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Evaluation of PDKV *Bacillus thuringiensis* formulation against fall army worm *Spodoptera frugiperda* (J.E. Smith) on maize

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Abstract

The present investigation entitled "Evaluation of Novel PDKV *Bacillus thuringiensis* Formulation against *Spodoptera frugiperda* on Maize" was carried out during the year 2024-2025 in the Department of Entomology, Post Graduate Institute, Dr. Panjabrao Deshmukh Krishi Vidyapeeth Akola. The results were found to be statistically significant. However, numerically minimum cumulative percentage and mean of larvae of fall armyworm was recorded after three spraying in descending order of their efficacy in treatment of (treatment T₂₄ Quinalphos 25% EC@1L/ha showed most effective result with minimum infestation of fall armyworm 28.33 percent. Whereas it found statistically at par with the treatment, T₂₃ Delfin @1kg/ha with 30.55, T₅ (PDKV-SA-20 25% WP)@1kg/ha with 31.10, T₁₁ (PDKV-SGd-1 25% WP)@1kg/ha with 31.66, T₂₁ (PDKV-SY-4 25% WP)@1kg/ha with 33.32, T₆ (PDKV-SA-20 75% SC)@1L/ha with 33.88, T₉ (PDKV-SAK-9 25% WP)@1kg/ha with 38.33, T₃ (PDKV-SA-18 25% WP)@1kg/ha with 39.44, T₁₃ (PDKV-SGn-4 25% WP)@1kg/ha with 41.11, T₁₄ (PDKV-SGn-4 75% SC)@1L/ha with 41.66, T₁ (PDKV-SA-6 25% WP)@1kg/ha with 41.10, T₇(PDKV-SAK-6 25% WP)@1kg/ha with 41.66 recorded percent infestation. The next best treatment found was T₁₉ (PDKV-I-3 25% WP)@1kg/ha with recorded 42.77 percent and found at par with T₁₈ (PDKV-SBn-2 75% SC)@1L/ha with 43.33, T₄ (PDKV-SA-18 SC)@1L/ha with 44.44, T₈ (PDKV-SAK-6 75% SC)@1L/ha with 44.99, T₁₀ (PDKV-SAK-9 75% SC)@1L/ha with 44.44, T₂ (PDKV-SA-6 75% SC)@1L/ha with 47.73, T₂₀ (PDKV-I-3 75% SC)@1L/ha with 48.33 were proved to be effective in controlling the fall armyworm.

Keywords: *Bt* formulations, maize fall armyworm, *Spodoptera frugiperda*

Introduction

There are several reasons for the low productivity of maize viz., environmental factors, low mechanization, pest and diseases etc. Of these, insect pests are the major constraints as this attacking maize not only directly as borers, sap suckers, stem and root feeders etc. but also indirectly as vectors of diseases (Wayal *et al.*, 2022) [19]. There are four major pests of maize prevalent in India. These are spotted stem borer *Chilo partellus* (Swinhoe), pink stem borer *Sesamia inferens* (Walker), shoot fly *Atherigona* spp. and fall armyworm *Spodoptera frugiperda*. (Suby, 2020) [16]. In India, the Fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) is an invasive insect pest causing serious damage to maize at all stages of its growth. (Basappa *et al.* 2018) [2]. FAW is a polyphagous multivoltine insect pest that feeds about 353 different plant species belonging to 76 families, but it attacks maize, rice, sugarcane and forage grasses to a large extent. The majority of chemical insecticides now in use failed to manage this pest, and lead to environmental implications such as ecological disequilibrium, pollution, risk during application and high-cost of application. Furthermore, the insecticides kill the natural enemies, favouring rapid re-infestation of the pest. *Bacillus thuringiensis* (*Bt*) is a ubiquitous gram-positive, spore-forming bacterium that forms a parasporal crystal proteins during the stationary phase of its growth cycle. The crystals contain one or more *Cry* proteins (δ -endotoxins) that are specifically toxic to insect orders such as Lepidoptera, Diptera, and Coleoptera.

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Cry protein is believed to be toxic to many insects and that is why *Bt* is used as microbial insecticide for improved resistance in plants and genetic modification. The Department of Entomology, Dr. PDKV Akola currently documented novel *Bt* strains which were found effective against lepidopteron insects (NCBI website: ncbi.nlm.nih.gov). The bioassay studies revealed higher toxicity of some of these *Bt* strains against *S. frugiperda* in laboratory (Tejaswini *et al.*, 2024) [4]. Further studies also reported presence of cry1AC, Cry2 Ab abd Cry9 genes encoded in some of the strains indicating specific activity against *S. frugiperda*. However, the efficacy of these novel *Bt* strains has yet to be explored against *Spodoptera frugiperda* under field conditions. The present investigations were conducted to know the bio- efficacy of two types of formulations prepared from these novel PDKV *Bt* strains against *S. podoptera* in field.

