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RESEARCH

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Efficacy of *Trichoderma harzianum* against okra jassid (*Amrasca biguttula biguttula*) (Hemiptera: Cicadellidae): a two-year comparative study of biopesticides

Dhurba Saud[1*], Bishnu Dawadi[1] and Kailash Bhatta[1,2]

Abstract

Background Okra (*Abelmoschus esculentus* L.) is widely cultivated in tropical and subtropical regions, where its production is significantly constrained by insect pests. Among them, the jassid (*Amrasca biguttula biguttula*), a polyphagous pest with piercing-sucking mouthparts, causes serious yield losses. The experiments were conducted during the Kharif seasons (June to September) of 2023 and 2024 in the mid-hills of Nepal, using a Randomized Complete Block Design (RCBD) with five treatments and four replications to evaluate the efficacy of different biopesticides against jassid populations. The treatments comprised neem oil (1% EC), Jholmal (a locally prepared organic formulation), *Trichoderma harzianum* (1×10^8 CFU/ml), *Beauveria bassiana* (1×10^8 CFU/ml), and an untreated control.

Results The highest jassid mortality was recorded in plots treated with *T. harzianum*, with reductions of 76.72 and 77.26% per plant at 7 days after the third spray during the 2023 and 2024 Kharif seasons, respectively. These reductions were statistically significant ($P < 0.01$) compared to the other biopesticide treatments. In 2023, both neem oil and *T. harzianum* exhibited comparable efficacy after the first and third sprays, while in 2024, their effectiveness aligned during the first and second sprays. *B. bassiana* showed lower efficacy in the second and third sprays of 2023 but demonstrated improved performance in 2024, consistently reducing jassid populations compared to Jholmal and the control. Yield assessments revealed that *T. harzianum*-treated plots produced the highest okra yields of 18.73 t/ha in 2023 and 21.25 t/ha in 2024, while the untreated control consistently recorded the lowest yields of 8.75 t/ha and 8.00 t/ha, respectively.

Conclusion Among the tested biopesticides, *T. harzianum* was the most effective in reducing jassid populations and enhancing okra yield under mid-hill conditions. These findings highlight the potential of *T. harzianum* as an eco-friendly alternative to chemical pesticides, promoting safer food, healthier soils, and sustainable pest management for resource-limited farmers in Nepal's mid-hill regions.

Keywords Jassid, Microbial pesticides, Biocontrol, Bioassay, Jholmal

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Background

Okra (*Abelmoschus esculentus*) is a widely cultivated crop belonging to the Malvaceae family (2n = 130), commonly known as Bhindi or ladyfinger. It is an economically important vegetable crop grown in tropical, subtropical, and warm temperate regions across Africa, Asia, Southern Europe, and the Americas (Islam 2019). It is believed to have originated in Ethiopia and

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later spread to North Africa, the Mediterranean, Arabia, and India (Durazzo et al. 2018). It is highly valued for its nutritional content and plays a significant role in the livelihoods of smallholder farmers in subtropical regions (Dantas et al. 2021). The crop grows best at temperatures ranging from 24 to 32 °C in well-drained sandy loam soil rich in organic matter. Its root system typically extends 30–45 cm into the soil, enabling efficient nutrient and water absorption. It is valued for edible fruits and oil-rich seeds, containing nutrients that aid health (Gemede et al. 2015). In Nepal, it covers 9,337 ha, yielding 103,353 t at 11.07 t/ha in 2022/23 (MOALD 2024). Okra yield losses due to weed infestations range from 54.1 to 90.6% (Uwiringiyimana et al. 2024); pests cause about 69% (Sakriya et al. 2022), and leafhoppers not only cause sap-sucking damage but also transmit viral diseases such as okra yellow vein mosaic and enation leaf curl, resulting in severe plant deterioration and yield losses of up to 90% (Mishra et al. 2017). Okra cultivation is severely affected by key insect pests, including *Amrasca biguttula biguttula* (Ishida 1913) (Hemiptera: Cicadellidae), *Bemisia tabaci* (Gennadius, 1889) (Hemiptera: Aleyrodidae), and *Helicoverpa armigera* (Hübner, 1808) (Lepidoptera: Noctuidae) (Rahman 2012).

Jassid (*Amrasca biguttula biguttula*, Hemiptera: Cicadellidae) is the most common and destructive pest of okra, capable of reducing yield and quality by up to 50%. It is a polyphagous pest with sucking mouthparts. It feeds on plant leaves and young tender stems, extracting sap and transmitting toxins, resulting in a decrease in the photosynthetic area. The nymph and adult are the most destructive phases of the jassid pest, and they suck sap from the underside of the leaves, causing upward curling along the margin, giving a crinkling appearance (Bhutto et al. 2017). These infestations lead to leaf curling, marginal chlorosis (yellowing), reddening, and eventual drying of the foliage, causing 'hopper burn' symptoms in okra (Devi et al. 2018).

