DOI: https://doi.org/10.59983/s2024020302
AgroEnvironmental Sustainability, 2024, 2(3), 113-123

RESEARCH

Efficacy of Biopesticides and Botanical for Controlling Red Pumpkin Beetle of Cucumber (*Cucumis sativus* L.) in Surkhet District, Nepal

Anjal Nainabasti [1,*], Sangita Badayak [2], Bishesh Subedi [1], Babin Kharel [1], Binita Bhattarai [1] and Sandip Panth [1]

[1] Institute of Agriculture and Animal Science, Institute of Agriculture and Animal Science, Tribhuwan University, Kathmandu 44600, Nepal
[2] Agriculture and Forestry University, Agriculture and Forestry University, Chitwan 44200, Nepal
[*] Author responsible for correspondence; Email: anjalnaina99@gmail.com.

ARTICLE HISTORY
Received: 13 July 2024
Revised: 27 July 2024
Accepted: 08 August 2024
Published: 26 September 2024

KEYWORDS
Bacillus thuringiensis
Beauveria bassiana
fruit fly
pumpkin beetle

EDITOR
Sami Abou Fayssal

Abstract

This study evaluated the efficacy of biopesticides against major insect pests of cucumber (*Cucumis sativus* L.) in Lekbeshi, Surkhet, Nepal. A randomized complete block design experiment was conducted with four treatments: *Beauveria bassiana* (1 mL/L), *Bacillus thuringiensis* (2 mL/L), Jholmol (1:5 concentration), and an untreated control. After the third spray, *B. bassiana* reduced red pumpkin beetle populations from 1.4 to 0.4 insects per plant, while *B. thuringiensis* reduced fruit fly populations from 2.8 to 1.6 insects per plant, compared to the control (4.2 to 2.2). At 60 days after transplanting, *B. thuringiensis*-treated plants were significantly taller (137.45 cm) than control plants (111.28 cm). Fruit damage was lowest in *B. thuringiensis*-treated plots (1.8% and 0.69 kg damage weight) compared to the control (3.8% and 0.69 kg). While yield attributes showed no significant differences, total yield was highest in *B. bassiana*-treated plots (35.58 t/ha) compared to the control (17.8 t/ha). Economic analysis revealed that *B. bassiana* treatment had the highest benefit-cost ratio (4.19), followed by *B. thuringiensis* (2.9), control (2.8), and Jholmol (2.3). These findings suggest that biopesticides, particularly *B. bassiana* and *B. thuringiensis*, can effectively manage major cucumber pests while improving yield and economic returns, offering a sustainable alternative to chemical pesticides in subtropical regions.

Citation: Nainabasti, A., Badayak, S., Subedi, B., Kharel, B., Bhattarai, B., & Panth, S. (2024). Efficacy of Biopesticides and Botanical for Controlling Red Pumpkin Beetle of Cucumber (*Cucumis sativus* L.) in Surkhet District, Nepal. *AgroEnvironmental Sustainability*, 2(3), 113-123. https://doi.org/10.59983/s2024020302

Statement of Sustainability: This study shows a comprehensive evaluation of biopesticides such as *B. bassiana* and *B. thuringiensis* in controlling major pests of cucumber in Surkhet, Nepal. By significantly reducing pest populations and improving yield, these biopesticides present a sustainable alternative to chemical pesticides, aligning with the Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger) and SDG 15 (Life on Land). This research promotes environmentally friendly pest management practices that enhance agricultural productivity and economic returns while minimizing adverse impacts on health and ecosystems.

1. Introduction

Cucumber (*Cucumis sativus* L.) is a significant cucurbitaceous vegetable cultivated under various environmental conditions, including open fields and greenhouses, for both local consumption and export (Mallick, 2022; Subedi et al., 2024). In Nepal, cucumber cultivation has seen substantial growth due to its economic importance and demand in the market (Khanal and Dhakal, 2020). According to the latest data from the Ministry of Agriculture and Livestock Development, the total area under cucumber cultivation in Nepal is approximately 11,000 ha, with an annual production of around 160,000 metric tons. The average productivity of cucumber in Nepal is about 14.5 metric tons per hectare (MoALD, 2023), which is relatively low compared to other leading cucumber-producing countries, indicating potential for yield improvement through better pest management practices. Biopesticides, derived from biological sources such as naturally occurring toxins, are used to manage (Prabha et al., 2016; Thapa et al., 2022). According to the European Environmental Agency (EEA), a biopesticide is a pesticide in which the active ingredient is a virus, fungus, bacteria, or a natural product from a plant source. These agents work by causing specific biological effects rather than chemical poisoning (Glare and Nollet, 2015). Biopesticides act through various mechanisms, such as non-specific multi-site inhibitors, neuromuscular toxins, metabolic toxins, growth regulators, and intestinal disruptors, which help reduce pest populations (Fenibo et al., 2022). The diverse mechanisms of action of biopesticides decrease the likelihood of pest resistance, a common issue with chemical pesticides (Dara, 2017). Biopesticides, made from living microorganisms or natural products, are known for their economic viability, environmental friendliness, and target specificity (Archana et al., 2022). They have the potential to control yield loss without compromising crop quality. One of the most commonly used microbial biopesticides is the bacterium *B. thuringiensis* (Kumar et al., 2021).

Many cucumber farmers lack appropriate knowledge and information about effective pest control management, leading to significant production challenges. Red pumpkin beetle, fruit fly, spotted cucumber beetle, aphid, and mites are common pests that can be effectively managed and controlled using biopesticides applied at weekly intervals (Sharma et al., 2016; Srivastava and Joshih, 2021). However, due to a lack of know-how and ignorance, farmers often resort to using chemical pesticides indiscriminately to combat pest infestations (Dhopte, 2020). Studies have shown that fruit flies and red pumpkin beetles can cause yield losses ranging from 30 to 100% in cucumbers (Miah, 2018). In Surkhet district, traditional pest management practices such as using cow urine, Jholmol, and wood ash are temporarily effective but not sufficient for long-term control. Poor knowledge and techniques in pest management persist in many regions, and the application of chemical pesticides degrades the quality of vegetables, posing health risks to consumers. Haphazard and irrational pesticide use harms the environment by eroding soil surfaces, reducing agricultural productivity, and affecting micro and macro flora and fauna (Adhikari, 2017). The excessive use of synthetic pesticides results in pest resurgence and introduces new pests, increasing production costs and affecting the quality and quantity of cucumbers (Abrol and Shankar, 2014).