Materials and Methods

The present studies were undertaken in the department of Entomology, Dr. PDKV, Akola (MS) during the *khariif* season of 2024-25.

Culturing of *Bt* strains

Locally isolated 11 *Bacillus thuringiensis* strains viz., PDKV SA-20 (NCBI Acc. No. ON331908.1), PDKV SY-4 (NCBI Acc. No. ON331906.1), PDKV SGd-1 (NCBI Acc. No. ON331905.1); PDKV SA-6 (NCBI Acc. No. ON331907.1); PDKV SA-18 (NCBI Acc. No. OP209984); PDKV SBn-2 (NCBI Acc. No. OP209989); PDKV SAK-6 (NCBI Acc. No. OP209985); PDKV SAK-9 (NCBI Acc. No. OP209987); PDKV I -3 (NCBI Acc. No. OP209990); PDKV SGn-4 (OP209987); PDKV SGn-5 (NCBI Acc. No. OP209988) along with *Btk* HD-1 (Acc No. 5118) as a standard were sub cultured and maintained on Luria broth medium (Travers *et al.*, 1987) [17] in conical flask (250 ml) and allowed for fermentation for 72 hr at 35°C temperature on automatic shaker cum incubator at 100 - 120 rpm in toxicology laboratory.

Preparation of *Bt* formulations

Two types of *Bt* formulations viz., wettable powder (WP) and suspension concentrate (SC) were prepared from 11 PDKV *Bt* strains,

The wettable powder formulation of PDKV *Bt* strains was prepared according to the method developed by Marzaban *et al.* (2021). To formulate the PDKV *Bt* strains, 25% of the biomass of the strains was used with 75% of the additive. About 60% from 75% additives was allocated to the filler, talc powder, kaolin and diatomaceous earth and 3% to one of the suspension materials. To this preparation 12% moisturizer, sodium lauryl sulfate, sorbic acid and titanium dioxide was added.

The suspension concentrate formulation (SC) of PDKV *Bt* strains was prepared according to the method developed by Vimala Devi *et al.* (2014). For this purpose, 75 g of *Bt* (technical-70 µm particles) and 25 g of boric acid was mixed well with a sterile stainless-steel spatula in a 500 ml sterile glass beaker. Tween -80 was added to a light mineral oil in 1:6:84 ratio and vortexed to get a uniform mixture (T-M mixture). A 50 ml of this mixture was added initially to the *Bt* and boric acid mixture and mixed with a sterile spatula to obtain fine paste. This paste was further ground in a mortar and pestle to obtain a fine slurry. This was

followed by addition of 142 ml of T-M mixture to the slurry and mixing to get a fine suspension. This suspension was poured into a mixer jar and blended for 2-3 min to ensure proper mixing of the components for obtaining a uniform SC formulation.

The wettable powder (WP) and suspension concentrate (SC) formulations, were named as PDKV-SA-6 (25% WP and 75% SC), PDKV-SA-18 (25% WP and 75% SC), PDKV-SA-20 (25% WP and 75% SC), PDKV-SAK-6 (25% WP and 75% SC), PDKV-SAK-9 (25% WP and 75% SC), PDKV-SGd-1 (25% WP and 75% SC), PDKV-SGn-4 (25% WP and 75% SC), PDKV-SGn-5 (25% WP and 75% SC), PDKV-SBn-2 (25% WP and 75% SC), PDKV-I-3 (25% WP and 75% SC), and PDKV-SY-4 (25% WP and 75% SC) and were used for field application. In addition, one commercial *Bt* formulation (Delfin) and a chemical insecticide (Quinalphos 25% EC) were also included in the study.

Estimation of CFU count

The colony forming unit (CFU) count of each of the formulated product was recorded on luria agar medium for comparing with the commercial *Bt* formulation. The required formulation was dissolved as per the recommended dose in 100 ml of sterile distilled water. The resulting suspension was serially diluted using sterile techniques. An appropriate dilution was selected and plated onto LB-agar medium. The plates were incubated overnight at 30±2°C. After incubation, the number of colony-forming units (CFUs) was counted using a colony counter to determine the spore concentration. The formula used to determine spore count is given below:

$$\text{CFU / ml} = \frac{(\text{Number of colonies} \times \text{Dilution factor})}{\text{Volume of culture plate (in ml)}}$$

Application of *Bt* formulations

The treatments were applied thrice on maize crop (var. S 6668 plus) which was sown on the field of Department of Entomology in *Khariif*, 2024-25 in randomized block design following all the recommended cultural operations. The first application of the treatments were made as soon as the first incidence of *Spodoptera frugiperda* (J. E. Smith) was noticed in the plot. The subsequent sprayings were given at 12 days intervals with knapsack sprayer. The observations on percent shoot infestation and larval population of *S. frugiperda* on maize were recorded on the 3rd, 7th and 10th days after the application of the treatments. The occurrence of natural enemies, such as the spider population, was also recorded in each treatment plot.