Pest management primarily involves two common methods: chemical and biological control. In FY 2019/20, Nepal imported 681.5 t of pesticides, averaging 1,605 g/ha for vegetables (PQPMC 2021). According to the Pesticide Registration and Management Division (MoAD/GoN), pesticide use in 2009/10 was 211.0 t a.i., which was 124–145 t less than in 2007/08–2011/12 (Chhetri et al. 2014). Synthetic pesticides are used frequently and provide effective results for jassid management (Dahal et al. 2020). However, the excessive use of chemical pesticides leads to hazardous bioaccumulation and bio-magnification in water and soil, causing environmental pollution and human health problems (Saimandir & Gopal 2012). The major drawback of synthetic pesticides is insect resistance to different classes of pesticides (Ramzan et al. 2019).

To address these issues, biopesticides are provided as an effective method for controlling the jassid population, and it is also useful for target specificity and reducing environmental risks (Kivett et al. 2015). Plant-based biopesticides, such as neem oil and garlic bulb extract, have been recorded to be effective against jassid (Kharjule et al. 2023). These biopesticides contain bioactive compounds, including azadirachtin, nimbin, nimbolide, allicin, and diallyl sulphides that help develop greater pesticide resistance. The plant-based Jholmal-3 was used as a bio-pesticide to control insects and pests (Bhusal & Udas 2020). According to Sachdev & Singh (2020), the interaction between microbial pesticide *Trichoderma* spp. and plants results in the production of volatile chemicals that assist in pest control, and it also acts as a fertilizer and reduces fungal disease infestations.

While several previous studies have investigated the effectiveness of individual biopesticides against jassid and other sucking pests, comprehensive comparisons between microbial and botanical biopesticides under real field conditions remain limited. In particular, there is a lack of multi-season evaluations assessing their efficacy in the mid-hill agro-ecological zones of Nepal, where pest pressure, climatic variability, and limited access to chemical inputs challenge sustainable okra production. This study was designed to address these gaps by evaluating and comparing the performance of *T. harzianum*, *B. bassiana*, neem oil, and Jholmal over two consecutive Kharif seasons. We hypothesized that *T. harzianum*, due to its entomopathogenic and growth-promoting properties, would significantly reduce jassid populations and enhance okra yield more effectively than the other biopesticides tested.

Methods

Experimental site

A field experiment was carried out during the Kharif seasons (June–September) of 2023 and 2024 at the Horticulture Research Field of the Institute of Agriculture and Animal Science (IAAS), Lamjung, Nepal. The study site is situated at 28.1448°N latitude and 84.4120°E longitude, with an elevation of 695.5 m above sea level. The recorded annual precipitation at the research site was 2,955.30 mm in 2023 and 2,944.23 mm in 2024 (Joshi et al. 2024). Temperature and relative humidity data were systematically recorded from April to August during the Kharif seasons of 2023 (Fig. 1) and 2024 (Fig. 2).

Experimental design and treatments

The experiment was conducted using a Randomized Complete Block Design (RCBD) with five treatments