The objective of the study is to evaluate the efficacy of biopesticides in controlling major pests of cucumbers in Surkhet district, Nepal. Specifically, it aims to assess the impact of biopesticides on the population of red pumpkin beetle (*Aulacophora foveicollis*) and fruit fly (*Drosophila melanogaster*), evaluate the effect of biopesticides on yield and yield-related parameters of cucumber, and analyze the economic benefits of using biopesticides in cucumber cultivation.

2. Materials and Methods

2.1. Study Site

The research was conducted in Lekbeshi, Surkhet, Nepal (28°29'30" N, 81°45'40" E) from February 25 to July 2023. This river basin area has a subtropical climate with hot summers, cool winters, and a distinct wet season. The sandy loam soil was suitable for cucumber cultivation, and the field had proper irrigation and drainage systems. During the experiment, total rainfall was 3902 mm, with a peak of 49 mm in the 16th week after planting. Temperatures ranged from 14 to 34°C, with maxima during the fruiting stage, and relative humidity was 40-50%. This data was obtained from the Weather station of Lekhbesi, Surkhet, Nepal.

2.2. Experimental Design and Treatments

The experiment was conducted using a Randomized Complete Block Design (RCBD) to evaluate the efficacy of different biopesticides in controlling major pests of cucumber. The study comprised four treatments, each replicated five times, with a total experimental area of 148.5 m^2 (13.5 × 11 m) and individual plot sizes of 1.5 m^2 (1 × 1.5 m). The spacing between plants was maintained at 60 cm, and rows were spaced 45 cm apart. A 1 m gap was maintained between replications, and a 25 cm buffer was left between plots to prevent cross-contamination.

The treatments included: (1) *B. bassiana* (1 mL/L water), an entomopathogenic fungus known for its effectiveness against various insect pests; (2) *B. thuringiensis* (2 mL/L water), a gram-positive bacterium producing insecticidal proteins; (3) Jholmol (1:5 concentration), a traditional botanical pesticide made from leaf extracts, cow urine, cow dung, and spices; and (4) a Control treatment, where no biopesticides were applied, and only standard crop management practices were followed. The biopesticides were administered using a knapsack sprayer at seven-day intervals during the peak infestation period, starting ten days after transplanting. Care was taken to prevent drift between plots to ensure the accuracy of the results.

2.3. Cultural Operation

The plot was prepared by thorough tilling with a disc Plow, followed by cross-plowing twice using a disc harrow. On March 4th, the land was leveled, and all stubbles, weeds, and residues were removed. Farmyard manure (FYM) was incorporated to enhance soil nutrient content. Dynasty, a hybrid cucumber variety popular in the terai and mid-hill regions, was selected for the study. Seeds were purchased locally and sown on February 18th. Seedlings were transplanted at the 3-leaf stage on March 8th, planted 10-15 cm deep in the prepared land. Gap filling was performed in the second week after transplanting to address early insect damage. Crop management involved timely weeding, irrigation, fertilizer application, and removal of unwanted plant parts. The recommended doses of fertilizer and FYM were manually incorporated during land preparation. Hand weeding was carried out on April 12th, and irrigation was provided as needed. Mustard straw was used as a bio-mulch to conserve soil moisture and control weeds. For plant support, staking was implemented by creating four holes in each plot and fixing logs to facilitate tendril climbing.

2.4. Parameters

Data were collected on several parameters in the field, including insect population, fruit damage, fruit characteristics, and plant height. The insect population, specifically red pumpkin beetle and fruit fly numbers, was manually counted just before spraying and at 1, 3, and 6 days after spraying in each plot. Fruit damage was assessed by recording the number and weight of fruits damaged by these pests at each harvest. Fruit characteristics such as length, diameter, and weight were measured using a scale and Vernier caliper. Plant height was measured from ground level to the plant tip at 30, 45, and 60 days after transplanting using scales and measuring tapes.

2.5. Statistical Analysis

Data entry and processing were carried out using Microsoft Office Excel 2016. Analysis of variance (ANOVA) and mean estimation were done with the R Studio (version 4.3.1). Duncan's Multiple Range Test (DMRT) was used to determine significant differences between mean values at a 5% level of significance.

3. Results and Discussion

3.1. Effects on Plant Height (cm)

Table 1 shows the impact of *B. bassiana*, *B. thuringiensis*, and Jholmol on plant height at 30, 45, and 60 days after transplanting (DAT), compared to untreated control plants. At 30 DAT, there were no significant differences between the treatments. However, at 45 and 60 DAT, significant differences were observed at the 5% and 1% levels respectively based on the F-test. The *B. thuringiensis* treatment resulted in the tallest plants at 137.45 cm, followed by Jholmol at 127.23 cm. These results indicate that *B. thuringiensis* and Jholmol have growth-promoting effects in addition to their insecticidal properties. The enhanced plant height under *B. thuringiensis* treatment might be attributed to its ability to produce insecticidal proteins that not only target pests but may also promote plant growth by reducing pest-related stress and damage (Jouzani et al., 2017). The findings align with previous studies, which have reported similar growth benefits from *B. thuringiensis*, likely due to its suppression of pest populations that otherwise divert plant resources from growth to defense mechanisms (Sayed and Behle, 2017).

Table 1. Plant height of cucumber at 30 DAT, 45 DAT, 60 DAT in Surkhet, Nepal.

Treatment	30 DAT	45 DAT	60 DAT
B. bassiana	94.760	120	120.30
B. thuringiensis	10570	111.23	137.45
Jholmol	93.296	109.18	127.23
Control	88.860	100.73	111.28
F-test	ns	*	**
LSD	11.87	12.79	12.365
SEm (±)	0.96	1.03	1.0
CV (%)	9.10	8.42	7.23
Grand mean	94.62	110.28	124.06

*= Significant, ns = not significant, DAT= Days after transplanting; LSD= Least Significant Difference; SEm = Standard error mean; CV= Coefficient of Variation.

Jholmol, a botanical pesticide, also demonstrated significant growth-promoting effects, albeit slightly less pronounced than *B. thuringiensis*. This could be due to its composition, which includes nutrients and bioactive compounds from cow urine, cow dung, and plant extracts, potentially providing a nutrient boost and enhancing microbial activity in the soil, thereby promoting plant growth (Gurung and Azad, 2013). *B. bassiana*, while effective in increasing height compared to the control, was less potent than the other two biopesticides. This differential effectiveness could be due to the specific modes of action of these biopesticides, where *B. thuringiensis* primarily targets larvae through crystal proteins, and Jholmol works through multiple mechanisms, including repellence and toxicity, but perhaps less directly influences growth (Dara, 2024; Iida et al., 2023).