Results and Discussion

Effect of PDKV *Bt* formulations on infestation of *Spodoptera frugiperda* on maize

Data presented in Table 1 revealed all the treatments are significant and all the treatments are significantly superior over untreated control which recorded 68.88 percent of infestation of *S. frugiperda* on maize. Amongst the PDKV *Bt* formulations, treatment PDKV-SA-20 25 WP was the most effective with 31.10 percent infestation of *S. frugiperda* on maize. It was followed by PDKV-SGd-1 25WP; PDKV-SY-4 25WP; PDKV-SA-20 75SC; PDKV-SAK-9 25WP, PDKV-SA-18 25WP; PDKV-SGn-4 25WP, PDKV-SGn-4 75SC, PDKV-SAK-6 25WP and PDKV-SA-

6 25WP. However, all these treatments were at par with Quinalphos 25EC (28.33%) and Delfin (30.55%).

The efficacy of all the treatments in terms of reducing the infestation of *S. frugiperda* on maize can be given descending order as Quinalphos 25EC > Delfin > PDKV-SA-20 25WP > PDKV-SGd-1WP > PDKV-SY-4 PDKV-SA-20 SC > PDKV-SAK-9 WP > PDKV-SA-18 WP > PDKV-SGn-4-WP > PDKV-SGn-4-SC > PDKV-SAK-6-WP > PDKV-SA-6-WP > PDKV-I-3-WP > PDKV-SBn-2-SC > PDKV-SA-18-SC > PDKV-SAK-9-SC > PDKV-SAK-6-SC > PDKV-SA-6-SC > PDKV-I-3-SC > PDKV-I-3-WP > PDKV-SBn-2-SC > PDKV-SA-18-SC > PDKV-SAK-9-SC > PDKV-SAK-6-SC > PDKV-SA-6-SC > PDKV-I-3-SC.

The present result pertaining to percentage infestation of fall armyworm are in agreement with the finding of Aranda *et al.* (1996) [1] who reported that indigenous *Bacillus thuringiensis* isolates were effective in managing maize fall armyworm by reducing both percent leaf damage and percent cob damage under greenhouse and open field conditions. According to Kumar (2019), the lowest leaf damage (3.47%) was observed in the treatment with spinetoram, while plots treated with *Bacillus thuringiensis* recorded a leaf damage of 21.83% after the second spray. Nasu, (1999) also noted that *S. litura* larval mortality was 90 percent after eight days of treatment with *B. thuringiensis* subsp. *kurstaki* (H3a, 3b @ 12 x 10⁷ spores/ml) and the value of LC₅₀ was found to be 1.10 x 10⁷ viable spores/ml. Bioassay was conducted against *S. litura* and *A. janata* treated with *B. thuringiensis* GAU CT₂ isolate (109/ml spore concentrations) which causes 70.8 and 66.4 percent mortality, respectively after seven days of treatment showing the effectiveness of *Bt* against Lepidoptera.

Effect of PDKV *Bt* formulations on larval population of *Spodoptera frugiperda* on maize

Data presented in Table 2 revealed all the treatments are significant and all the treatments are significantly superior over untreated control which recorded 0.70 larvae per 10 plant population of *S. frugiperda* on maize. Amongst the PDKV *Bt* formulations, treatment PDKV-SA-20 25WP was the most effective with 0.28 larval population of *S. frugiperda* on maize. It was followed by PDKV-SGd-1 75SC; PDKV-SA-20 75SC; PDKV-SY-4 25WP PDKV-SGd-1 25WP; PDKV-SY-4 75SC; PDKV-SGn-5 25WP; PDKV-SGn-5 75SC; PDKV-SBn-2 25WP; PDKV-SAK-9 25WP. However, all these treatments were at par with Quinalphos 25EC with 0.26 larvae and Delfin with 0.32 larvae per 10 plants.