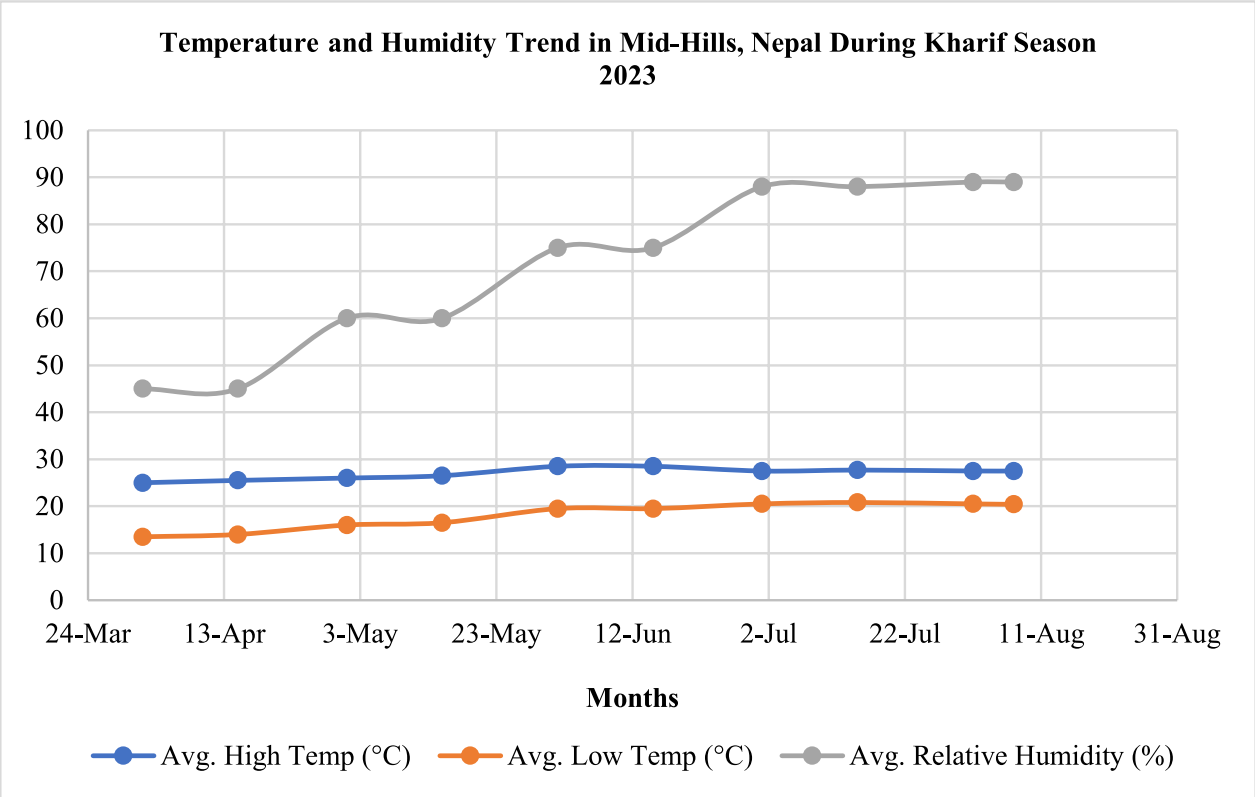


Fig. 1 Seasonal trends in temperature and humidity during Kharif 2023, Mid-Hills, Nepal

and four replications (Table 1). Each plot measured 4 m2 (2 m × 2 m), with the Arka Anamika variety of okra sown at a spacing of 50 × 30 cm between rows and plants. Individual plots and blocks were separated by a 50 cm distance. For the data collection, five plants were randomly selected and tagged from each plot.

Agronomic practices

All recommended agronomic practices were uniformly followed across all treatment plots, excluding insecticide application. A basal dose of 160:120:60 kg $N:P_2O_5:K_2O$ per hectare was applied, with urea split into two equal doses: half at sowing and half at 30 days after sowing (DAS). Light irrigation was applied 2–3 days before land preparation to improve soil tilth, followed by four field irrigations during the crop growth period, at 20 DAS, 35 DAS, 50 DAS, and 65 DAS, each with an estimated 4–5 cm water depth depending on rainfall and soil moisture.

Manual hand weeding was done twice, at 25 DAS and 50 DAS, using hand hoes to reduce weed competition and maintain uniform field conditions. All other management practices, including thinning and staking, were carried out as per recommended cultivation guidelines for okra to ensure fair yield comparison among treatments.

Preparation of treatments

A standard procedure for Jholmal preparation was followed. The formulation involved mixing chopped, locally sourced insecticidal or insect-repellent plants with animal urine and water in a 1:5:5 ratio, allowing it to decompose for one month. After complete decomposition, the mixture was filtered through a cotton sieve and applied at a rate of 125 ml/l of water (Bhusal & Udas 2020).

The biopesticides were applied as foliar sprays using a hand-held sprayer during early morning hours. Commercial formulations of neem oil, *T. harzianum*, and *B. bassiana* were freshly prepared before application and applied at rates of 2 ml/l for neem oil, 5 ml/l (1×10^8 CFU/ml) for *T. harzianum*, and 1 ml/l (1×10^8 CFU/ml) for *B. bassiana*.

Data collection

A total of three sprays were applied at 15-day intervals, starting 30 days after planting. The jassid population was recorded one day before each spray (pre-treatment count) and then on the 3rd, 5th, and 7th days after treatment. Jassid counts were based on visual observations of one upper, one middle, and one lower leaf from each sample plant (Sharma et al. 2018). Abbott's formula was

