Efficacy of Commonly used Insecticides against Sucking Pests on PGPR treated Okra Plants

RA Maheerthanan[1]; M Ravi[2*]; G Preetha[3]; B Jeberlin Prabina[4]; A Sowmiya[5]

[1,4]Department of Agricultural Entomology, V.O. Chidhambaranar Agricultural College and Research Institute, Tamil Nadu Agricultural University, Killikulam, Vallanadu, Tamil Nadu 628 252 India
[2,5]Tamil Nadu Agricultural University, ICAR-Krishi Vigyan Kendra, Salem, Tamil Nadu 636 203 India
[3]Directorate of Seeds, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu 641 003 India
*Corresponding Author

Received:- 04 January 2025/ Revised:- 13 January 2025/ Accepted:- 18 January 2025/ Published: 31-01-2025

***Abstract*—** *A field experiment was conducted during Kharif 2021 at the Agricultural College and Research Institute, Killikulam, Vallanadu, Tamil Nadu, India to assess the efficacy of commonly used insecticides against sucking pests on okra plants treated with Bacillus subtilis Bbv57, a plant-growth-promoting rhizobacterium (PGPR). The experiment was designed in a completely randomized block design with three replications. Okra seeds were treated with a talc-based formulation of B. subtilis Bbv57, and the PGPR was also applied to the soil before sowing. Insecticides, including imidacloprid, thiamethoxam, acetamiprid, and thiacloprid, were sprayed on both PGPR-treated and untreated plots. Pest populations, including aphids and leafhoppers, were monitored at 3, 7, 10, and 14 days after treatment. The results indicated that insecticide treatments on PGPR-treated plants significantly reduced pest populations compared to untreated plants. Acetamiprid 20 SP at 100 g ha^{-1} was the most effective, reducing aphid and leafhopper populations to the lowest levels on PGPR-treated plants. Furthermore, PGPR treatment enhanced pest resistance, likely through induced biochemical changes. The highest yield (18.55 tonnes ha^{-1}) and benefit-cost ratio (1:2.53) were observed in PGPR-treated plants treated with acetamiprid. This study demonstrates that combining PGPR with insecticide treatments provides an effective, sustainable solution for managing sucking pests in okra, offering both improved pest control and higher economic returns.*

***Keywords*— Bacillus subtilis, Okra, PGPR, Sucking pests, Yield.**

I. INTRODUCTION

Okra (*Abelmoschus esculentus* [L.] Moench), commonly known as bhindi or lady's finger, is a widely cultivated vegetable in tropical and subtropical regions globally (Elkhalifa et al., 2021). However, its cultivation faces significant challenges due to pest infestations. In India, okra is commercially grown over approximately 0.53 million hectares, yielding an annual production of 6.46 million tonnes contributing 62% of the global output and playing a vital role in meeting the nation's vegetable demand (Mohapatra et al., 2024). Despite its importance, okra is highly susceptible to various insect pests which include shoot and fruit borers (*Earias insulana* [Boisd.] and *Earias vittella* [Fab.]), leafhopper (*Amrasca biguttula biguttula* [Ishida]), leaf roller (*Sylepta derogata* Fab.), whitefly (*Bemisia tabaci* Genn.), aphid (*Aphis gossypii* Glover), and mite (*Tetranychus cinnabarinus* Boisduval) (Kodandaram et al., 2017) and yield loss range between 50.00% and 63.41% (Asi et al., 2008 and Mohapatra et al., 2024). Sap-sucking pests like leafhoppers extract chlorophyll, disrupting photosynthesis and causing leaf cupping, yellowing, and bronzing, which slow crop growth. Leafhoppers can cause production losses of 50% to 63.41% (Mohapatra et al., 2024). Aphids, especially *A. gossypii*, harm young plants, causing stunted growth, wilting, and plant death in severe cases. Their honeydew encourages sooty mold, further blocking photosynthesis and damaging buds, flowers, and fruits (Murovhi et al., 2020; Kedar et al., 2014).

