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Comparative economic evaluation of PDKV *Bacillus thuringiensis* formulations, commercial *Bacillus thuringiensis* and *Chlorpyriphos* against brinjal fruit borer, *Leucinodes orbonalis* (Guenée)

Manali Pradip Dhawase, Darshan Sanjay Tajne
Department of Entomology, Post Graduate Institute, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India
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Abstract
The present investigation was undertaken to evaluate the economic performance of PDKV *Bacillus thuringiensis* (*Bt*) formulations in comparison with commercial *Bt* and Chlorpyriphos 20 EC against brinjal fruit borer, *Leucinodes orbonalis* (Guenée). The field experiment was conducted during the *Kharif* season of 2025–26 at Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, using a Randomized Block Design comprising 25 treatments with two replications. The treatments included eleven indigenous PDKV *Bt* isolates formulated as 25% wettable powder (WP) and 75% suspension concentrate (SC), commercial *Bt* (Delfin), Chlorpyriphos 20 EC and an untreated control. Three foliar sprays were applied, and the economic performance of each treatment was assessed based on treatment application cost, fruit yield, value of increased yield, incremental benefit and incremental cost-benefit ratio (ICBR). Among all treatments, Chlorpyriphos 20 EC recorded the highest fruit yield (432.84 q/ha), incremental benefit (Rs. 2,16,203.24/ha) and ICBR (1:49.36). Among the indigenous *Bt* formulations, PDKV-SY-4 25% WP recorded the highest fruit yield (429.56 q/ha), value of increased yield (Rs. 2,17,780.29/ha), incremental benefit (Rs. 2,12,080.29/ha) and ICBR (1:37.21). It was followed by PDKV-SA-20 25% WP (1:35.52) and PDKV-SGd-1 25% WP (1:35.08). Commercial *Bt* (Delfin) recorded an ICBR of 1:36.96. The untreated control recorded the lowest fruit yield (175.20 q/ha). The findings indicated that PDKV-SY-4 25% WP was the most economically promising indigenous *Bt* formulation among those evaluated. Thus, it may be considered a potential microbial insecticide for inclusion in integrated management strategies against *Leucinodes orbonalis*.

Keywords: Brinjal, *Bacillus thuringiensis*, *Leucinodes orbonalis*, economic evaluation, incremental cost-benefit ratio

Introduction
Brinjal (*Solanum melongena* L.) is an important vegetable crop cultivated widely in tropical and subtropical regions, particularly in Asian countries. It is valued for its nutritional importance, regular market demand and contribution to farmer's income (Tindall, 1983) [12]. However, its production is affected by several insect pests, among which the brinjal shoot and fruit borer, *Leucinodes orbonalis* Guenée, is considered one of the most destructive. The larvae bore into tender shoots and developing fruits, resulting in shoot wilting, fruit damage, reduced marketable yield and considerable economic losses (Alam *et al*., 2003; Chakraborti & Sarkar, 2011; Srinivasan, 2008) [1, 3, 11].
Management of *L. orbonalis* largely depends on insecticide applications. However, repeated use of conventional chemical insecticides may create concerns regarding pesticide residues, insecticide resistance and environmental safety. Therefore, microbial insecticides such as *Bacillus thuringiensis* (*Bt*) have gained importance as potential alternatives in integrated pest management. (Krishnaiah *et al*., 1981, Puranik *et al.*, 2002) [5, 8]
The performance and practical usefulness of microbial insecticides also depend on their formulation and application cost. Indigenous *Bt* isolates developed into wettable powder (WP) and suspension concentrate (SC) formulations may provide additional options for pest management. However, their economic performance needs to be assessed in comparison with established commercial *Bt* products and conventional insecticides. Economic evaluation based on treatment cost, additional yield, monetary returns and incremental cost-benefit ratio (ICBR) is therefore important for identifying economically feasible treatments. (Singh and Sachan, 2015) [10]
Considering these aspects, the present investigation was undertaken to evaluate and compare the economic performance of indigenous PDKV *Bacillus thuringiensis* formulations, commercial *Bt* (Delfin) and Chlorpyriphos 20 EC against *L. orbonalis* on brinjal under field conditions during the *kharif* 2025 at Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. The study focused on treatment application costs, fruit yield, additional monetary returns and incremental cost-benefit ratio to identify economically promising treatments.

Materials and Methods
Experimental Site and Design
The field investigation was carried out during the *kharif* season of 2025 at the experimental farm of the Department of Entomology, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India. The experiment was conducted using Brinjal cv. Super Gaurav under a randomized block design (RBD) with 25 treatments, each replicated twice.