3.2. Effects on Diversity of Insects

The diversity of insect pests in cucumber crops significantly influences crop health and yield (Hossain et al., 2018; Ratnadass et al., 2012). In this experiment, various pests were observed, with red pumpkin beetles being the most predominant. Field observations revealed that the red pumpkin beetle population was substantially higher than other pests, consistent with previous studies in similar agroecological zones (Hassain, 2013; Islam, 2015; Miah, 2018). These beetles primarily feed on leaves and flowers, reducing photosynthetic capacity and causing yield losses (Chandi et al., 2022). Their high prevalence underscores the need for effective management strategies (Patel and Dabhi, 2021). Other pests, including fruit flies, melon flies, and melon aphids, were also present, albeit in lower numbers, contributing to the overall pest pressure on cucumber crops (HGIC, 2021). Fruit flies pose a significant concern due to their ability to infest and damage fruits, potentially leading to substantial economic losses (10 to 30%) in commercial cucumber production (Papadopoulos et al., 2024). Fruit fly larvae cause internal damage that renders fruits unmarketable (Sapkota et al., 2010). Melon flies similarly target fruits, while melon aphids cause direct damage by feeding on plant sap and act as vectors for various plant viruses (Dhillon et al., 2005). The relatively lower population of these pests compared to red pumpkin beetles and fruit flies may reflect differences in pest pressure or seasonal variations. This observed diversity of insect pests highlights the complex pest dynamics in cucumber cultivation and emphasizes the necessity of a comprehensive pest management approach that addresses multiple pest species to ensure optimal crop protection and yield (Azad et al., 2013; Jia and Wang, 2021).

3.2.1. Effect of Biopesticides on Red Pumpkin Beetle Population

The application of biopesticides *B. bassiana*, *B. thuringiensis*, and Jholmol significantly affected the population of red pumpkin beetles across three separate sprays, as shown in Table 2. The initial beetle populations were highest in the control group, with *B. bassiana* showing the lowest numbers before application. One day after the first spray, *B. bassiana* had a marked reduction in the beetle population, decreasing from 3.0 to 1.4, while the control group had only a slight decrease from 4.6 to 3.4. This trend continued with *B. bassiana* consistently showing the lowest beetle counts, reaching as low as 0.4 beetles per plant by the sixth day after the first spray. The superior efficacy of *B. bassiana* can be attributed to its unique mode of action, where fungal spores infect and proliferate within the insect, eventually causing death (Keswani et al., 2013; Wang et al., 2021). This method is particularly effective because it targets the insect's natural defenses, leading to high mortality rates even at low doses (Bahadur, 2023). The persistence of *B. bassiana* in the environment further contributes to sustained pest suppression (Acharya et al., 2015; Inglis et al., 1997), as evidenced by the consistently low beetle numbers across the six days following each spray.

For the second spray, the trend observed in the first spray persisted. Before the second spray, the beetle population was highest in the control group (4.6 beetles per plant) and lowest in the *B. bassiana* treatment (1.8 beetles per plant). One day after the second spray, *B. bassiana* again showed the highest efficacy, reducing the beetle population from 1.8 to 1.4, whereas the control group saw a minimal decrease from 4.6 to 3.8. By the sixth day after the second spray, *B. bassiana* maintained the lowest beetle population at 0.4, demonstrating sustained pest control. *B. thuringiensis* showed a slower reduction in beetle numbers, decreasing from 3.0 to 1.6 beetles per plant, while Jholmol reduced the population from 4.0 to 1.8 beetles per plant. These results highlight the superior efficacy of *B. bassiana* due to its mode of action, where fungal spores infect and proliferate within the insect, leading to high mortality rates (Keswani et al., 2013). In contrast, *B. thuringiensis* works by producing crystalline proteins that disrupt the insect's digestive system, leading to a slower decline in population (Kumar et al., 2021). Jholmol, though effective, showed moderate efficacy, possibly due to its less well-documented mechanism involving repellent properties and mild toxicity (Rogers, 2012). The third spray further reinforced the effectiveness of *B. bassiana*. Before this spray, the beetle population was again highest in the control group (4.2 beetles per plant) and lowest in *B. bassiana* (1.4 beetles per plant). One day after the third spray, *B. bassiana* reduced the beetle population to 0.6, while the control group had a slight reduction from 4.2 to 3.4. By the sixth day, *B. bassiana* maintained a low beetle count of 0.6, significantly lower than *B. thuringiensis* (1.2) and Jholmol

(1.6). The consistent low beetle counts in the *B. bassiana* treatment across all sprays highlight its persistence in the environment and ability to provide long-term pest suppression (Iida et al., 2023). *B. thuringiensis* and Jholmol, while effective, were less efficient, with *B. thuringiensis* reducing beetle numbers through digestive disruption (Redmond et al., 2020) and Jholmol through its repellent and mildly toxic properties (Azad et al., 2013). The control group consistently had the highest beetle populations, underscoring the necessity of biopesticide application for effective pest management.

Table 2. Effect of biopesticides on red pumpkin beetle population in Surkhet, Nepal.

Treatments	1st Spray				2nd Spray				3rd Spray			
	BS	1 DAS	3 DAS	6 DAS	BS	1 DAS	3 DAS	6 DAS	BS	1 DAS	3 DAS	6 DAS
B. bassiana	3.0	1.4	1.0	0.4	1.8	1.4	1.2	0.4	1.4	0.6	0.4	0.6
B. thuringiensis	3.2	1.6	1.8	1.6	3.0	3.4	3.4	1.6	3.0	1.8	1.8	1.2
Jholmol	4.2	2.8	2.6	1.8	4.0	3.2	3.6	1.8	3.6	2.0	1.8	1.6
Control	4.6	3.4	3.4	3.0	4.6	3.8	4.0	2.2	4.2	3.4	2.8	2.2
F-test	*	**	***	***	***	***	***	**	***	***	***	**
LSD (0.05)	1.025	1.03	0.95	0.77	0.94	0.99	0.88	0.74	0.93	0.62	0.58	0.71
SEm (±)	0.117	0.11	0.109	0.06	0.10	0.081	0.07	0.24	0.075	23.4	0.06	0.05
CV (%)	19.83	32.53	31.43	33.27	20.5	24.56	21.16	36	22.19	1.95	24.95	36.88
Grand Mean	3.75	2.3	2.2	0.77	3.35	2.95	3.05	1.5	3.05	1.95	1.7	1.4

*= Significant, ns = not significant, DAS= Day after Spray; LSD= Least Significant Difference; SEm = Standard error mean; CV= Coefficient of Variation; BS= Before Spray.