Okra growers opt synthetic insecticides based pest management as a primary strategy (Jan et al., 2022). However, prolonged use of insecticides exerts selection pressure, leading to insecticide resistance in pest populations globally (Cerna et al., 2013; Szczepaniec et al., 2019) and escalates production costs and reduces profitability. In India, okra farmers often apply 10–12 pesticidal sprays in a single growing season^{-1} to manage sucking pests and fruit borers, resulting in fruits with high pesticide residues, posing serious risks to consumer health (Ounis et al., 2024). Therefore, adopting sustainable practices, particularly Integrated Pest Management (IPM), is imperative for safeguarding both the environment and human health. Plant growth promoting rhizobacteria (PGPR), present a sustainable alternative in agriculture (Santoyo et al., 2021; Harris, 2009) by enhancing plant growth by facilitating nitrogen uptake, phytohormone synthesis, mineral solubilization, and iron chelation (Bowen and Rovira, 1999). PGPR also enhance resistance against pests and pathogens by inducing physical and chemical defenses in plants, a phenomenon termed induced systemic resistance (Kloepper et al., 2004; Nelson, 2004 and Bostock, 2005). This resistance mechanism has been extensively documented in plant–pathogen and plant–insect interactions (Zehnder et al., 2001; Conrath et al., 2006).

PGPR are characterized by their ability to colonize root surfaces, survive and multiply in competitive microbial environments, and express growth-promotion and protection activities (Mohanty et al., 2021; Kloepper and Okon, 1994). About 2–5% of rhizobacteria exert beneficial effects on plant growth when inoculated into soils with competitive microflora (Kloepper, 1978). These bacteria, thriving in the rhizosphere, enhance plant growth via diverse mechanisms (Vocciante et al., 2022; Vessey, 2003). The below-ground colonization of PGPR triggers various biological processes, altering interactions with above-ground herbivores through changes in plant abundance, nutritional quality, and defenses (Hartley and Gange, 2009; Grunseich et al., 2019). Thus, incorporating PGPR into pest management frameworks offers a promising approach to reduce reliance on synthetic pesticides, mitigate environmental hazards, and enhance agricultural sustainability (Basu et al., 2021). This study was conducted to evaluate the efficacy of commonly used insecticides in controlling sucking pests on plants treated with plant-growth-promoting rhizobacteria (PGPR). By integrating PGPR treatment with insecticide use, the study aimed to explore potential improvements in pest management, plant resistance, and overall crop health, providing insights into sustainable pest management strategies.

II. MATERIALS AND METHODS

Field experiment was conducted in completely randomized block design with three replications at Agricultural College and Research Institute, Killikulam, Vallanadu, Tamil Nadu, India farm during Kharif 2021(8°46 N latitude and 77°42 E longitude) to study the efficacy of commonly used insecticides against sucking pests of okra on PGPR treated plants. Okra F_1 hybrid CoBh4 seeds were treated with talc-based formulation (containing $1x10^8$ cfu g^{-1}) of *B. subtilis* Bbv57 @10 g kg^{-1} of seed which has been identified as the effective PGPR strain from the pot culture and field experiments. Okra seeds were sown in plots of size 6x5 m^2. Soil application of *B. subtilis* Bbv57 @2.5 kg $hectare^{-1}$ was done before sowing. Similarly, untreated plots without any seed treatment were maintained to study the efficacy of insecticides. The insecticides were applied on *B. subtilis* Bbv57 treated plots and untreated plots with high volume knapsack sprayer using solid cone nozzle. Observations on sucking pests before the application of insecticide and 3,7,10 and 14 days after treatment were recorded. The field experiment was conducted with following treatments.

TABLE
TREATMENTS USED IN FIELD EXPERIMENT

T_1	*Bacillus subtilis* Bbv57 (ST-SA)	**T_6**	Imidacloprid 17.8 SL @100 ml ha^{-1}
T_2	*Bacillus subtilis* Bbv57 (ST-SA) - Imidacloprid 17.8 SL @100 ml ha^{-1}	**T_7**	Thiamethoxam 25 WG @100 g ha^{-1}
T_3	*Bacillus subtilis* Bbv57 (ST-SA) - Thiamethoxam 25 WG @100 g ha^{-1}	**T_8**	Acetamiprid 20 SP @100 g ha^{-1}
T_4	*Bacillus subtilis* Bbv57 (ST-SA) - Acetamiprid 20 SP @100 g ha^{-1}	**T_9**	Thiacloprid 21.7 SC @500 ml ha^{-1}
T_5	*Bacillus subtilis* Bbv57 (ST-SA) - Thiacloprid 21.7 SC @500 ml ha^{-1}	**T_{10}**	Untreated control

The fruit yield was recorded at each harvest and pooled. Gross income, net income and benefit cost ratio (BCR) were worked out for each treatment.