Preparation of formulations
Two formulation types, namely wettable powder (WP) and suspension concentrate (SC), were developed using 11 indigenous PDKV *Bacillus thuringiensis* strains. The WP formulation was prepared following the procedure described by Marzaban *et al.* (2021). Briefly, the formulation consisted of 25% bacterial biomass and 75% additives. Of the additive fraction, approximately 60% was allotted to

filler materials, including talc powder, kaolin and diatomaceous earth, while 3% was assigned to a suspension material. The preparation was further supplemented with 12% moisturizer and other components, including sodium lauryl sulfate, sorbic acid and titanium dioxide.

The suspension concentrate (SC) formulation of the PDKV *Bacillus thuringiensis* strains was prepared following the procedure described by Vimala Devi *et al.* (2015) [13]. Briefly, 75 g of technical-grade *Bt* material (70 µm particle size) was thoroughly blended with 25 g of boric acid using a sterile stainless-steel spatula in a 500 ml sterile glass beaker. Separately, Tween-80 and light mineral oil were combined in a ratio of 1:6:84 and vortexed to obtain a uniform Tween–mineral oil (T–M) mixture. Initially, 50 ml of this mixture was added to the *Bt*–boric acid blend and mixed thoroughly with a sterile spatula to form a fine paste. The paste was then ground using a mortar and pestle to obtain a smooth slurry. Subsequently, 142 ml of the T–M mixture was added, and the contents were mixed thoroughly to form a uniform suspension. The resulting suspension was transferred to a mixer jar and blended for 2–3 min to ensure proper homogenization and obtain the final SC formulation.

Treatment details

A total of 25 treatments were evaluated in the experiment. Among these, 11 indigenous PDKV *Bacillus thuringiensis* (*Bt*) strains were tested in two formulations, viz., wettable powder (WP) and suspension concentrate (SC). The powder formulations included PDKV *Bt*-SA-6 25% WP (T1), PDKV *Bt*-SA-18 25% WP (T3), PDKV *Bt*-SA-20 25% WP (T5), PDKV *Bt*-SAK-6 25% WP (T7), PDKV *Bt*-SAK-9 25% WP (T9), PDKV *Bt*-SGd-1 25% WP (T11), PDKV *Bt*-SGn-4 25% WP (T13), PDKV *Bt*-SGn-5 25% WP (T15), PDKV *Bt*-SBn-2 25% WP (T17), PDKV *Bt*-I-3 25% WP (T19) and PDKV *Bt*-SY-4 25% WP (T21), each applied at a dose of 1 kg/ha. Similarly, the liquid formulations comprised PDKV *Bt*-SA-6 75% SC (T2), PDKV *Bt*-SA-18 75% SC (T4), PDKV *Bt*-SA-20 75% SC (T6), PDKV *Bt*-SAK-6 75% SC (T8), PDKV *Bt*-SAK-9 75% SC (T10), PDKV *Bt*-SGd-1 75% SC (T12), PDKV *Bt*-SGn-4 75% SC (T14), PDKV *Bt*-SGn-5 75% SC (T16), PDKV *Bt*-SBn-2 75% SC (T18), PDKV *Bt*-I-3 75% SC (T20) and PDKV *Bt*-SY-4 75% SC (T22), each applied at a dose of 1 l/ha. In addition, commercial *B. thuringiensis* formulation (Delfin) at 1 kg/ha (T23) and chlorpyriphos 20% EC at 1 l/ha (T24) were included as standard treatments. An untreated control (T25), without any insecticidal application, was maintained for comparison

Application of Treatments

Three foliar sprays were administered at 15-day intervals, beginning at the onset of fruit infestation. The treatments were applied with a knapsack sprayer at the specified experimental doses: 1 kg ha^{-1} for the 25% WP formulations and 1 L ha^{-1} for the 75% SC formulations, commercial *Bt* formulation (Delfin) and chlorpyriphos 20 EC. Precautions were taken during spraying to prevent spray drift and avoid contamination of neighbouring plots.