The efficacy of all the treatments in terms of reducing the infestation of *S. frugiperda* on maize can be given descending order as Quinalphos 25EC > Delfin PDKV-SA-20 WP > PDKV-SGd-1 SC > PDKV-SA-20 SC > PDKV-SY-4 WP > PDKV-SGd-1 WP > PDKV-SY-4 SC > PDKV-SGn-5 WP

> PDKV-SGn-5 SC > PDKV-SBn-2 WP > PDKV-SAK-9 WP > PDKV-SGn-4 WP PDKV-SBn-2 SC > PDKV-SA-18 WP > PDKV-SAK-6 SC > PDKV-I-3 SC > PDKV-SA-6 WP PDKV-SAK-9 SC > PDKV-SGn-4 SC > PDKV-SA-6 SC.

The present pertaining to larval population of fall armyworm are in agreement with the finding of Behle *et al.* (1997) [3] reported that repeated application of *Bacillus thuringiensis* (*Bt*) formulations was adopted during the present study. Two effective isolates, *Bt*-Oa1 and *Bt*-257, were tested for their efficacy against *Spodoptera frugiperda* under field conditions using maize as the test plant. The number of larvae in each treatment was counted before each spray, and larval populations were maintained uniformly. However, *Bt* formulations applied to foliage can be washed off by rain or inactivated by sunlight, which may lead to reduced efficacy and failure in providing long-term protection against pest species. likewise Khan *et al.* (1999) [9] recorded the bio-efficacy of commercial *Bacillus thuringiensis* products such as Delfin® (*B. thuringiensis* var. *kurstaki*), Specturin® (*B. thuringiensis* subsp. *gallariae*), and Agree® (*B. thuringiensis* subsp. *kurstaki* + *B. thuringiensis* subsp. *aizawai*) along with the botanical Palmarosa oil, which were found to be highly active against *Spodoptera litura* and *Helicoverpa armigera thuringiensis* has also been reported to cause significantly higher mortality and reduced pupation of the jute hairy caterpillar, *Spilosoma obliqua* (Walker).

Krishna *et al.* (2008) [10] evaluated five insecticidal molecules along with two microbial formulations against the groundnut defoliator *Spodoptera litura* (Fab.) at the Regional Agricultural Research Station, Tirupati, Andhra Pradesh, India, during 2006-07 and 2007-08. The results showed that Novaluron 10% EC @ 1 ml/lit was the most effective treatment, recording the lowest incidence (20.99%) of *S. litura*, followed by Chlorfenapyr 10% SC @ 2 ml/lit and Thiodicarb 75 WP @ 1 g/lit, which were statistically on par with each other. The highest pod yield was observed in Thiodicarb-treated plots, which was comparable to yields from Novaluron- and Chlorfenapyr-treated plots. *Bacillus thuringiensis* (*Bt*)-treated plots also recorded considerable yields, indicating its potential for inclusion as a component of Integrated Pest Management (IPM). Regarding the benefit-cost ratio, Thiodicarb yielded the highest net returns (1.43), followed by Novaluron (1.29). Harika *et al.* (2021) [7] recorded the LT₅₀ values of different native *B. thuringiensis* isolates against third instar larvae of *S. frugiperda* at a higher dose of 1×10¹² CFU ml⁻¹. The reference strain HD1 achieved the fastest kill with 50% mortality at 101.65 hours. Native *Bt* isolates ranged from 110.71 to 146.16 hours. Isolate 493 had the fastest lethal action at 110.71 hours, followed by 51, 49, and 55 with varying lethal times for 50% mortality.

Table 1: Effect of PDKV *Bt* formulations on infestation of *Spodoptera frugiperda* on maize

Treatment	% infestation of <i>S. frugiperda</i>				% reduction over control
	1 st Spray	2 nd Spray	3 rd Spray	Mean	
T ₁ - PDKV <i>Bt</i> -SA-6- 25WP [cfu 2.63 x10 ⁸]	53.33 (46.92)	38.33 (38.18)	31.66 (34.21)	41.10 (39.87)	40.33%
T ₂ - PDKV <i>Bt</i> -SA-6 75% SC[cfu 7.88 x10 ⁸]	56.66 (48.88)	50.00 (44.95)	36.66 (37.22)	47.73 (43.72)	30.71%
T ₃ - PDKV <i>Bt</i> -SA-18 25% WP[cfu 1.58 x10 ⁸]	50.00 (45.00)	40.00 (39.18)	28.33 (32.10)	39.44 (38.90)	42.73%
T ₄ -PDKV <i>Bt</i> -SA-18 75% SC[cfu 4.73 x10 ⁸]	58.33 (49.80)	40.00 (39.18)	35.00 (36.17)	44.44 (41.80)	35.48%
T ₅ -PDKV <i>Bt</i> -SA-20 25% WP[cfu 5.5 x10 ⁸]	40.00 (39.07)	31.66 (33.96)	21.66 (27.07)	31.10 (33.89)	54.84%
T ₆ - PDKV <i>Bt</i> -SA-20 75% SC[cfu 16.5 x10 ⁸]	46.66 (43.07)	35.00 (36.03)	20.00 (25.71)	33.88 (35.60)	50.81%
T ₇ - PDKV <i>Bt</i> -SAK-6 25% WP[cfu 1 x10 ⁸]	53.33 (46.96)	40.00 (39.18)	31.66 (34.21)	41.66 (40.20)	39.54%

