of treatment (Rs 9450/ha) was recorded with Spinosad 45 SC @ 150 ml/ha. The data (Table-1) recorded on net profit revealed that the highest net profit of Rs. 110970/ha was obtained with the treatment Spinosad 45 SC @ 150 ml/ha during Zaid, 2019 and followed by Emamectin benzoate 5 SG @ 250 gm/ha, Spinosad 45 SC @ 150 ml/ha, Indoxacarb 14.5 SC @ 500 ml/ha, Profenophos 50EC @ 1000 ml/ha, Lambda-cyhalothrin 5 EC @ 1000 ml/ha, Quinalphos 25 EC@ 1000 ml/ha, Neem oil (1500 PPM) @ 2500 ml/ha and *Bacillus thurnigiensis* @ 1000 gm/ha of with net profit of Rs 107688, 89802, 40590, 32622, 25938 and14655 per hectare, respectively. The bio-pesticides and newer insecticides with the lowest net profit (Rs. 9987 /ha) were calculated from the treatment water during Zaid, 2019. The data (Table-2) during Zaid, 2020, the highest net profit of Rs 111906/ha was observed with the treatment Spinosad 45SC @ 150 ml/ha. The net profit of other effective treatments was found Emamectin benzoate 5SG @ 250 gm/ha, Spinosad 45 SC @ 150 ml/ha, Indoxacarb14.5 SC@ 500 ml/ha, Profenophos 50EC @ 1000 ml/ha, Lambda-cyhalothrin 5 EC @ 500 ml/ha, Quinalphos 25 EC@ 1000 ml/ha, Neem oil (1500 PPM) @ 2500 ml/ha and *Bacillus thuringiensis* @ 1000 gm/ha with net profit of Rs. 106068, 86346, 38250, 28770, 21678 and 9195 per hectare, respectively. The lowest net profit (Rs. 7155 /ha) was calculated from the treatment water during Zaid, 2020 for bio-pesticides and newer insecticides. The bio-pesticides and newer insecticides, the lowest net profit (Rs. 7155 /ha) was calculated from the treatment water during Zaid, 2020. The maximum incremental cost-benefit ratio of 1:14.96 during Zaid, 2019 and 1:14.73 during Zaid, 2020 was recorded in the treatment of Emamectin benzoate 5 SG @ 250 gm/ha Table-1 and 2 followed by Spinosad 45 SC @ 150 ml/ha water, Indoxacarb 14.5SC @ 500 ml/ha, Profenophos 50 EC @1000 ml/ha, Lambda-cyhalothrin 5 EC @500 ml/ha, Quinalphos 25 EC @ 1000 ml/ha, *Bacillus thuringiensis* @ 1000 gm/ha and Neem oil (1500 PPM) 2500 ml/ha with an incremental cost-benefit ratio of 1:11.74, 1:11.30, 1:11.04, 1:10.98, 1:2.83 and 1:2.15 during the first year, *i.e*. Zaid, 2019 and 1:11.84, 1:10.86, 1:10.40, 1:9.69, 1:6.51 and 1:2.03 during second year *i.e*. Zaid, 2020, respectively. Whereas the minimum ICBR of 1:2.15 during Zaid, 2019 and 1:1.35 during Zaid, 2020 was observed in neem oil treatment (1500 PPM) @ 2500 ml/ha water. The findings partially agree with Sundar Pal (2018) [17], who reported that the maximum cost-benefit ratio was recorded in treating Emamectin benzoate 5 SG @ 250 gm/ha. The present findings also agree with the observations of Raina *et al*. (2016) [22], who reported that the treatment Emamectin benzoate 5 SG had the highest C: B ratio. The present results corroborate with Sunder Pal (2018) [17], who reported that the treatment Emamectin benzoate 5 SG, Spinosad 45 SC and Indoxacarb 14.5 SC was highly effective with a higher C: B ratio. This is in also accordance with Adiroubane and Raghuraman (2008) [1] indicated that spinosad 45 SC was effective.

Conclusion
Findings of the present study reveal strong it may be concluded that all the treatments were found significantly superior over untreated control, Spinosad 45SC @ 150 ml/ha was found most effective in comparison, followed by Emamectin benzoate 5SG @ 250 gm/ha. The maximum ICBR was obtained in Emamectin benzoate by Spinosad. In the case of net income, Spinosad 45SC @150 ml/ha was superior to other treatments but placed second in the view of the CB ratio.

Acknowledgements
The author thanks the Head Department of Entomology for financial support and Dean, Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, UP, for providing the necessary facilities and financial support to conduct the research.

Disclosure statement
The authors declare no conflict of interest.

Declarations: Author contribution statement
D. V. Singh conceived the idea, and Gajendra Singh improved the idea and designed the experiment; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, material, analysis tools or data; Abhishek Yadav and Mahendra Pratap Gautam helped in data analysis and arranging material in to perform experiments. Archana Anokhe has corrected and revised the manuscript.

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