3.2.2. Effect of Biopesticides on Fruit Fly Population

Before the second spray, the fruit fly population was highest in the control group (4.2) and lowest in the *B. bassiana* treatment (0.8). After spraying, there was a significant reduction in the insect population. One day after the second spray, the population of fruit flies decreased markedly, with *B. bassiana* reducing the population from 2.0 to 0.8, *B. thuringiensis* from 3.2 to 2.0, Jholmol from 3.2 to 2.0, and the control from 4.2 to 3.0 (Table 3). By the third day after the second spray, *B. bassiana* showed continued effectiveness, maintaining the lowest population at 1.0, while *B. thuringiensis* and Jholmol both had populations of 2.2. The control group remained the highest at 3.6. On the sixth day, the fruit fly population was similar in all treatments except for the control, which was significantly lower at 1.25 compared to *B. bassiana*, *B. thuringiensis*, and Jholmol, each maintaining a population of 2.0. These results highlight the efficacy of *B. bassiana* in reducing fruit fly populations rapidly and sustainably (Homayoonzadeh et al., 2022; Tomar et al., 2024). For the third spray, similar trends were observed. *B. bassiana*, *B. thuringiensis*, and Jholmol significantly reduced fruit fly counts from before spraying to three days after spraying, followed by a partial rebound by the sixth day. *B. bassiana* reduced the population from 1.8 to 0.6 by the third day, then slightly increased to 1.0 by the sixth day. *B. thuringiensis* lowered counts from 2.8 to 1.6 by the third day and then to 1.8 by the sixth day. Jholmol saw a reduction from 3.4 to 1.8, remaining stable by the sixth day. The control group also showed a reduction from 4.2 to 2.2 by the third day, ending at 2.4 by the sixth day. By the sixth day, counts in all treatments had somewhat recovered, yet *B. bassiana* maintained lower populations overall.

Table 3. Effect of biopesticides on fruit fly population in Surkhet, Nepal.

Treatment	2nd Spray				3rd Spray			
	BS	1 DAS	3 DAS	6 DAS	BS	1 DAS	3 DAS	6 DAS
B. bassiana	2.0	0.8	1.0	2.0	1.8	1.2	0.6	1.0
B. thuringiensis	3.2	2.0	2.2	2.0	2.8	2.2	1.6	1.8
Jholmol	3.2	2.0	2.2	2	3.4	2.2	1.8	1.8
Control	4.2	3.0	3.6	1.25	4.2	3.4	2.2	2.4
F-test	*	*	***	***	*	*	**	**
LSD (0.05)	1.20	1.36	0.67	0.65	1.34	1.34	0.84	0.58
SEm (±)	0.09	0.11	0.05	0.04	0.10	0.10	0.06	0.04
CV (%)	27.79	50.89	21.69	22.9	32	43.5	39.41	24.24
Grand Mean	3.15	1.92	2.25	1.85	3.05	2.25	1.55	1.75

*= Significant, ns = not significant, DAS= Day after Spray; LSD= Least Significant Difference; SEm = Standard error mean; CV= Coefficient of Variation; BS= Before Spray

The consistent reduction in fruit fly numbers, especially after the second and third sprays, indicates that regular application of *B. bassiana* can effectively manage fruit fly infestations, leading to reduced fruit damage and better yield quality (Toledo et al., 2007). The results highlight the importance of understanding the mode of action and environmental interactions of biopesticides to optimize their use in integrated pest management strategies (Fenibo et al., 2022). The superior efficacy of *B. bassiana* can be attributed to its unique mode of action. This entomopathogenic fungus infects its host through contact with its conidia (spores). Upon adhering to the insect cuticle, the conidia germinate and penetrate the insect's exoskeleton, reaching the hemocoel (body cavity). There, it proliferates, producing toxins that weaken the insect's immune response, eventually leading to death. This mode of action is particularly effective because it targets the insect's natural defenses, leading to high mortality rates even at low doses (Rogers, 2012). The repeated application of *B. bassiana*, a biopesticide, builds up a reservoir of spores in the environment, leading to sustained pest suppression and consistently low beetle numbers for six days after each spray (Wang et al., 2021). In contrast, *B. thuringiensis* works through the production of crystalline (Cry) proteins that disrupt the insect's digestive system. When ingested by the insect, these proteins are activated in the alkaline environment of the gut, forming pores in the gut cells and causing cell lysis and septicemia (Bravo et al., 2007).

Although effective, *B. thuringiensis* efficacy can be influenced by environmental factors and pest developmental stage, potentially contributing to less pronounced pest suppression compared to *B. bassiana*, while insect-feeding behavior also affects *B. thuringiensis* uptake, with non-feeding stages being less susceptible (Becker et al., 1992). Jholmol, a traditional biopesticide, showed moderate efficacy. The exact mechanism by which Jholmol affects pests is less well-documented, but it may involve a combination of repellent properties and mild toxicity. Jholmol is believed to have antimicrobial properties that can deter pests and inhibit their development (Dhakal et al., 2019). The use of Jholmol as a biopesticide is particularly interesting as it represents a traditional and potentially sustainable option for pest management (Maligimani, 2024). Its effectiveness may vary depending on the formulation and application method, and further research is needed to fully understand its mechanisms and optimize its use (Agrawal et al., 2016). The superior performance of *B. bassiana* across multiple pest species underscores its potential as a versatile and sustainable solution for pest control in Surkhet, Nepal.

Table 4. Effect of biopesticide on decay loss of cucumber due to pest in Surkhet, Nepal.

Treatment	Damage (%)	Damage Weight (kg)
B. bassiana	2.2	0.83
B. thuringiensis	1.8	0.69
Jholmol	2.0	0.77
Control	3.8	0.69
SEM (±)	0.062	0.02
LSD	0.76	0.31
CV	22.66	26.45
F- Test	***	*
Grand mean	2.45	0.86

*= Significant, ns = not significant, DAS= Day after Spray; LSD= Least Significant Difference; SEm = Standard error mean; CV= Coefficient of Variation; BS= Before Spray.