Methods of recording observations

Observations on fruit infestation were obtained from five randomly selected plants in each treatment plot at every harvest. Baseline observations were taken 24 hours before the initial treatment application, followed by post-treatment assessments at seven-day intervals after each spray until the final harvest. Healthy and infested fruits were counted and weighed separately for each observation. Fruit damage was subsequently expressed as percentage infestation on both numerical and weight bases using the standard formula described by Mollah *et al.* (2023) [7].

$$\text{Per cent of fruit damage (Number basis)} = \frac{\text{No. of damaged fruits}}{\text{Total no. of fruits}} \times 100$$

$$\text{Per cent of fruit damage (Weight basis)} = \frac{\text{Weight of damaged fruits}}{\text{Total weight of fruits plucked}} \times 1000$$

Fruit yield from each net plot was recorded at every picking and converted to quintals per hectare for statistical analysis.

$$\text{Fruit yield (q/ha)} = \frac{\text{Fruit yield (kg/plot)} \times 10000\ (m^2)}{\text{Plot size } (m^2) \times 100}$$

Statistical Analysis

The experimental data were subjected to analysis of variance (ANOVA) appropriate for a randomized block design. Population data were transformed as appropriate before analysis, and treatment means were compared using the critical difference (CD) test at the 5% significance level, following Gomez and Gomez (1984) [4].

Result and Discussion

Cost of treatment application

The cost of treatment application for different treatments evaluated against *Leucinodes orbonalis* (Guenée), is presented in Table 1. The total treatment cost varied according to the cost of the plant-protection material, whereas the labour and spraying expenditure was reported to be uniform across the treated plots.

Table 1: Cost of treatments

Treatments	Cost of Plant protection (Rs/ha)	Labour charges for spraying (Rs/ha)	Total Cost of treatment application (Rs/ha)
T1- PDKV-SA-6 25% WP	3000 RS	2700 RS	5700 RS
T2- PDKV-SA-6 75% SC	3000 RS	2700 RS	5700 RS
T3- PDKV-SA-18 25% WP	3000 RS	2700 RS	5700 RS
T4- PDKV-SA-18 75% SC	3000 RS	2700 RS	5700 RS
T5- PDKV-SA-20 25% WP	3000 RS	2700 RS	5700 RS
T6- PDKV-SA-20 75% SC	3000 RS	2700 RS	5700 RS
T7- PDKV-SAK-6 25% WP	3000 RS	2700 RS	5700 RS
T8- PDKV-SAK-6 75% SC	3000 RS	2700 RS	5700 RS
T9- PDKV-SAK-9 25% WP	3000 RS	2700 RS	5700 RS

T10- PDKV-SAK-9 75% SC	3000 RS	2700 RS	5700 RS
T11- PDKV-SGd-1 25% WP	3000 RS	2700 RS	5700 RS
T12- PDKV-SGd-1 75% SC	3000 RS	2700 RS	5700 RS
T13- PDKV-SGn-4 25% WP	3000 RS	2700 RS	5700 RS
T14- PDKV-SGn-4 75% SC	3000 RS	2700 RS	5700 RS
T15- PDKV-SGn-5 25% WP	3000 RS	2700 RS	5700 RS
T16- PDKV-SGn-5 75% SC	3000 RS	2700 RS	5700 RS
T17- PDKV-SBn-2 25% WP	3000 RS	2700 RS	5700 RS
T18- PDKV-SBn-2 75% SC	3000 RS	2700 RS	5700 RS
T19- PDKV-I-3 25% WP	3000 RS	2700 RS	5700 RS
T20- PDKV-I-3 75% SC	3000 RS	2700 RS	5700 RS
T21- PDKV-SY-4 25% WP	3000 RS	2700 RS	5700 RS
T22- PDKV-SY-4 75% SC	3000 RS	2700 RS	5700 RS
T23- Delfin	3000 RS	2700 RS	5700 RS
T24- Chlorpyriphos 20% EC	1680 RS	2700 RS	4380 RS
T25- Untreated control	-	-	-

Labour charges Rs. 300/day @3 labours/spray; spray pump charges Rs100/Day @ 2 pump/ spray; Price of *Bt* formulation 1kg/ha@ 1000/kg price; Chlorpyriphos 20% EC @ 1000ml/ha (@Rs.560/1000ml); Market price of Brinjal is 1500 Rs/q

All indigenous PDKV *Bacillus thuringiensis* formulations, including the 25% WP and 75% SC formulations, and the commercial *Bt* formulation (Delfin) recorded a plant-protection cost of Rs.3,000/ha. With an additional labour and spraying cost of Rs.2,700/ha, the total cost of treatment application was Rs.5,700/ha. In comparison, Chlorpyriphos 20 EC recorded a plant-protection cost of Rs.1,680/ha and a total treatment application cost of Rs.4,380/ha. No treatment expenditure was incurred in the untreated control. The comparatively lower cost of Chlorpyriphos 20 EC was attributable to its lower plant-protection material cost than the *Bt* formulations. Thus, the economic comparison indicated that the cost of the insecticidal formulation was an important component influencing the overall expenditure on pest management. Similar economic assessments considering pesticide cost, labour expenditure and additional yield have been reported by Sarsaiya *et al.* (2020) and Singh and Sachan (2015) [9, 10] in their studies on the management of brinjal shoot and fruit borer.