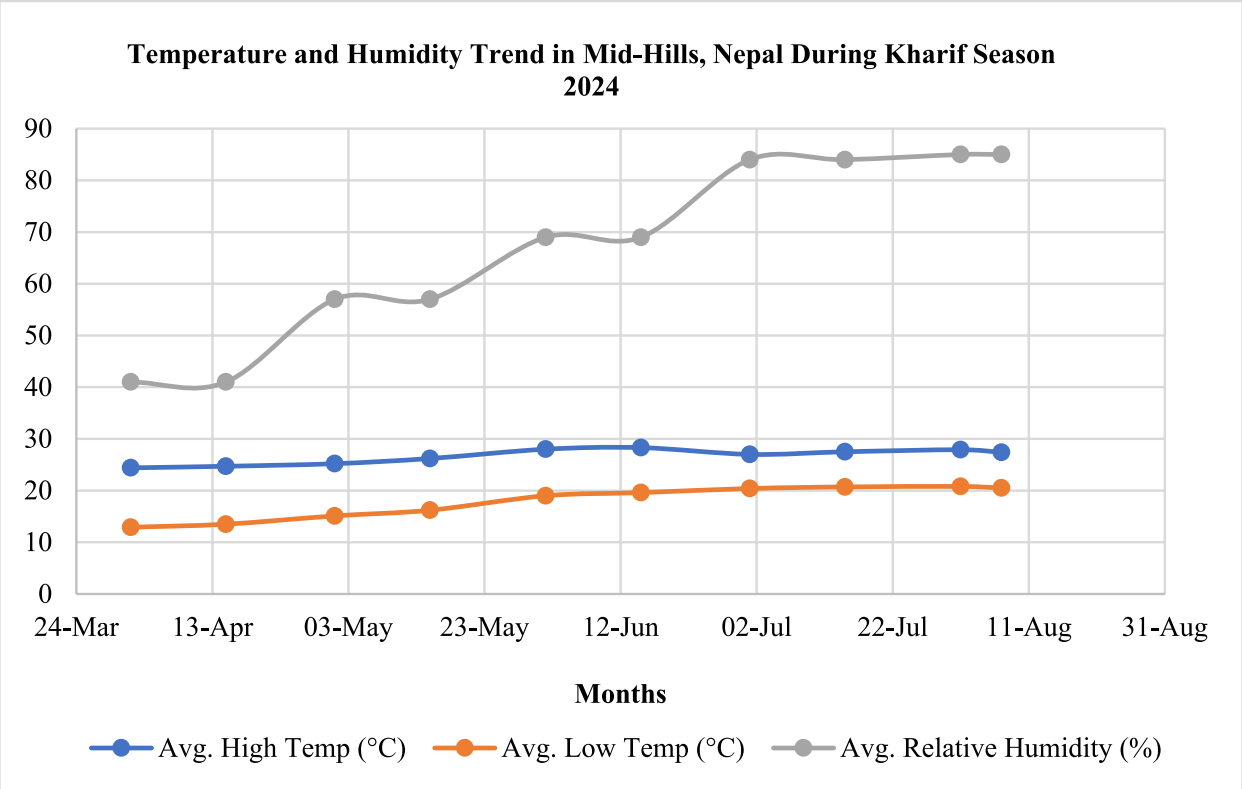


Fig. 2 Seasonal trends in temperature and humidity during Kharif 2024, Mid-Hills, Nepal

Table 1 List of treatments and doses used in the experiment

Treatments	Treatments details	Dose
T1	Neem oil (1% EC)	2 ml/l
T2	Jholmal	125 ml/l
T3	*Trichoderma harzianum*	5 ml/l
T4	*Beauveria bassiana*	1 ml/l
T5	Control	–

used to adjust mortality by correcting for natural deaths in the control group (Abbott 1925).

Yield

The young, tender fruits were harvested five times between 55 and 80 days after sowing (DAS) at five-day intervals. The total yield from each harvest was recorded plot-wise. Yield converted into t/ha by using following formula (Jan et al. 2022).

Statistical analysis

Data collected during the study were subjected to analysis of variance (ANOVA) to assess the significance of differences among the treatments using R-Studio (version 4.4.1). Mean comparisons were performed using the Duncan multiple range test (DMRT) at a 5% significance level, following the methods outlined by Gomez & Gomez (1984). Insect mortality was calculated according to Abbott (1925), while yield was determined as outlined by Jan et al. (2022).

$$\text{Corrected Mortality (\%)} = \left(\frac{Mortalityintreatment - Mortalityincontrol}{100 - Mortalityincontrol}\right) \times 100$$

$$\text{Yield (t/ha)} = \left(\frac{\text{Total yield per plot (kg)}}{\text{Plot area (m}^{2)}}\right) \times 10{,}000 \div 1000$$

Results

The effectiveness of various biopesticide treatments was assessed by measuring the mortality percentage of jassids per plant. Data on the jassid population was recorded one day prior to spraying, and the mortality percentage was calculated following the application of treatments. This evaluation was conducted over two consecutive years during the Kharif seasons of 2023 and 2024 to ensure reliable and consistent results. All the biopesticide treatments were found to be significantly more effective than the control in reducing jassid infestation.

Effectiveness of different biopesticides on jassid mortality during Kharif 2023

During the Kharif season of 2023, a total of three sequential sprays of biopesticides were carried after sowing, with initial observations showing non-significant difference ($P > 0.05$) in jassid population across all treatments (Table 2). However, by the third day after first spraying, neem oil (6.24%) and *Trichoderma harzianum* (6.29%) exhibited the highest insect mortality rates, which were statistically comparable ($P > 0.05$), indicating similar effectiveness. Jholmal and *B. bassiana* demonstrated moderate control but remained significantly superior ($P < 0.05$) to the untreated control. By the fifth day, neem oil and *T. harzianum* sustained their efficacy, while Jholmal (9.65%) achieved higher mortality than *B. bassiana* (6.46%). After seven days, *T. harzianum* recorded the highest insect mortality rate (28.72%), which was significantly higher ($P < 0.01$) than *B. bassiana* (12.92%) and the control (8.02%), and statistically comparable to neem oil (26.06%). Mortality caused by Jholmal (21.21%) was moderately effective, differing significantly from *B. bassiana* and the control.

Before the second spray, jassid populations were significantly higher ($P < 0.05$) in the *B. bassiana* and untreated control plots compared to other treatments (Table 2). Three days after the second application, *T. harzianum* again achieved the highest insect mortality percentage, statistically comparable to neem oil and significantly more effective ($P < 0.01$) than Jholmal and *B. bassiana*. *T. harzianum* maintained its lead with a 22.62% reduction, outperforming neem oil (19.18%) and Jholmal (16.47%). *B. bassiana* (9.08%) and the control (5.48%) displayed relatively low control levels by the fifth days. On the seventh day, *T. harzianum* continued to show the highest efficacy at 42.03%, followed by neem oil (35.79%), Jholmal (31.10%), and *B. bassiana* (16.88), all of which were significantly more effective ($P < 0.05$) than the control.