III. RESULTS AND DISCUSSION

Microplot experiments and biochemical analysis showed that *Bacillus subtilis* strain Bbv57 was the best PGPR strain in reducing the incidence of major sucking insect pests of okra. Hence the efficacy of commonly used insecticides on *B. subtilis* Bbv57 treated plants for the management of sucking pests was evaluated under field conditions. The field experiment revealed that all the chemical insecticides significantly reduced the population of sucking pests up to 14 days after treatment (DAT) on plants treated with *B. subtilis* Bbv57. Among them, acetamiprid 20 SP @100 g ha-1 was better in reducing the aphid and leafhopper population on *B. subtilis* Bbv57 treated and untreated plants (Table 1 and 2).

TABLE 1
EFFICACY OF COMMONLY USED INSECTICIDES AGAINST A. GOSSYPII ON PGPR TREATED OKRA DURING KHARIF 2021

S.No.	Treatments	Number of aphids plant^{-1}*				
		PTC	**3 DAT**	**7 DAT**	**10 DAT**	**14 DAT**
T$_1$	*Bacillus subtilis* Bbv57 (ST-SA)	38.42	27.32	30.55	45.66	69.88
		-6.24	(5.27)^{b}	(5.57)^{d}	(6.79)^{d}	(8.39)^{f}
T$_2$	*Bacillus subtilis* Bbv57 (ST-SA) - Imidacloprid 17.8 SL @100 ml ha^{-1}	37.98	0	5.41	12.36	22.64
		-6.2	(0.71)^{a}	(2.43)^{bc}	(3.59)^{bc}	(4.81)^{bcd}
T$_3$	*Bacillus subtilis* Bbv57 (ST-SA) - Thiamethoxam 25 WG @100 g ha^{-1}	40.11	0	0	4.88	17.21
		-6.37	(0.71)^{a}	(0.71)^{a}	(2.32)^{a}	(4.21)^{abc}
T$_4$	*Bacillus subtilis* Bbv57 (ST-SA) - Acetamiprid 20 SP @100 g ha^{-1}	42.29	0	0	3.82	10.54
		-6.54	(0.71)^{a}	(0.71)^{a}	(2.08)^{a}	(3.32)^{a}
T$_5$	*Bacillus subtilis* Bbv57 (ST-SA) - Thiacloprid 21.7 SC @500 ml ha^{-1}	44.58	0	6.21	14.59	29.11
		-6.71	(0.71)^{a}	(2.59)^{bc}	(3.88)^{bc}	(5.44)^{cde}
T$_6$	Imidacloprid 17.8 SL @100 ml ha^{-1}	41.14	0	9.44	21.66	38.74
		-6.45	(0.71)^{a}	(3.15)^{c}	(4.71)^{c}	(6.26)^{e}
T$_7$	Thiamethoxam 25 WG @100 g ha^{-1}	38.85	0	3.18	8.31	18.73
		-6.27	(0.71)^{a}	(1.92)^{b}	(2.97)^{ab}	(4.39)^{abc}
T$_8$	Acetamiprid 20 SP @100 g ha^{-1}	41.02	0	0	7.21	15.33
		-6.44	(0.71)^{a}	(0.71)^{a}	(2.78)^{ab}	(3.98)^{ab}
T$_9$	Thiacloprid 21.7 SC @500 ml ha^{-1}	43.66	0.22	8.54	19.11	35.98
		-6.65	(0.85)^{a}	(3.01)^{bc}	(4.43)^{c}	(6.04)^{de}
T$_{10}$	Untreated control	45.22	51.72	66.54	80.22	86.94
		-6.61	(7.07)^{c}	(8.01)^{e}	(8.78)^{e}	(9.14)^{f}
CD (*p*=0.05)		ns	1.01**	1.15**	1.26**	1.32**

DAT – Days after treatment ***PTC – Pretreatment count*** ****Mean of three replications***

Figures in parentheses are $\sqrt{x+0.5}$ transformed values.