3.3. Effects on Fruit Infestation

It is evident from Table 4 that the total number of fruits damaged in each plot is higher control condition followed by *B. bassiana* (2.2) The minimum number of fruits damaged was obtained from *B. thuringiensis* (1.8). Similarly, a higher number of unmarketable fruits were recorded under Control conditions (3.8) and *B. bassiana* (2.2) was recorded. The descending order of comparative efficacy of several insecticides based on damage weight was *B. thuringiensis* > Control > Jholmol > *B. bassiana*. The results of statistical analysis showed that the damage weight number was significantly variation among the bio-pesticides used. Damage weight was observed to be least in *B. thuringiensis* (0.69) and control condition.

The data on fruit infestation further supports the efficacy of biopesticides. *B. thuringiensis* showed the least fruit damage, suggesting that it is highly effective in preventing fruit infestation, possibly due to its bactericidal properties that target insect larvae (Chandrakasan et al., 2022). *B. bassiana*, while effective, resulted in slightly higher damage compared to *B. thuringiensis*, but still significantly reduced damage compared to the control. Jholmol, although less effective than *B. thuringiensis*, also contributed to lower damage levels. These findings suggest that *B. thuringiensis* and *B. bassiana* are particularly useful in reducing fruit damage, thereby improving marketable yield (Skinner et al., 2014).

3.4. Effect of Biopesticides on Yield Attributing Characters

The attributes measured were fruit length, average fruit weight, and fruit diameter. Statistical analysis using ANOVA showed no significant (P > 0.05) differences between any treatments and the control for all three yield parameters (Table 5). Fruit length ranged from 17.61 cm to 18.27 cm, fruit weight from 269.46 g to 282.22 g, and diameter from 4.538 mm to 5.0 mm across treatments. However, these small numerical differences were statistically non-significant as determined by the LSD test at the 5% level. The coefficient of variation was moderately high for fruit weight (24.60%). Despite the lack of statistically significant differences, the observed numerical trends may provide insight into the interaction between biopesticides and plant growth (Azad et al., 2013; Sampiano, 2022). *B. bassiana,* known for its entomopathogenic properties, not only targets insect pests but may also influence plant health indirectly by reducing pest pressure. Studies by Azad et al. (2013) and Wei et al., (2020) have demonstrated that *B. bassiana* can colonize plant roots and promote growth, potentially explaining the observed fruit dimensions in this treatment group. *B. thuringiensis* works primarily through the production of crystalline toxins that target insect digestive systems. This mode of action is specific to pest control and does not directly affect plant physiological processes (Tetreau et al., 2021). However, by reducing pest numbers, *B. thuringiensis*-treated plants might have experienced less biotic stress, contributing to the moderately high fruit weight observed. Similar findings were reported by Cebolla and Berry (2023), where *B. thuringiensis* application resulted in improved plant vigor and yield in various crops.

Table 5. Effect of biopesticide on yield attributing character of cucumber in Surkhet, Nepal.

Treatment	Fruit Length (cm)	Fruit Weight (kg)	Fruit Diameter (mm)
B. bassiana	18.270	250.94	4.538
B. thurigiensis	17.99	258.11	4.606
Jholmol	17.61	269.46	4.872
Control	18.12	282.22	5.0
LSD	3.43	89.92	0.669
SEm(±)	0.27	7.29	0.054
F-test	ns	ns	ns
CV (%)	13.83	24.60	10.22

LSD = Least Significant Difference; SEm = Standard error mean; CV= Coefficient of Variation.

Jholmol, a traditional organic formulation, includes a mixture of locally available biocontrol agents and nutrients. Its effect on yield attributes, though less documented, can be attributed to the combined action of these agents providing both pest control and nutrient supplementation. The observed fruit dimensions in the Jholmol treatment align with those reported by Sorathiya et al. (2023), who noted improvements in crop yield and quality with the use of similar organic formulations. The control group, exhibiting the highest fruit weight and diameter, may reflect the absence of any biotic stressors typically managed by biopesticides (Radames et al., 2018). This observation underscores the role of pest pressure in modulating yield attributes. However, it also raises questions about the potential trade-offs between pest management and yield optimization, a topic explored by Green et al. (2020) in their review of biopesticide applications in integrated pest management (IPM) systems. The high coefficient of variation for fruit weight suggests a considerable degree of variability within treatments, (Bartaula et al., 2019; Ene et al., 2016). This aspect warrants further investigation to isolate and understand the contributory elements more precisely.

Table 6. Effect of biopesticides on total yield and yield related parameters of cucumber in Surkhet, Nepal.

Treatment	Total Yield (kg)	Total Fruit Number	Productivity (t/ha)
B. bassiana	14.10	32.0	35.58
B. thuringiensis	8.32	29.6	29.0
Jholmol	6.10	24.0	23.6
Control	5.09	0.53	17.8
LSD (0.05)	2.16	6.64	6.05
SeM (±)	0.17	17.20	0.69
F- test	***	***	***

LSD= Least Significant Difference; SEm = Standard error mean

3.5. Total Yield and Yield Related Parameters

The study demonstrated that the application of biopesticides significantly enhanced cucumber yield compared to the untreated control (Table 6). Specifically, *B. bassiana* achieved the highest fruit yield at 35.58 mt/ha, while the control treatment recorded the lowest yield at 22.7 mt/ha. *B. thuringiensis* and Jholmal treatments also showed improved yields of 29.6 mt/ha and 24.0 mt/ha, respectively. The effectiveness of these biopesticides can be attributed to their pest-control properties. *B. bassiana*, an entomopathogenic fungus, infects and kills insects, thus reducing pest pressure and promoting plant health (Iida et al., 2023; Pedrini, 2022). Similarly, *B. thuringiensis* produces toxins that target specific insect larvae, leading to reduced crop damage and better fruit set (Bravo et al., 2007; Palma et al., 2014; Roh et al., 2007). Jholmal, an organic concoction, provided moderate yield improvements, likely due to minor pest suppression and nutrient supplementation (Bhusal and Udas, 2020). The lower yield in the control treatment underscores the importance of pest management in maintaining crop productivity. The variability in yield among treatments, as indicated by the coefficient of variation, suggests that factors such as environmental conditions and pest populations influence the efficacy of biopesticides. These findings align with previous studies, such as those by Rani et al. (2021) and Rogers (2012), which reported similar increases in crop yield with the use of biopesticides. The study highlights the need for careful selection and application of biopesticides to optimize crop performance.