A similar trend was observed during the third spray (Table 2). Prior to this application, both *B. bassiana* and the control plots had significantly higher ($P < 0.05$) jassid populations. By the third day, *T. harzianum* once again demonstrated the peak insect mortality rate (16.23%), followed by neem oil and Jholmal (6.80%). *B. bassiana* (5.22%) and the control (2.23%) remained less effective. This trend continued on the fifth day. By the seventh day after the final spray, *T. harzianum* achieved the most substantial insect mortality rate of 76.72%, significantly higher ($P < 0.01$) than neem oil (63.52%), Jholmal (40.17%), and *B. bassiana* (23.12%), all of which were significantly better than the control. The overall findings from Kharif 2023 suggest that repeated applications of *T. harzianum* offer the most reliable and sustained jassid management, followed by neem oil and Jholmal, while *B. bassiana* showed comparatively lower efficacy throughout the study period.

Effectiveness of different biopesticides on jassid mortality during Kharif 2024

The experiment investigated the mortality of jassids following three sequential biopesticide applications during the Kharif 2024 season. Before the first spray (1DBS), jassid populations were statistically similar ($P > 0.05$)

Table 2 Mortality percentage of jassids at different days after spray (DAS) following application of biopesticides during Kharif 2023

Treatments	First Spray				Second Spray				Third Spray			
	Number of jassid per plant	Mortality percentage (%) of jassid per plant			Number of jassid per plant	Mortality percentage (%) of jassid per plant			Number of jassid per plant	Mortality percentage (%) of jassid per plant		
	1 DBS	3DAS	5DAS	7DAS	1DBS	3DAS	5DAS	7DAS	1DBS	3DAS	5DAS	7DAS
Neem oil (1% EC)	30.98^{a}	6.24^{a}	13.98^{a}	26.06^{a}	`24.25^{b}	7.42^{ab}	19.18^{ab}	35.79^{b}	15.40^{bc}	10.18^{b}	32.01^{b}	63.52^{a}
Jholmal	30.55^{a}	3.91^{b}	9.65^{b}	21.21^{b}	24.50^{b}	5.49^{bc}	16.47^{b}	31.10^{b}	17.17^{b}	6.80^{bc}	23.46^{c}	40.17^{c}
Trichoderma harzianum	30.28^{a}	6.29^{a}	14.66^{a}	28.72^{a}	23.65^{b}	10.55^{a}	22.62^{a}	42.03^{a}	13.25^{c}	16.23^{a}	42.80^{a}	76.72^{a}
Beauveria bassiana	31.60^{a}	3.23^{b}	6.46^{bc}	12.92^{c}	28.28^{a}	4.26^{bc}	9.08^{c}	16.88^{c}	23.72^{a}	5.22^{cd}	10.60^{d}	23.12^{d}
Control	30.68^{a}	1.02^{c}	4.12^{c}	8.02^{d}	28.68^{a}	2.37^{c}	5.48^{c}	10.83^{d}	25.77^{a}	2.23^{d}	6.47e	8.80^{e}
F- Test	ns	***	***	***	*	**	***	***	***	***	***	***
CV (%)	7.13	34.43	21.37	16.23	8.44	36.16	17.28	13.15	7.35	31.21	10.38	10.53
$LSD_{0.05}$	3.38	2.19	3.22	4.85	3.37	3.35	3.88	5.54	2.16	3.91	3.69	6.89
SEm (±)	1.09	0.17	1.04	1.57	1.09	1.08	1.26	1.79	0.70	1.27	1.19	2.23
Grand Mean	30.82	4.13	9.77	19.39	6.02	6.02	14.56	27.33	19.08	8.13	27.07	42.47

Note: Means followed by the same letter(s) indicate in a column are not significantly different at P = 0.05 by the DMRT. CV = coefficient of variation. LSD = least significant difference. SEm = standard error of means. ns = non-significant, * = significant at 5% probability level, ** = significant at 1% probability level, *** = significant at 0.1% probability level, DBS = Day Before Spray, and DAS = Day After Spray

Table 3 Mortality percentage of jassids at different days after spray (DAS) following application of biopesticides during Kharif 2024