T ₈ -PDKV <i>Bt</i> -SAK-6 75% SC[cfu 3 x10 ⁸]	58.33 (49.84)	43.33 (41.11)	33.33 (35.00)	44.99 (42.12)	34.67%
T ₉ -PDKV <i>Bt</i> -SAK-9 25% WP[cfu 4.08 x10 ⁸]	48.33 (44.03)	33.33 (34.96)	33.33 (35.00)	38.33 (38.52)	44.37%
T ₁₀ -PDKV <i>Bt</i> -SAK-9 75% SC[cfu12.23 x10 ⁸]	58.33 (49.84)	36.66 (37.18)	38.33 (38.22)	44.44 (41.80)	35.48%
T ₁₁ -PDKV <i>Bt</i> -SGd-1 25%WP[cfu 1 x10 ⁸]	43.33 (41.11)	28.33 (31.85)	23.33 (28.18)	31.66 (34.24)	54.03%
T ₁₂ -PDKV <i>Bt</i> -SGd-1 75% SC[cfu 3 x10 ⁸]	43.33 (41.11)	31.66 (33.96)	23.33 (28.18)	32.77 (34.92)	52.45%
T ₁₃ -PDKV <i>Bt</i> -SGn-4 25%WP[cfu 4.9 x10 ⁸]	45.00 (42.11)	43.33 (41.15)	35.00 (36.07)	41.11 (39.87)	40.32%
T ₁₄ -PDKV <i>Bt</i> -SGn-4 75% SC[cfu 14.7 x10 ⁸]	48.33 (43.99)	45.00 (42.03)	31.66 (34.21)	41.66 (40.20)	39.54%
T ₁₅ -PDKV <i>Bt</i> -SGn-5 25%WP[cfu 4.4 x10 ⁸]	40.00 (39.14)	31.66 (34.11)	23.33 (28.42)	31.66 (34.24)	54.03%
T ₁₆ -PDKV <i>Bt</i> -SGn-5 75% SC[cfu 13.2 x10 ⁸]	50.00 (45.00)	35.00 (36.17)	25.00 (29.88)	36.66 (37.26)	46.78%
T ₁₇ -PDKV <i>Bt</i> -SBn-2 25% WP[cfu 2.88 x10 ⁸]	43.33 (41.15)	40.00 (39.23)	31.66 (34.21)	38.33 (38.25)	44.37%
T ₁₈ -PDKV <i>Bt</i> -SBn-2 75% SC[cfu 8.63 x10 ⁸]	51.66 (45.96)	43.33 (41.15)	35.00 (36.22)	43.33 (41.16)	37.11%
T ₁₉ -PDKV <i>Bt</i> -I-3 25% WP[cfu 1.6 x10 ⁸]	56.66 (48.88)	38.33 (38.18)	33.33 (35.21)	42.77 (40.84)	37.89%
T ₂₀ -PDKV <i>Bt</i> -I-3 75% SC[cfu 4.8 x10 ⁸]	61.66 (51.77)	45.00 (42.11)	38.33 (38.22)	48.33 (44.04)	29.85%
T ₂₁ -PDKV <i>Bt</i> -SY-4 25% WP[cfu 5.85 x10 ⁸]	46.66 (43.07)	31.66 (33.96)	21.66 (27.42)	33.32 (35.26)	51.62%
T ₂₂ -PDKV <i>Bt</i> -SY-4 75% SC[cfu 17.6 x10 ⁸]	48.33 (43.99)	35.00 (36.03)	23.33 (28.18)	35.55 (36.60)	48.37%
T ₂₃ -Delfin	40.00 (47.88)	31.66 (34.24)	20.00 (26.56)	30.55 (33.55)	55.65%
T ₂₄ -Quinalphos 25% EC	38.33 (38.25)	28.33 (32.16)	18.33 (25.35)	28.33 (32.16)	58.89%
T ₂₅ -Untreated Control	76.66 (61.46)	65.00 (53.82)	65.00 (53.82)	68.88 (56.19)	-
F test	SIG	SIG	SIG	SIG	
SE(M)+	2.95	2.71	2.76	2.80	
CD@5%	8.91	7.93	8.06	8.30	
CV	9.54	10.29	11.98	10.60	