4. Conclusion

It can be inferred from the results of the present investigation that the insecticides had no effect on the flowering behavior in Cucumber but caused significant variation in terms of red pumpkin beetle and fruit fly population. The number of damaged fruit and weight percent of fruit infestation (by number and weight) was lowest under *Bacillus thuringensis* followed by Jholmol. The potential effect of botanicals/bio-pesticides can be unraveled when studied under multiple seasons which have been seriously limited in current research. Nevertheless, we must keep in mind that chemical insecticides are detrimental to human health, the environment, and beneficial insects and may lead to long-term problems related to pest resistance and resurgence as well. It is also suggested to use botanicals like Jholmol and *B. thuringiensis* for safe use and to promote the fruit quality in cucurbits. Future studies must prioritize exploring the potential efficacy of botanicals and bio-pesticides against red pumpkin beetle and Fruit fly while decreasing the use of chemical insecticides at the same time.

Author Contributions: Conceptualization: Sangita Badayak, Anjal Nainabasti; Data curation: Anjal Nainabasti; Investigation: Sangita Badayak, Anjal Nainabasti, Binita Bhattarai, Bishesh Subedi, Babin Kharel; Methodology: Anjal Nainabasti, Bishesh Subedi; Software: Anjal Nainabasti, Sangita Badayak; Supervision: Anjal Nainabasti, Sangita Badayak; Validation: Anjal Nainabasti Writing – original draft preparation: Anjal Nainabasti, Sangita Badayak, Bishesh Subedi; Writing – review & editing: Anjal Nainabasti, Bishesh Subedi, Babin Kharel, Sandip Panth. All authors have read and agreed to the published version of the manuscript.

Funding: The authors received no funds from any sources.

Acknowledgment: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Institutional/Ethical Approval: Not applicable.

Data Availability/Sharing: The authors confirm that the data supporting the findings of this study are available within the article (and/or) its supplementary materials.

Supplementary Information Availability: Not applicable.

References

Abrol, D. P., & Shankar, U. (2014). Pesticides, Food Safety and Integrated Pest Management. In Integrated Pest Management (pp. 167–199). Springer Netherlands. https://doi.org/10.1007/978-94-007-7796-5_7

Acharya, N., Seliga, R. A., Rajotte, E. G., Jenkins, N. E., & Thomas, M. B. (2015). Persistence and efficacy of a *Beauveria bassiana* biopesticide against the house fly, *Musca domestica*, on typical structural substrates of poultry houses. *Biocontrol Science and Technology*, 25(6), 697–715. https://doi.org/10.1080/09583157.2015.1009872

Adhikari, J. (2017). Organic farming and its prospects in peri-urban area of Pokhara, Nepal. *Journal of Forest and Livelihood*, 15(2), 19.

Agrawal, N. K., Marechal, J., Leikanger, I., Choudhury, D., Maden, U., Sellmyer, A., Bhatta, L. D., & Datta, K. (2016). Preparation of Jholmal in RMV Pilot Sites: Upscaling a local practice. pp. 1–4.

Archana, H. R., Darshan, K., Lakshmi, M. A., Ghoshal, T., Bashayal, B. M., & Aggarwal, R. (2022). Biopesticides: A key player in agro-environmental sustainability. In Trends of Applied Microbiology for Sustainable Economy (pp. 613–653). Elsevier.

Azad, A. K., Sardar, A., Yesmin, N., Rahman, M., & Islam, S. (2013). Eco-Friendly Pest Control in Cucumber (*Cucumis sativa* L.) Field with Botanical Pesticides. *Natural Resources*, 4(05), 404–409. https://doi.org/10.4236/nr.2013.45050

Bahadur, A. (2023). The potential of the entomopathogenic fungus *Beauveria bassiana* to manage insect pests and diseases. *Natural Resources Conservation and Research*, 6(2), 2543. https://doi.org/10.24294/nrcr.v6i2.2543

Bartaula, S., Adhikari, A., Panthi, U., Karki, P., & Timalsena, K. (2019). Genetic variability, heritability and genetic advance in cucumber (*Cucumis sativus* L.). *Journal of Agriculture and Natural Resources*, 2(1), 215–222. https://doi.org/10.3126/janr.v2i1.26074

Becker, N., Zgomba, M., Ludwig, M., Petric, D., & Rettich, F. (1992). Factors influencing the activity of *Bacillus thuringiensis* var. *israelensis* treatments. *Journal of the American Mosquito Control Association*, 8(3), 285–289.

Bhusal, K., & Udas, E. (2020). A nature-based solution for mountain farming systems. February.

Bravo, A., Gill, S. S., & Soberón, M. (2007). Mode of action of *Bacillus thuringiensis* Cry and Cyt toxins and their potential for insect control. *Toxicon*, 49(4), 423–435. https://doi.org/10.1016/j.toxicon.2006.11.022

Chandi, R. S., Kaur, A., & Aggarwal, N. (2022). Management of red pumpkin beetle, *Aulacophora foveicollis* (Lucas) with traditional method of dusting with dung ash in cucurbits. *Indian Journal of Traditional Knowledge*, 21(1), 208–214. https://doi.org/10.56042/ijtk.v21i1.34310

Chandrakasan, G., Ayala, M. T., García Trejo, J. F., Marcus, G., Maruthupandy, M., Kanisha, C. C., Murugan, M., AL-mekhlafi, F. A., & Wadaan, M. A. (2022). Bio controlled efficacy of *Bacillus thuringiensis* cry protein protection against tomato fruit borer *Helicoverpa armigera* in a laboratory environment. *Physiological and Molecular Plant Pathology*, 119, 101827. https://doi.org/10.1016/j.pmpp.2022.101827

Dara, S. K. (2017). Insect resistance to biopesticides. UCANR E-Journal of Entomology and Biologicals. Available online https://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=25819 (accessed on 10 June 2024).

Dara, S. K. (2024). Entomopathogenic fungi-based biopesticides contribute to more than pest management. UCANR E-Journal of Entomology and Biologicals. Available online https://ucanr.edu/blogs/strawberries-vegetables/index.cfm?start=2 (accessed on 10 June 2024).