Treatments	First Spray				Second Spray				Third Spray			
	Number of jassid per plant	Mortality percentage (%) of jassid per plant			Number of jassid per plant	Mortality percentage (%) of jassid per plant			Number of jassid per plant	Mortality percentage (%) of jassid per plant		
	1 DBS	3DAS	5DAS	7DAS	1DBS	3DAS	5DAS	7DAS	1DBS	3DAS	5DAS	7DAS
Neem oil (1% EC)	29.75^{a}	5.28^{ab}	11.37^{b}	20.83^{b}	24.25^{bc}	3.81^{b}	12.09^{b}	25.23^{b}	18.48^{c}	12.16^{b}	28.81^{b}	50.98^{b}
Jholmal	28.80^{a}	3.09^{cd}	6.93^{c}	10.74^{d}	25.75^{b}	3.46^{b}	7.95^{c}	14.19^{c}	22.25^{b}	5.79^{c}	14.50^{d}	22.93^{d}
Trichoderma harzianum	29.53^{a}	7.04^{a}	14.22^{b}	27.96^{a}	22.40^{c}	9.18^{a}	18.55^{a}	36.64^{a}	14.20^{d}	21.14^{a}	44.45^{a}	77.26^{a}
Beauveria bassiana	29.98^{a}	4.77^{bc}	11.47^{b}	18.67^{c}	25.03^{b}	4.13^{b}	11.50^{b}	18.62^{c}	20.58^{bc}	9.90^{b}	22.42^{c}	38.45^{c}
Control	29.43^{a}	1.73^{d}	3.36^{d}	4.88^{e}	28.25^{a}	1.33^{c}	4.11^{d}	8.21^{d}	25.53^{a}	2.82d	7.22^{e}	11.82^{e}
F- Test	ns	***	***	***	**	***	***	***	***	***	***	***
CV (%)	5.42	26.22	9.82	5.60	6.30	30.38	14.80	14.24	8.30	16.36	12.14	8.10
$LSD_{0.05}$	2.46	1.77	1.43	1.43	2.44	2.05	2.47	4.52	2.52	2.61	4.39	5.03
SEm (±)	1.09	0.57	0.46	0.46	0.79	0.67	0.80	1.47	0.82	0.85	1.43	1.63
Grand Mean	29.50	4.38	9.47	16.62	25.12	4.38	10.84	20.58	20.21	10.36	23.48	40.29

across all treatments, ranging from 28.80 to 29.98 jassids per plant (Table 3). At 3DAS, *T. harzianum* showed the highest mortality (7.04%), followed closely by neem oil (5.28%) and *B. bassiana* (4.77%), while Jholmal and control lagged behind. By the fifth day, *T. harzianum* again led (14.22%), followed by *B. bassiana* and neem oil, while Jholmal and the control remained significantly low ($P<0.05$). At 7DAS, the superiority of *T. harzianum* became more evident with 27.96% mortality, whereas neem oil (20.83%) and *B. bassiana* (18.67%) showed moderate control. Jholmal (10.74%) and the control (4.88%) remained the least effective, and statistically different from the microbial treatments ($P<0.05$).

Before the second spray, pest populations were again uniform across plots (Table 3). At the final spray after third day, *T. harzianum* recorded a sharp increase in effectiveness (9.18%), ahead of other treatments. This trend continued through fifth day after spraying (18.55%) and peaked at 7DAS with 36.64% mortality. Neem oil showed moderate performance across the same timeline (12.09% at 5DAS and 25.23% at 7DAS), while *B. bassiana* remained close in range. Jholmal remained less effective than microbial agents, and the control plots consistently had the lowest mortality percentages.

In the third spray, jassid populations ranged from 14.20 to 25.53 per plant before application. At 3DAS, *T. harzianum* again led in mortality (21.14%), with neem oil (12.16%) and *B. bassiana* (9.90%) trailing. By the fifth day spray, *T. harzianum* achieved 44.45% mortality and rose dramatically to 77.26% at after the seventh day of spray. Neem oil and *B. bassiana* followed the same trend with 50.98% and 38.45% mortality, respectively, by the seventh day after spray. Jholmal (22.93%) maintained a modest effect, while the control remained consistently ineffective with only 11.82% mortality. These differences were statistically significant ($P<0.01$), confirming the highest efficacy of *T. harzianum* across all spray intervals. Overall, *T. harzianum* proved to be the most effective biopesticide, showing increasing effectiveness across sprays and observation periods, with neem oil and *B. bassiana* offering moderate but reliable suppression. Jholmal, though better than untreated control, failed to match the microbial treatments in efficacy.

Effect of different biopesticides on yield (t/ha) of okra during Kharif Seasons

The application of different biopesticide treatments had a noticeable effect on the yield of okra during both the Kharif seasons of 2023 and 2024 (Fig. 3). Among all the treatments, *T. harzianum* consistently produced the highest yield in both years. In the Kharif season of 2023,