In a column, means followed by common letters are not significantly different by LSD (P=0.05)

Among the insecticides, acetamiprid 20 SP @100 g ha-1 effectively reduced the aphid population (3.82 and 10.54 aphids plant-1 on 10 DAT and 14 DAT respectively) on *B. subtilis* Bbv57 treated plants and untreated plants (7.21 and 15.33 aphids plant-1 on 10 DAT and 14 DAT respectively). The efficacy of all insecticides on *B. subtilis* Bbv57 treated plants was high when compared with untreated plants which received the same insecticide (Table 1). Similarly, no incidence of leafhopper was recorded up to 7 DAT on *B. subtilis* Bbv57 treated plants with acetamiprid 20 SP @100 g ha^{-1}. Furthermore, it recorded 0.24 and 0.61 hoppers plant^{-1} on 10 DAT and 14 DAT respectively on *B. subtilis* Bbv57 treated plants. Thiamethoxam 25 WG @100 g ha-1 on *B. subtilis* Bbv57 treated plants also recorded less number of leafhopper population (0.43 and 1.08 hoppers plant^{-1} respectively) on 10 DAT and 14 DAT. The hopper population was high in the untreated plants (5.76, 6.17, 6.98 and 7.91 hoppers plant-1) on 3,7,10 and 14 DAT respectively when compared with B. subtilis Bbv57 treated plants (4.21, 4.16, 5.27, 6.91 and 7.64) (Table 2). The present findings are in line with Sharma (2020) and Reddy and Gowdar (2006) who showed that acetamiprid 20 SP @20 g a.i ha^{-1} significantly reduced the population of sucking pests in okra. However, the efficacy of insecticides persisted more in *B. subtilis* Bbv57 treated plants when compared with untreated plants.

TABLE 2
EFFICACY OF COMMONLY USED INSECTICIDES AGAINST A. DEVASTANS ON PGPR TREATED OKRA DURING KHARIF 2021

S.No.	Treatments	Number of aphids plant^{-1}*				
		PTC	3 DAT	7 DAT	10 DAT	14 DAT
T$_1$	*Bacillus subtilis* Bbv57 (ST-SA)	4.21	4.16	5.27	6.91	7.64
		-2.17	(2.12)^{b}	(2.36)^{b}	(2.67)^{b}	(2.85)^{d}
T$_2$	*Bacillus subtilis* Bbv57 (ST-SA) - Imidacloprid 17.8 SL @100 ml ha^{-1}	3.65	0	0.24	0.76	1.15
		-2.04	(0.71)^{a}	(0.86)^{a}	(1.12)^{a}	(1.28)^{ab}
T$_3$	*Bacillus subtilis* Bbv57 (ST-SA) - Thiamethoxam 25 WG @100 g ha^{-1}	4.14	0	0	0.43	1.08
		-2.15	(0.71)^{a}	(0.71)^{a}	(0.96)^{a}	(1.26)^{ab}
T$_4$	*Bacillus subtilis* Bbv57 (ST-SA) - Acetamiprid 20 SP @100 g ha^{-1}	4.11	0	0	0.24	0.61
		-2.15	(0.71)^{a}	(0.71)^{a}	(0.86)^{a}	(1.05)^{a}
T$_5$	*Bacillus subtilis* Bbv57 (ST-SA) - Thiacloprid 21.7 SC @500 ml ha^{-1}	3.55	0	0.61	0.85	2.06
		-2.01	(0.71)^{a}	(1.05)^{a}	(1.16)^{a}	(1.6)^{bc}
T$_6$	Imidacloprid 17.8 SL @100 ml ha^{-1}	3.14	0.12	0.45	0.91	2.57
		-1.91	(0.79)^{a}	(0.97)^{a}	(1.19)^{a}	(1.75)^{c}
T$_7$	Thiamethoxam 25 WG @100 g ha^{-1}	4.01	0	0.18	0.51	1.22
		-2.12	(0.71)^{a}	(0.82)^{a}	(1.00)^{a}	(1.31)^{ab}
T$_8$	Acetamiprid 20 SP @100 g ha^{-1}	3.66	0	0	0.33	1.05
		-2.04	(0.71)^{a}	(0.71)^{a}	(0.91)^{a}	(1.24)^{ab}
T$_9$	Thiacloprid 21.7 SC @500 ml ha^{-1}	3.89	0	0.66	1.06	2.71
		-2.09	(0.71)^{a}	(1.07)^{a}	(1.25)^{a}	(1.79)^{c}
T$_{10}$	Untreated control	4.18	5.76	6.17	6.98	7.91
		-2.12	(2.46)^{b}	(2.53)^{b}	(2.68)^{b}	(2.84)^{d}
CD (p=0.05)		ns	0.40**	0.45**	0.50**	0.38**