Dhakal, R., Ghimire, R., Sapkota, M., Thapa, S., Bhatta, A. K., & Regmi, R. (2019). Bioefficacy of different insecticides on cowpea aphid (*Aphis craccivora* Koch). *International Journal of Entomological Research*, 7(1), 01–07. https://doi.org/10.33687/entomol.007.01.2629

Dhillon, M. K., Singh, R., Naresh, J. S., & Sharma, H. C. (2005). The melon fruit fly, *Bactrocera cucurbitae*: A review of its biology and management. *Journal of Insect Science*, 5(1), 1-10. https://doi.org/10.1093/jis/5.1.40

Dhopte, A. M. (2020). Sustainable dryland farming. Scientific Publishers. "Granthlok" 4806/24, Ansari Road, Bharat Ram Road, Darya Ganj New Delhi 110002 India.

Ene, C. O., Ogbonna, P. E., Agbo, C. U., & Chukwudi, U. P. (2016). Studies of phenotypic and genotypic variation in sixteen cucumber genotypes. *Chilean Journal of Agricultural Research*, 76(3), 307–313. https://doi.org/10.4067/S0718-58392016000300007

Fenibo, E. O., Ijoma, G. N., & Matambo, T. (2022). Biopesticides in Sustainable Agriculture: Current Status and Future Prospects. In New and Future Development in Biopesticide Research: Biotechnological Exploration (pp. 1–53). Springer Nature Singapore. https://doi.org/10.1007/978-981-16-3989-0_1

Glare, T. R., & Nollet, L. M. L. (2015). Types of biopesticides. In Biopesticides handbook (pp. 7–24). CRC Press.

Gomis-Cebolla, J., & Berry, C. (2023). *Bacillus thuringiensis* as a biofertilizer in crops and their implications in the control of phytopathogens and insect pests. *Pest Management Science*, 79(9), 2992–3001. https://doi.org/10.1002/ps.7560

Green, K. K., Stenberg, J. A., & Lankinen, Å. (2020). Making sense of Integrated Pest Management (IPM) in the light of evolution. *Evolutionary Applications*, 13(8), 1791–1805. https://doi.org/10.1111/eva.13067

Gurung, T. R., & Azad, A. K. (2013). Extent and potential use of bio-pesticides for crop protection in SAARC Countries. SAARC Agriculture Centre. Bangladesh Agricultural Research Council Complex, Farmgate, Dhaka, Bangladesh.

Hassain, M. D. S. (2013). Host Preference of Red Pumpkin Beetle (*Aulacophora foveicollis*, Lucas) on different cucurbits. Department of Entomology, Sher-e-Bangla Agricultural University, Dhaka, 1207, Bangladesh.

HGIC. (2021). Cucumber , Squash , Melon & Other Cucurbit Insect Pests. pp. 19.

Homayoonzadeh, M., Esmaeily, M., Talebi, KhalilAllahyari, H., Reitz, S., & Michaud, J. P. (2022). Inoculation of cucumber plants with *Beauveria bassiana* enhances resistance to *Aphis gossypii* (Hemiptera: Aphididae) and increases aphid susceptibility to pirimicarb. *European Journal of Entomology*, 119, 1–11. https://doi.org/10.14411/eje.2022.001

Hossain, M., Yeasmin, F., Rahman, M., Akhtar, S., & Hasnat, M. (2018). Role of insect visits on cucumber (*Cucumis sativus* L.) yield. *Journal of Biodiversity Conservation and Bioresource Management*, 4(2), 81–88. https://doi.org/10.3329/jbcbm.v4i2.39854

Iida, Y., Higashi, Y., Nishi, O., Kouda, M., Maeda, K., Yoshida, K., Asano, S., Kawakami, T., Nakajima, K., Kuroda, K., Tanaka, C., Sasaki, A., Kamiya, K., Yamagishi, N., Fujinaga, M., Terami, F., Yamanaka, S., & Kubota, M. (2023). Entomopathogenic fungus *Beauveria bassiana*–based bioinsecticide suppresses severity of powdery mildews of vegetables by inducing the plant defense responses. *Frontiers in Plant Science*, 14, 1-13. https://doi.org/10.3389/fpls.2023.1211825

Inglis, G. D., Duke, G. M., Kanagaratnam, P., Johnson, D. L., & Goettel, M. S. (1997). Persistence of *Beauveria bassiana* in soil following application of conidia through crop canopies. *Memoirs of the Entomological Society of Canada*, 129(S171), 253–263. https://doi.org/10.4039/entm129171253-1

Islam, M. D. J. (2015). Host preference of red pumpkin beetle, *Aulacophora foveicollis lucas* in different cucurbits. Department of entomology, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh.

Jia, H., & Wang, H. (2021). Introductory Chapter: Studies on Cucumber. In Cucumber Economic Values and Its Cultivation and Breeding. IntechOpen. https://doi.org/10.5772/intechopen.97360

Jouzani, G. S., Valijanian, E., & Sharafi, R. (2017). *Bacillus thuringiensis*: a successful insecticide with new environmental features and tidings. *Applied Microbiology and Biotechnology*, 101(7), 2691–2711. https://doi.org/10.1007/s00253-017-8175-y

Keswani, C., Singh, S. P., & Singh, H. B. (2013). *Beauveria bassiana*: Status, Mode of action, Applications and Safety issues. *Biotech Today*, 3(1), 1-16. https://doi.org/10.5958/j.2322-0996.3.1.002

Khanal, R., & Dhakal, S. C. (2020). Value chain analysis of cucumber in Arghakhanchi, Nepal. *Journal of Agriculture and Forestry University*, 4(1), 295–302. https://doi.org/10.3126/jafu.v4i1.47102

Kumar, P., Kamle, M., Borah, R., Mahato, D. K., & Sharma, B. (2021). *Bacillus thuringiensis* as microbial biopesticide: uses and application for sustainable agriculture. *Egyptian Journal of Biological Pest Control*, 31(1), 95. https://doi.org/10.1186/s41938-021-00440-3

Maligimani, P. (2024). Bioefficacy and residues of imidacloprid and spiromesifen in/on cucumber (*Cucumis sativus* L.). *The Pharma Innovation Journal*, 12(12), 1446-1451.

Mallick, P. K. (2022). Evaluating Potential Importance of Cucumber (*Cucumis sativus* L. -Cucurbitaceae): A Brief Review. *International Journal of Applied Sciences and Biotechnology*, 10(1), 12–15. https://doi.org/10.3126/ijasbt.v10i1.44152

Miah, M. R. (2018). Damage Potentiality and Eco-Friendly Management of Red Pumpkin Beetle and Cucurbit Fruit Fly on Squash Vegetable. Department of Entomology, Sher-E-Bangla Agricultural University, Dhaka-1207, Bangladesh.