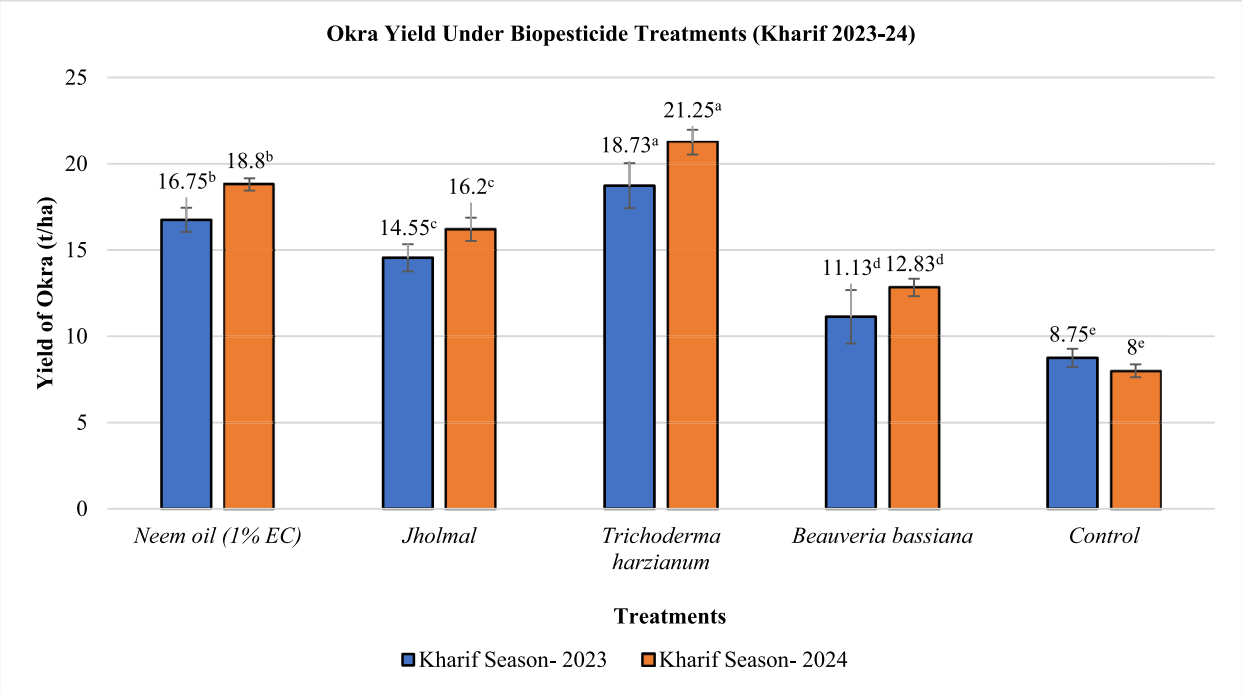


Fig. 3 Okra Yield Response to Biopesticide Treatments During Kharif Seasons (2023–2024)

plots treated with *T. harzianum* yielded 18.73 t/ha, which further increased to 21.25 t/ha in 2024. This result highlights the promising potential of *T. harzianum* in enhancing okra productivity under mid-hill conditions, and was found to be statistically superior ($P<0.05$) to other treatments.

Neem oil (1% EC) was the second most effective treatment, recording yields of 16.75 t/ha in 2023 and 18.80 t/ha in 2024. Although slightly lower than *T. harzianum*, it consistently performed better than the other treatments tested in the study. Jholmal, a locally prepared organic mixture, ranked third, with yields of 14.55 t/ha and 16.20 t/ha recorded in 2023 and 2024, respectively. Its steady improvement across both years suggests moderate potential as an eco-friendly yield enhancer for okra cultivation.

In contrast, *B. bassiana* resulted in comparatively lower yields of 11.13 t/ha in 2023 and 12.83 t/ha in 2024. Although it showed improvement over the untreated control, its performance remained statistically lower ($P<0.05$) than the top-performing treatments. The untreated control consistently produced the lowest yields of 8.75 t/ha in 2023 and 8.00 t/ha in 2024, indicating the importance of biopesticide application for maintaining and increasing okra productivity. These findings confirm *T. harzianum* as the most effective treatment for yield maximization, followed by Neem oil (1% EC) and Jholmal. The consistency of this trend across both seasons underscores the reliability of these biopesticides under mid-hill field conditions, with detailed statistical values (Table 4).

Table 4 Effect of Different Biopesticides on Okra Yield (t/ha) during Kharif 2023 and 2024

Treatments	Yield (t/ha)	
	Kharif Season- 2023	Kharif season- 2024
Neem Oil (1% EC)	16.75^{b}	18.80^{b}
Jholmal	14.55^{c}	16.20^{c}
Trichoderma harzianum	18.73^{a}	21.25^{a}
Beauveria bassiana	11.13^{d}	12.83^{d}
Control	8.75^{e}	8.00^{e}
F- test	***	***
CV (%)	7.78	3.53
$LSD_{0.05}$	1.68	0.84
SEm (±)	0.54	0.27
Grand Mean	13.98	15.42

Discussion

This study evaluated the effectiveness of two microbial pesticides (*T. harzianum* and *B. bassiana*) and two botanical alternatives (neem oil and Jholmal). Among them, *T. harzianum* and neem oil emerged as the most potent, with microbial pesticide *T. harzianum* demonstrating slightly superior efficacy in both Kharif seasons.

The remaining treatments, Jholmal and *B. bassiana*, contributed modestly to jassid suppression yet performed noticeably better than the untreated control. These findings align with the research (Bhandari et al. 2022) reinforcing their validity. The microbial pesticide *T. harzianum* resulted in the highest okra yield, primarily due to reduced pest infestation, and also acted as a biofertilizer. It was followed by neem oil, Jholmal, and *B. bassiana* in effectiveness. In contrast, untreated plots recorded significantly lower yields due to severe pest infestation and viral diseases, mainly transmitted by sucking pests such as jassids, aphids, and whiteflies. The outcomes of this study are consistent with those observed by (Bhandari et al. 2021). *Trichoderma* spp. are microbial pesticides that exhibit biocontrol activity against sucking pests through parasitism and production of secondary metabolites, including antifeedant and repellent compounds (Poveda 2021). Higher conidial density promotes fungal growth and increases insect contact, enhancing conidial adhesion, germination, and penetration, which ultimately leads to greater insect mortality (Nasution et al. 2018).