Figures in parentheses are corresponding arc sin transformation, DAS- Day after spraying

Table 2: Effect of PDKV *Bt* formulations on larval population of *Spodoptera frugiperda* on maize

Sr. No.	Treatment	Larva population of <i>S. frugiperda</i>				% reduction over control
		1 st Spray	2 nd Spray	3 rd Spray	Cumulative Mean	
1	T ₁ - PDKV <i>Bt</i> -SA-6- 25WP [cfu 2.63 x10 ⁸]	0.45 (0.67)	0.45 (0.67)	0.31 (0.56)	0.40 (0.63)	42.86%
2	T ₂ - PDKV <i>Bt</i> -SA-6 75% SC[cfu 7.88 x10 ⁸]	0.50 (0.70)	0.46 (0.68)	0.36 (0.65)	0.44 (0.66)	37.14%
3	T ₃ - PDKV <i>Bt</i> -SA-18 25% WP[cfu 1.58 x10 ⁸]	0.45 (0.67)	0.41 (0.60)	0.33 (0.57)	0.39 (0.62)	44.29%
4	T ₄ -PDKV <i>Bt</i> -SA-18 75% SC[cfu4.73 x10 ⁸]	0.51 (0.71)	0.38 (0.61)	0.26 (0.51)	0.38 (0.61)	45.71%
5	T ₅ -PDKV <i>Bt</i> -SA-20 25% WP[cfu5.5 x10 ⁸]	0.38 (0.61)	0.26 (0.51)	0.20 (0.44)	0.28 (0.53)	60.00%
6	T ₆ - PDKV <i>Bt</i> -SA-20 75% SC[cfu16.5 x10 ⁸]	0.43 (0.65)	0.30 (0.54)	0.21 (0.46)	0.31 (0.55)	55.71%
7	T ₇ - PDKV <i>Bt</i> -SAK-6 25% WP[cfu 1 x10 ⁸]	0.46 (0.68)	0.40 (0.60)	0.35 (0.59)	0.40 (0.63)	42.86%
8	T ₈ -PDKV <i>Bt</i> -SAK-6 75% SC[cfu 3 x10 ⁸]	0.48 (0.69)	0.40 (0.63)	0.30 (0.54)	0.39 (0.62)	44.29%
9	T ₉ -PDKV <i>Bt</i> -SAK-9 25% WP[cfu 4.08 x10 ⁸]	0.45 (0.67)	0.33 (0.57)	0.30 (0.54)	0.36 (0.60)	48.57%
10	T ₁₀ -PDKV <i>Bt</i> -SAK-9 75% SC[cfu12.23 x10 ⁸]	0.43 (0.65)	0.41 (0.64)	0.38 (0.61)	0.40 (0.63)	42.86%
11	T ₁₁ -PDKV <i>Bt</i> -SGd-1 25%WP[cfu 1 x10 ⁸]	0.38 (0.61)	0.31 (0.56)	0.30 (0.54)	0.33 (0.57)	52.86%
12	T ₁₂ -PDKV <i>Bt</i> -SGd-1 75% SC[cfu 3 x10 ⁸]	0.40 (0.62)	0.28 (0.52)	0.23 (0.59)	0.30 (0.55)	57.14%
13	T ₁₃ -PDKV <i>Bt</i> -SGn-4 25%WP[cfu 4.9 x10 ⁸]	0.45 (0.67)	0.40 (0.63)	0.30 (0.54)	0.38 (0.61)	45.71%
14	T ₁₄ -PDKV <i>Bt</i> -SGn-4 75% SC[cfu 14.7 x10 ⁸]	0.48 (0.69)	0.43 (0.65)	0.35 (0.59)	0.42 (0.64)	40.00%
15	T ₁₅ -PDKV <i>Bt</i> -SGn-5 25%WP[cfu 4.4 x10 ⁸]	0.38 (0.61)	0.33 (0.57)	0.31 (0.56)	0.34 (0.58)	51.43%
16	T ₁₆ -PDKV <i>Bt</i> -SGn-5 75% SC[cfu 13.2 x10 ⁸]	0.40 (0.63)	0.40 (0.62)	0.26 (0.51)	0.35 (0.59)	50.00%
17	T ₁₇ -PDKV <i>Bt</i> -SBn-2 25% WP[cfu 2.88 x10 ⁸]	0.41 (0.64)	0.36 (0.60)	0.30 (0.54)	0.35 (0.59)	50.00%
18	T ₁₈ -PDKV <i>Bt</i> -SBn-2 75% SC[cfu 8.63 x10 ⁸]	0.45 (0.67)	0.33 (0.50)	0.38 (0.61)	0.38 (0.62)	45.71%
19	T ₁₉ -PDKV <i>Bt</i> -I-3 25% WP[cfu 1.6 x10 ⁸]	0.43 (0.65)	0.40 (0.62)	0.38 (0.61)	0.40 (0.63)	42.86%
20	T ₂₀ -PDKV <i>Bt</i> -I-3 75% SC[cfu 4.8 x10 ⁸]	0.50 (0.70)	0.36 (0.60)	0.31 (0.61)	0.39 (0.62)	44.29%
21	T ₂₁ -PDKV <i>Bt</i> -SY-4 25% WP[cfu 5.85 x10 ⁸]	0.41 (0.64)	0.33 (0.57)	0.23 (0.47)	0.32 (0.56)	54.29%
22	T ₂₂ -PDKV <i>Bt</i> -SY-4 75% SC[cfu 17.6 x10 ⁸]	0.41 (0.64)	0.35 (0.58)	0.23 (0.47)	0.33 (0.57)	52.86%
23	Delfin@1kg/ha	0.40 (0.63)	0.33 (0.50)	0.23 (0.48)	0.32 (0.57)	54.29%
24	Quinalphos 25% EC@1L/ha	0.33 (0.57)	0.28 (0.53)	0.16 (0.40)	0.25 (0.50)	64.29%
25	Control	0.76 (0.86)	0.68 (0.82)	0.68 (0.82)	0.70 (0.83)	-
	F test	SIG	SIG	SIG	SIG	-
	SE(M)+	0.03	0.03	0.03	0.03	-
	CD@5%	0.10	0.11	0.13	0.11	-
	CV	7.96	9.97	11.65	9.86	-