DAT – Days after treatment ***PTC – Pretreatment count*** ****Mean of three replications***

Figures in parentheses are $\sqrt{x+0.5}$ transformed values.

In a column, means followed by common letters are not significantly different by LSD (p=0.05)

The yield, net income and benefit cost ratio (BCR) were high in PGPR treated plants sprayed with insecticides compared to the untreated plants. On PGPR treated plants, acetamiprid 20 SP @100 g ha-1 recorded higher yield of 18.55 tonnes ha^{-1} followed by thiamethoxam 25 WG @100 g ha^{-1} (18.21 tonnes ha^{-1}) compared to untreated plants (14.39 tonnes ha^{-1}). The benefit cost ratio (BCR) was also high for acetamiprid 20 SP @100 g ha-1 on *B. subtilis* Bbv57 treated plants (1:2.53) than the untreated plants (1:1.80) (Table 3). The prolonged efficacy of chemical insecticides against the insect pests on B. subtilis Bbv57 treated plants may be due to the increased levels of biochemicals which might have reduced the feeding preference and affected the physiology of insect pests on okra as reported by Barman et al (2024) and Singh et al. (2022). The present findings are in line with the reports of Kahia et al. (2021) and Myresiotis et al. (2015) where *B. subtilis* strain FZB24 significantly enhanced the root uptake of thiamethoxam in corn, Zea mays L. thereby reduced the usage of chemical insecticides.

TABLE 3
EFFICACY OF INSECTICIDES AGAINST SUCKING PESTS ON PGPR TREATED OKRA PLANTS - YIELD AND ECONOMICS

S. No.	Treatments	Yield	Cost of cultivation (₹)	Gross income (₹)	Net income	BCR
		(t/ha)			(₹)	
T_1	*Bacillus subtilis* Bbv57 (ST-SA)	16.02^{e}	94554	288360	193806	01:02.1
T_2	*Bacillus subtilis* Bbv57 (ST-SA) - Imidacloprid 17.8 SL @100 ml ha^{-1}	17.63^{abcd}	94829	317340	222511	01:02.4
T_3	*Bacillus subtilis* Bbv57 (ST-SA) - Thiamethoxam 25 WG @100 g ha^{-1}	18.21^{ab}	94954	327780	232826	01:02.5
T_4	*Bacillus subtilis* Bbv57 (ST-SA) - Acetamiprid 20 SP @100 g ha^{-1}	18.55^{a}	94714	333900	239186	01:02.5
T_5	*Bacillus subtilis* Bbv57 (ST-SA) - Thiacloprid 21.7 SC @500 ml ha^{-1}	17.99^{abc}	95954	323820	227866	01:02.4
T_6	Imidacloprid 17.8 SL @100 ml ha^{-1}	16.65^{de}	92894	299700	206806	01:02.2
T_7	Thiamethoxam 25 WG @100 g ha^{-1}	17.20^{bcd}	92950	309600	216650	01:02.3
T_8	Acetamiprid 20 SP @100 g ha^{-1}	17.41^{abcd}	92630	313380	220750	01:02.4
T_9	Thiacloprid 21.7 SC @500 ml ha^{-1}	16.96^{cde}	92900	305280	212380	01:02.3
T_{10}	Untreated control	14.39^{f}	92550	259020	166470	01:01.8
CD (*p*=0.05)		1.15^{**}				

Mean of three replications Okra fruits sold @18 kg^{-1}

In a column, means followed by common letters are not significantly different by LSD (*p*=0.05)

IV. CONCLUSION

The combination of PGPR-treated plants and acetamiprid 20 SP @100 g ha⁻¹ significantly reduced aphid and leafhopper populations, increasing okra yields compared to untreated plants. This synergistic effect of *B. subtilis* Bbv57 and insecticide is likely due to the biochemical changes induced by the PGPR, which enhances plant resistance and boosting the effectiveness of insecticide treatments. This integrated approach offers a sustainable strategy for managing sucking pests in okra with reduced environmental impact, balancing pest control with ecological considerations.