Incremental cost-benefit ratio (ICBR)

The economic performance of the treatments was assessed in terms of additional fruit yield, value of increased yield, incremental benefit and incremental cost-benefit ratio (ICBR), as presented in Table 2. The results revealed considerable variation in economic returns among the evaluated treatments. Chlorpyriphos 20 EC (T24) recorded the highest ICBR of 1:49.36, with an incremental benefit of Rs.2,16,203.24/ha, followed by PDKV-SY-4 25% WP (T21), which recorded an ICBR of 1:37.21 and an incremental benefit of Rs.2,12,080.29/ha. Commercial Bt (Delfin) (T23) ranked third, with an ICBR of 1:36.96 and an incremental benefit of Rs.2,10,678.82/ha.

Among the indigenous PDKV *Bt* formulations, PDKV-SY-4 25% WP (T21) recorded the highest ICBR (1:37.21), followed by PDKV-SA-20 25% WP (T5) and PDKV-SGd-1 25% WP (T11), with ICBR values of 1:35.52 and 1:35.08, respectively. Other formulations showing comparatively favourable economic performance were PDKV-SY-4 75% SC (T22), PDKV-SA-20 75% SC (T6) and PDKV-SGd-1 75% SC (T12), which recorded ICBR values of 1:34.09, 1:33.93 and 1:33.61, respectively. The higher economic returns of these treatments were associated with their comparatively greater fruit yields and corresponding increases in monetary returns over the untreated control.

The comparatively lower ICBR values were recorded with PDKV-SBn-2 75% SC (T18), PDKV-SGn-5 25% WP (T15), PDKV-SGn-5 75% SC (T16) and PDKV-SA-18 75% SC (T4), recording 1:16.40, 1:17.52, 1:19.28 and 1:21.43, respectively. Their lower additional fruit yields resulted in comparatively lower incremental benefits. The untreated control recorded no additional yield or incremental benefit and, consequently, no positive ICBR.

The higher ICBR of Chlorpyriphos 20 EC may be attributed to its comparatively lower treatment application cost and the highest fruit yield recorded in the experiment. However, PDKV-SY-4 25% WP showed the best economic performance among the indigenous *Bt* formulations, with an ICBR close to that of commercial *Bt* (Delfin). These findings indicate that the economic performance of a treatment depends not only on its ability to increase fruit yield but also on the expenditure required for its application.

The present findings are in agreement with Singh and Sachan (2015) [10], who reported that *Bacillus thuringiensis* was an effective and economical biopesticide against *L. orbonalis*, recording a marketable fruit yield of 245.60 q/ha, a net return of Rs.96,850/ha and a cost-benefit ratio of 1:3.18. Similarly, Sarsaiya *et al.* (2020) [9] reported that *Bt* applied at 2.0 kg/ha recorded the highest net income among the evaluated biopesticides against brinjal shoot and fruit borer. These studies support the economic potential of *Bt*-based treatments for managing the pest and improving returns through increased marketable yield. In the present investigation, PDKV-SY-4 25% WP emerged as the most economically promising indigenous *Bt* formulation, although Chlorpyriphos 20 EC recorded the highest ICBR among all treatments.

Table 2: Effect of treatments on Incremental cost benefit ratio (ICBR).

Treatments	Cost of treatment application (Rs)	Yield of brinjal fruit (q/ha)	Yield increase over control (q/ha)	Value of increased yield (Rs)	Incremental benefit (Rs) (E-B)	ICBR (E-B)/B	Rank
A	B	C	D	E	F	G	H
T1- PDKV-SA-6 25% WP	5700	400.30	128.48	192723.67	187023.67	1:32.81	9
T2- PDKV-SA-6 75% SC	5700	391.47	123.44	185164.21	179464.21	1:31.48	11