Effect of PDKV *Bt* formulations on yield of maize

Data presented in Table 3 revealed all the treatments are significant and all the treatments are significantly superior over untreated control which recorded 22.53 yield of maize. Amongst the PDKV *Bt* formulations, treatment PDKV-SA-20 25WP was the most effective with 39.81 yield of maize. It was followed by PDKV-SA-20 SC; PDKV-SGn-5 WP; PDKV-SY-4 WP; PDKV-SGd-1 WP; PDKV-SA-18; PDKV-SGn-5 SC However, all these treatments were at par with Quinalphos 25EC (42.83) and Delfin (40.27).

The efficacy of all the treatments in terms of reducing the yield of maize can be given descending order as Quinalphos 25EC > Delfin PDKV-SA-20 > 25WP PDKV-SA-20 SC > PDKV-SGn-5 WP > PDKV-SY-4 WP > PDKV-SGd-1 WP > PDKV-SA-18 > PDKV-SGn-5 SC > PDKV-SA-6 WP > PDKV-SBn-2 WP > PDKV-I-3 WP > PDKV-SAK-6 WP > PDKV-I-3 > PDKV-SAK-9 SC > PDKV-SA-6 SC > PDKV-SGn-4 WP > PDKV-SBn-2 SC > PDKV-SA-18 SC > PDKV-SAK-6 SC > PDKV-SGn-4 SC.

Hutchison *et al.* (2010) [8] reported that the adoption of *Bt* maize has led to significant increases in maize production by suppressing major pests like *Ostriniana nubilalis*. Between 1996 and 2009, cumulative benefits were estimated at \$3.2 billion in Illinois, Minnesota, and Wisconsin, and \$3.6 billion in Iowa and Nebraska, largely due to yield protection. Notably, over \$4.3 billion of these gains accrued to non-*Bt* maize growers as a result of areawide pest suppression. Dively *et al.* (2018) [6] conducted a comprehensive analysis showing that widespread adoption of *Bt* field maize led to marked decreases in recommended insecticidal applications, underscoring region-wide pest

suppression benefits alongside direct yield gain. Wayal *et al.* (2020) [18] conducted a study involving the use of biopesticides of microbial origin—including *Metarhizium anisopliae*, *Nomuraea rileyi*, *Beauveria bassiana*, and *Bacillus thuringiensis* 85%—along with botanical treatments such as neem seed kernel extract and azadirachtin. These treatments were applied through four sequential sprayings. The results indicated that the fourth spray of *Bacillus thuringiensis* 85% at 20 g per 10 L was the most effective in managing fall armyworm under field conditions, resulting in the highest recorded grain yield of 46.88 q/ha.