T. harzianum produces several secondary metabolites, including palmitic acid, octadecenoic acid, 1,3-dipalmitin, oleic acid (Z)-9-octadecenoic acid, capric acid, and eugenol, with varying concentrations among different fungal strains. These compounds exhibit insecticidal activity against pests such as aphids, grasshoppers, caterpillars, and leaf suckers (Aker et al. 2023). Specifically, palmitic acid and oleic acid function as insecticides, eugenol affects the insect nervous system acting as a contact insecticide, fumigant, or feeding deterrent, while capric acid is employed in botanical formulations for mosquito control (Subekti et al. 2024). According to Kucuk & Kivank (2003), *Trichoderma* spp. have produced a number of antibiotics, such as harzianun, trichodernin, trichodermol, and harzianolide, which help in controlling the insect pathogens. They are entomopathogenic fungi that infect insects and grow both on the surface and inside their bodies, using them as a nutrient source for the production of new conidia (Zahran et al. 2017). The study found that Hemipteran insects treated with *T. harzianum* and *T. longibrachiatum* experienced mortality rates of 40, 90, and 100% at 4 days, 14 days, and after 15 days, respectively (Anwar et al. 2016). Most studies found that when *T. harzianum* was applied to against jassids, it resulted in a 100% mortality rate after two weeks, producing peptaibols, 6-pentyl-α-pyrone (a volatile compound), and antifeedant compounds such as free fatty acids methyl linoleate and linoleic acid and chitinases (Nawaz et al. 2020). The spray of *Trichoderma* spp. has effective control on pests, and they also noted a positive effect on titratable acidity, chlorophyll content, photosynthetic rate, pH, and electrical conductivity of fruits, which helps to increase the yield (Bhandari et al. 2021). Botanical plant extracts of neem contain the active ingredient azadirachtin, which acts on the mitotic cells and interrupts the microtubule polymerization (Salehzadeh et al. 2003). Neem based pesticide mostly don't directly kill pests but it instead disrupt various physiological process, leading to decreased enzyme activity, infertility, muscle weakness, molting abnormalities, and antifeedant effects (Mordue & Nisbet 2000). It was applied against the Hemiptera family of insects, with the mortality rate of insects being 37% to 80.1% after 10 days of application (Lorencetti et al. 2018). A study reported that the use of Jholmal, which contains indigenous plant extracts, cow urine, and effective microorganisms (EM), helps to improve the soil fertility as well as protect the vegetables from pest infestation (Nepal 2017).

While the study highlights the effectiveness of these biopesticides in managing jassids and improving okra yield, their practical adoption in the field may be influenced by factors such as seasonal variations, the consistency and availability of quality formulations, and ease of access for farmers. Even so, their eco-friendly, non-toxic nature, coupled with their ability to support sustainable farming practices without harming beneficial insects or the environment, makes them a valuable alternative to chemical pesticides for growers in Nepal's mid-hill regions. Future research should focus on multi-season, multi-location field trials, cost–benefit analyses, and farmer perception studies to better understand their long-term effectiveness, economic viability, and practical challenges under diverse agro-ecological conditions.

Conclusion

This study is the first to conduct a two-season field comparison of microbial and botanical biopesticides against okra jassid under mid-hill conditions in Nepal. Among the treatments, *T. harzianum* consistently provided the highest jassid suppression and yield improvement, while also contributing to soil health and sustainability. Neem oil also showed strong potential, followed by Jholmal and *B. bassiana*, which outperformed the untreated control. These findings highlight the practical value of integrating microbial and botanical biopesticides into eco-friendly pest management programs. Their local availability, affordability, and safety make them especially suitable for smallholder farmers. Further research should explore their long-term field stability, cost-effectiveness, and compatibility within integrated pest management (IPM) systems for wider adoption in sustainable agriculture.

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Author contributions

Dhurba Saud (D.S.) conceptualized and designed the study, conducted field experiments, performed data analysis, and prepared the original draft of the manuscript. D.S. is the main author and corresponding author of this work. Bishnu Dawadi (B.D.) provided supervision, critical feedback, and assisted in reviewing and revising the manuscript. Kailash Bhatta (K.B.) supported in field management and contributed to manuscript editing. All authors reviewed and approved the final manuscript.

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Data availability

The datasets generated and analyzed during the present study, including field observations, pest population counts, and yield measurements, are available from the corresponding author, Dhurba Saud, upon reasonable request. These data are stored securely at the Institute of Agriculture and Animal Science (IAAS), Tribhuvan University (TU), Lamjung, Nepal, and can be provided to qualified researchers for purposes of verification and further analysis, subject to institutional data sharing policies.

Declarations

Competing Interests

The authors declare no competing interests.

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