REFERENCES

[1] Asi, M.R., Afzal, M., Anwar, S.A., Bashir, M.H., 2008. "comparative efficacy of insecticides against sucking insect pests of cotton." Pakistan Journal of Life and Social Sciences 6(2), 140–142.

[2] Barman, M., Samanta, S., Atta, K., Dutta, S., Dey, S., Samanta, A., Tarafdar, J., Ahmed, B., 2024. "Biochemical and morphological basis of resistance in okra (Abelmoschus esculentus (L.)) against whitefly and jassid." International Journal of Tropical Insect Science 44(5), 2637–2654.

[3] Basu, A., Prasad, P., Das, S.N., Kalam, S., Sayyed, R.Z., Reddy, M.S., El Enshasy, H., 2021. "Plant growth promoting rhizobacteria (PGPR) as green bioinoculants: recent developments, constraints, and prospects." Sustainability 13(3), 1140.

[4] Bostock, R.M., 2005. "Signal crosstalk and induced resistance: straddling the line between cost and benefit." Annual Review of Phytopathology 43(1), 545–580.

[5] Bowen, G., Rovira, A., 1999. "The rhizosphere and its management to improve plant growth." Advances in Agronomy 66, 1–102.

[6] Cerna, E., Ochoa, Y., Aguirre, L., Flores, M., Landeros, J., 2013. "Determination of insecticide resistance in four populations of potato psillid Bactericera cockerelli (Sulc.)(Hemiptera: Triozidae)." Phyton 82, 63.

[7] Conrath, U., Beckers, G.J., Flors, V., García-Agustín, P., Jakab, G., Mauch, F., Newman, M.A., Pieterse, Poinssot, B., Pozo. M.J., 2006. "Priming: getting ready for battle." Molecular Plant-Microbe Interactions 19(10), 1062–1071.

[8] Elkhalifa, A.E.O., Alshammari, E., Adnan, M., Alcantara, J.C., Awadelkareem, A.M., Eltoum, N.E., Mehmood, K., Panda, B.P., Ashraf, S.A., 2021. "Okra (Abelmoschus esculentus) as a potential dietary medicine with nutraceutical importance for sustainable health applications." Molecules 26(3), p.696.

[9] Grunseich, J.M., Thompson, M.N., Aguirre, N.M., Helms, A.M., 2019. "The role of plant-associated microbes in mediating host-plant selection by insect herbivores." Plants 9(1), 6.

[10] Harris, J., 2009. "Soil microbial communities and restoration ecology: facilitators or followers?" Science 325(5940), 573–574.

[11] Hartley, S.E., Gange, A.C., 2009. "Impacts of plant symbiotic fungi on insect herbivores: mutualism in a multitrophic context." Annual Review of Entomology 54(1), 323–342.

[12] Jan, Q., Khan, I.A., Al-Shuraym, L.A., Alshehri, M.A., Ahmed, N., Saeed, M., El-Sharnouby, M., Sayed, S., 2022. "Comparative conventional preventive strategies for insect pest of okra." Saudi Journal of Biological Sciences 29(5), 3114–3121.

[13] Kahia, M., Nguyen, T.T.A., McCune, F., Naasz, R., Antoun, H., Fournier, V., 2021. "Insecticidal effect of *Bacillus pumilus* PTB180 and *Bacillus subtilis* PTB185 used alone and in combination against the foxglove aphid and the melon aphid (Hemiptera: Aphididae)." The Canadian Entomologist 153(6), 726–740.

[14] Kedar, S., Kumaranag, K., Bhujbal, D., Thodsare, N., 2014. "Insect pests of okra and their management." Popular Kheti 2(3), 112–119.