Table 3: Effect of PDKV *Bt* formulations on yield of Maize

Sr. No.	Treatment	Average yield (q/ha)	% increase over control
1	T ₁ - PDKV <i>Bt</i> -SA-6- 25WP [cfu 2.63 x10 ⁸]	36.41	61.61%
2	T ₂ - PDKV <i>Bt</i> -SA-6 75% SC[cfu 7.88 x10 ⁸]	34.87	54.78%
3	T ₃ - PDKV <i>Bt</i> -SA-18 25% WP[cfu 1.58 x10 ⁸]	37.96	68.44%
4	T ₄ -PDKV <i>Bt</i> -SA-18 75% SC[cfu 4.73 x10 ⁸]	34.56	53.41%
5	T ₅ -PDKV <i>Bt</i> -SA-20 25% WP[cfu 5.5 x10 ⁸]	40.06	77.75%
6	T ₆ - PDKV <i>Bt</i> -SA-20 75% SC[cfu 16.5 x10 ⁸]	39.81	76.66%
7	T ₇ - PDKV <i>Bt</i> -SAK-6 25% WP[cfu 1 x10 ⁸]	35.18	56.19%
8	T ₈ -PDKV <i>Bt</i> -SAK-6 75% SC[cfu 3 x10 ⁸]	34.25	52.03%
9	T ₉ -PDKV <i>Bt</i> -SAK-9 25% WP[cfu 4.08 x10 ⁸]	37.30	65.72%
10	T ₁₀ -PDKV <i>Bt</i> -SAK-9 75% SC[cfu 12.23 x10 ⁸]	35.07	55.69%
11	T ₁₁ -PDKV <i>Bt</i> -SGd-1 25%WP[cfu 1 x10 ⁸]	38.88	72.62%
12	T ₁₂ -PDKV <i>Bt</i> -SGd-1 75% SC[cfu 3 x10 ⁸]	36.72	63.08%
13	T ₁₃ -PDKV <i>Bt</i> -SGn-4 25%WP[cfu 4.9 x10 ⁸]	34.80	54.78%
14	T ₁₄ -PDKV <i>Bt</i> -SGn-4 75% SC[cfu 14.7 x10 ⁸]	33.95	50.67%
15	T ₁₅ -PDKV <i>Bt</i> -SGn-5 25%WP[cfu 4.4 x10 ⁸]	39.79	76.61%
16	T ₁₆ -PDKV <i>Bt</i> -SGn-5 75% SC[cfu 13.2 x10 ⁸]	37.34	65.77%
17	T ₁₇ -PDKV <i>Bt</i> -SBn-2 25% WP[cfu 2.88 x10 ⁸]	35.80	58.89%
18	T ₁₈ -PDKV <i>Bt</i> -SBn-2 75% SC[cfu 8.63 x10 ⁸]	34.77	54.78%
19	T ₁₉ -PDKV <i>Bt</i> -I-3 25% WP[cfu 1.6 x10 ⁸]	35.65	58.20%
20	T ₂₀ -PDKV <i>Bt</i> -I-3 75% SC[cfu 4.8 x10 ⁸]	35.10	56.15%
21	T ₂₁ -PDKV <i>Bt</i> -SY-4 25% WP[cfu 5.85 x10 ⁸]	39.55	77.24%
22	T ₂₂ -PDKV <i>Bt</i> -SY-4 75% SC[cfu 17.6 x10 ⁸]	37.88	68.36%
23	Delfin@1kg/ha	40.27	78.66%
24	Quinalphos 25% EC@1L/ha	42.83	90.07%
25	Control	22.53	-
F test		SIG	
SE(M)+		0.91	
CD@5%		2.68	
CV		-	-

Conclusion

The Evaluation of Novel PDKV *Bacillus thuringiensis* Formulation against *Spodoptera frugiperda* on maize revealed that Treatment Quinalphos 25% EC proved most effective against *Spodoptera frugiperda* by recording minimum infestation and larval population and also found statistically at par with treatment PDKV-SA-20 WP, T₁₂ PDKV-SGd-1 SC, PDKV-SA-20 SC, PDKV-SY-4 WP, PDKV-SGd-1 WP, PDKV-SY-4 SC, PDKV-SGn-5 WP, PDKV-SGn-5 SC, PDKV-SBn-2 WP, PDKV-SAK-9 WP. The next best treatment found was PDKV-SGn-4 WP and PDKV-SBn-2 SC this treatment showed at par with the PDKV-SA-18 WP, PDKV-SAK-6 SC, PDKV-I-3 SC, PDKV-SA-6 WP, PDKV-SAK-9 SC, PDKV-SGn-4 SC and PDKV-SA-6 SC. Hence, all these local *bt* formulation said to have equal toxicity potential to that of standard insecticides against *Spodoptera frugiperda* which can be used for further formulation studies and novel characterization of *bt* formulation can be used for development of transgenic plant against FAW and other lepidopteran insects.

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