T3- PDKV-SA-18 25% WP	5700	368.10	110.11	165161.38	159461.38	1:27.98	16
T4- PDKV-SA-18 75% SC	5700	324.50	85.22	127831.26	122131.26	1:21.43	21
T5- PDKV-SA-20 25% WP	5700	418.35	138.79	208182.33	202482.33	1:35.52	4
T6- PDKV-SA-20 75% SC	5700	407.74	132.73	199094.00	193394.00	1:33.93	7
T7- PDKV-SAK-6 25% WP	5700	359.47	105.18	157771.80	152071.80	1:26.68	17
T8- PDKV-SAK-6 75% SC	5700	378.32	115.94	173909.97	168209.97	1:29.51	14
T9- PDKV-SAK-9 25% WP	5700	382.24	118.18	177265.01	171565.01	1:30.10	13
T10- PDKV-SAK-9 75% SC	5700	395.48	125.74	188604.19	182904.19	1:32.09	10
T11- PDKV-SGd-1 25% WP	5700	415.38	137.09	205634.20	199934.20	1:35.08	5
T12- PDKV-SGd-1 75% SC	5700	405.60	131.51	197267.84	191567.84	1:33.61	8
T13- PDKV-SGn-4 25% WP	5700	340.43	94.31	141463.76	135763.76	1:23.82	20
T14- PDKV-SGn-4 75% SC	5700	353.37	101.70	152548.13	146848.13	1:25.76	18
T15- PDKV-SGn-5 25% WP	5700	298.51	70.39	105577.58	99877.58	1:17.52	23
T16- PDKV-SGn-5 75% SC	5700	310.22	77.07	115600.23	109900.23	1:19.28	22
T17- PDKV-SBn-2 25% WP	5700	346.28	97.65	146475.08	140775.08	1:24.70	19
T18- PDKV-SBn-2 75% SC	5700	291.02	66.11	99164.78	93464.78	1:16.40	24
T19- PDKV-I-3 25% WP	5700	373.51	113.19	169790.49	164090.49	1:28.79	15
T20- PDKV-I-3 75% SC	5700	387.65	121.26	181894.11	176194.11	1:30.91	12
T21- PDKV-SY-4 25% WP	5700	429.56	145.19	217780.29	212080.29	1:37.21	2
T22- PDKV-SY-4 75% SC	5700	408.83	133.35	200028.31	194328.31	1:34.09	6
T23- Delfin	5700	427.93	144.25	216378.82	210678.82	1:36.96	3
T24- Chlorpyriphos 20% EC	4380	432.84	147.06	220583.24	216203.24	1:49.36	1
T25- Untreated control	0	175.20	0	0	0	0	25

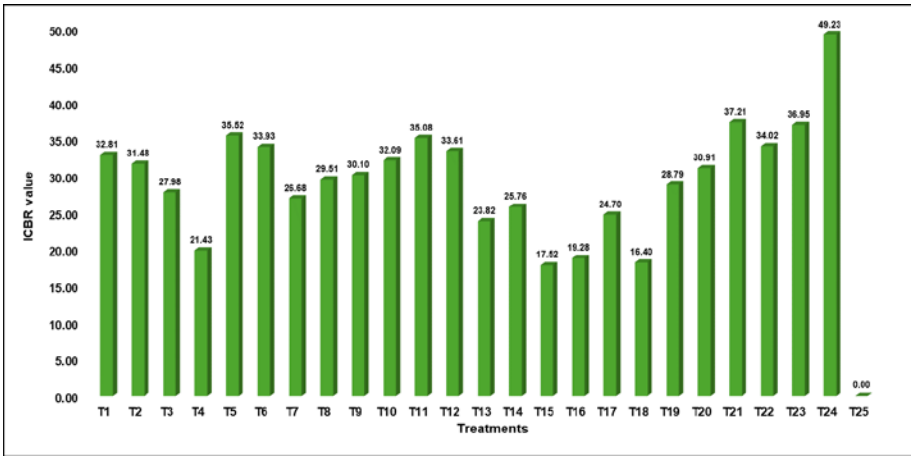


Fig 1: Effect of treatments on Incremental Cost Benefit Ratio

Conclusion

The economic analysis established that effective management of brinjal shoot and fruit borer can translate into substantial economic benefits for brinjal cultivation. The favourable ICBR recorded by the indigenous PDKV *Bacillus thuringiensis* formulations, particularly PDKV-SY-4 25% WP, demonstrates the economic potential of locally developed microbial insecticides. These findings underscore

the importance of evaluating pest-management strategies in terms of both biological effectiveness and economic feasibility. The adoption of promising indigenous formulations could provide growers with an economically viable option while strengthening the role of biopesticides in sustainable brinjal production.

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