[15] Kloepper, J.W., 1978. "Plant growth-promoting rhizobacteria on radishes." Proc. of the 4th Internet. Conf. on Plant Pathogenic Bacter, Station de Pathologie Vegetale et Phytobacteriologie INRA, Angers, France, 1978.

[16] Kloepper, J.W., Okon, Y., 1994. "Plant growth-promoting rhizobacteria (other systems)." Azospirillum/plant associations 187, 137–166.

[17] Kloepper, J.W., Ryu, C.M., Zhang, S., 2004. "Induced systemic resistance and promotion of plant growth by Bacillus spp." Phytopathology 94(11), 1259–1266.

[18] Kodandaram, M., Halder, J., Singh, N., Rai, A., 2017. "Pest management modules against major insect pests of okra." Pesticide Research Journal 29(2), 153–157.

[19] Mohanty, P., Singh, P.K., Chakraborty, D., Mishra, S., Pattnaik, R., 2021. "Insight into the role of PGPR in sustainable agriculture and environment." Frontiers in Sustainable Food Systems 5, 667150.

[20] Mohapatra, S., Padhi, J., Singh, S., 2024. "Enhancing yield and economic benefits through sustainable pest management in Okra cultivation." Scientific Reports 14(1), 22220.

[21] Murovhi, J., Phophi, M.M., Mafongoya, P., 2020. "Efficacy of plant materials in controlling aphids on okra (Abelmoschus esculentus L. Moench) in Limpopo Province of South Africa." Agronomy 10(12), 1968.

[22] Myresiotis, C.K., Vryzas, Z., Papadopoulou-Mourkidou, E., 2015. "Effect of specific plant-growth-promoting rhizobacteria (PGPR) on growth and uptake of neonicotinoid insecticide thiamethoxam in corn (*Zea mays* L.) seedlings." Pest Management Science 71(9), 1258–1266.

[23] Nelson, L.M., 2004. "Plant growth promoting rhizobacteria (PGPR): prospects for new inoculants." Crop Management 3(1), 1–7.

[24] Ounis, S., Turóczi, G., Kiss, J., 2024. "Arthropod pests, nematodes, and microbial pathogens of okra (Abelmoschus esculentus) and their management—a review." Agronomy 14(12), p.2841.

[25] Reddy, N.A., Gowdar, S., 2006. "Bio-efficacy of acetamiprid 20 sp against sucking pests of okra." Agricultural Science Digest 26(4), 235–240.

[26] Santoyo, G., Urtis-Flores, C.A., Loeza-Lara, P.D., Orozco-Mosqueda, M.D.C., Glick, B.R., 2021. "Rhizosphere colonization determinants by plant growth-promoting rhizobacteria (PGPR)." Biology 10(6), 475.

[27] Sharma, S.K., 2022. "Field efficacy of insecticides against *Amrasca biguttula biguttula* Ishida on okra under sub-tropical conditions." *Pesticide Research Journal* 34(1), 23–30.

[28] Singh, V., Mandhania, S., Pal, A., Kaur, T., Banakar, P., Sankaranarayanan, K., Arya, S.S., Malik, K., Datten, R., 2022. "Morpho-physiological and biochemical responses of cotton (Gossypium hirsutum L.) genotypes upon sucking insect-pest infestations." Physiology and Molecular Biology of Plants 28(11), 2023–2039.

[29] Szczepaniec, A., Varela, K.A., Kiani, M., Paetzold, L., Rush, C.M., 2019. "Incidence of resistance to neonicotinoid insecticides in Bactericera cockerelli across Southwest US." Crop Protection 116, 188–195.

[30] Vessey, J.K., 2003. "Plant growth promoting rhizobacteria as biofertilizers." Plant and Soil 255, 571–586.

[31] Vocciante, M., Grifoni, M., Fusini, D., Petruzzelli, G., Franchi, E., 2022. "The role of plant growth-promoting rhizobacteria (PGPR) in mitigating plant's environmental stresses." Applied Sciences 12(3), 1231.

[32] Zehnder, G.W., Murphy, J.F., Sikora, E.J., Kloepper, J.W., 2001. "Application of rhizobacteria for induced resistance." European Journal of Plant Pathology 107, 39–50.