MoALD. (2023). Statistical Infromation on Nepalese Agriculture 2078/79. Government of Nepal, Ministry of Agricultural Development, Agribusiness Promotion and Statistics Division, Agri Statistics Section: Kathmandu, Nepal.

Palma, L., Muñoz, D., Berry, C., Murillo, J., & Caballero, P. (2014). *Bacillus thuringiensis* Toxins: An Overview of Their Biocidal Activity. *Toxins*, 6(12), 3296–3325. https://doi.org/10.3390/toxins6123296

Papadopoulos, N. T., De Meyer, M., Terblanche, J. S., & Kriticos, D. J. (2024). Fruit Flies: Challenges and Opportunities to Stem the Tide of Global Invasions. *Annual Review of Entomology*, 69, 355–373. https://doi.org/10.1146/annurev-ento-022723-103200

Patel, D. R., Patel, R. M., Patel, P. H., & Dabhi, M. V. (2021). Evaluation of Different Botanicals against Red Pumpkin Beetle, *Aulacophora foveicollis* Lucas Infesting Cucumber. *International Journal of Current Microbiology and Applied Sciences*, 10(2), 3133–3140. https://doi.org/10.20546/ijcmas.2021.1002.343

Pedrini, N. (2022). The Entomopathogenic Fungus *Beauveria bassiana* Shows Its Toxic Side within Insects: Expression of Genes Encoding Secondary Metabolites during Pathogenesis. *Journal of Fungi*, 8(5), 488. https://doi.org/10.3390/jof8050488

Prabha, S., Yadav, A., Kumar, A., Yadav, A., Yadav, H. K., Kumar, S., Yadav, R. S., & Kumar, R. (2016). Biopesticides - An alternative and eco-friendly source for the control of pests in agricultural crops. *Plant Archives*, 16(2), 902–906.

Radames, T. V., Sánchez Acosta, L., Fortis Hernández, M., Preciado Rangel, P., Gallegos Robles, M. Á., Antonio Cruz, R. del C., & Vázquez Vázquez, C. (2018). Effect of Seaweed Aqueous Extracts and Compost on Vegetative Growth, Yield, and Nutraceutical Quality of Cucumber (*Cucumis sativus* L.) Fruit. *Agronomy*, 8(11), 264. https://doi.org/10.3390/agronomy8110264

Rani, A. T., Kammar, V., Keerthi, M. C., Rani, V., Majumder, S., Pandey, K. K., & Singh, J. (2021). Biopesticides: An Alternative to Synthetic Insecticides. In Microbial Technology for Sustainable Environment (pp. 439–466). Springer Singapore. https://doi.org/10.1007/978-981-16-3840-4_23

Ratnadass, A., Fernandes, P., Avelino, J., & Habib, R. (2012). Plant species diversity for sustainable management of crop pests and diseases in agroecosystems: a review. *Agronomy for Sustainable Development*, 32(1), 273–303. https://doi.org/10.1007/s13593-011-0022-4

Redmond, C. T., Wallis, L., Geis, M., Williamson, R. C., & Potter, D. A. (2020). Strengths and limitations of *Bacillus thuringiensis galleriae* for managing Japanese beetle (*Popillia japonica*) adults and grubs with caveats for cross-order activity to monarch butterfly (*Danaus plexippus*) larvae. *Pest Management Science*, 76(2), 472–479. https://doi.org/10.1002/ps.5532

Rogers, M. A. (2012). Efficacy of biopesticides for organic management of cucumber beetles. Doctoral dissertation at the University of Tennessee. Available online: https://trace.tennessee.edu/utk_graddiss/1556 (accessed on 10 June 2024).

Roh, J. Y., Choi, J. Y., Li, M. S., Jin, B. R., & Je, Y. H. (2007). *Bacillus thuringiensis* as a specific, safe, and effective tool for insect pest control. *Journal of Microbiology and Biotechnology*, 17(4), 547–559.

Sampiano, K. F. (2022). Plant Diversification with Biopesticide Application in the Production of Cucumber (Cucumis sativus Linn.) under Carmen, Davao del Norte Conditions. *Journal of Multidisciplinary Studies*, 11(1). https://doi.org/10.62249/jmds.2013.2419

Sapkota, R., Dahal, K. C., & Thapa, R. B. (2010). Damage assessment and management of cucurbit fruit flies in spring-summer squash. *Journal of Entomology and Nematology*, 2(1), 7–012.

Sayed, A. M. M., & Behle, R. W. (2017). Evaluating a dual microbial agent biopesticide with *Bacillus thuringiensis* var. kurstaki and *Beauveria bassiana* blastospores. *Biocontrol Science and Technology*, 27(4), 461–474. https://doi.org/10.1080/09583157.2017.1303662

Sharma, A., Rana, C., & Shiwani, K. (2016). 19 Important Insect Pests of Cucurbits and Their Management. In book: Handbook of Cucurbits: Growth, Cultural Practices and Physiology, CRC Press.

Skinner, M., Parker, B. L., & Kim, J. S. (2014). Role of Entomopathogenic Fungi in Integrated Pest Management. In Integrated Pest Management (pp. 169–191). Elsevier. https://doi.org/10.1016/B978-0-12-398529-3.00011-7

Sorathiya, K., Sorathiya, K., Kalariya, S., & Patel, L. (2023). Development and Evaluation of a Liquid Formulation of Trichoderma viride as a Bio-Pesticide for Pest Management. *International Journal of Applied Sciences and Biotechnology*, 11(2), 60–65. https://doi.org/10.3126/ijasbt.v11i2.56119

Srivastava, R. M., & Joshih, S. (2021). Integrated pest management for cucurbits in cucumber (Cucumis sativus L.). *Cucumber Economic Values and Its Cultivation and Breeding*, 1(5), 1–10.

Subedi, S., Bhandari, N., Basnet, M., Pradhan, N. G., & Gautam, I. P. (2024). Evaluation of cucumber genotypes under plastic house and open field conditions in Lalitpur, Nepal. *Cogent Food & Agriculture*, 10(1). https://doi.org/10.1080/23311932.2023.2298531

Tetreau, G., Andreeva, E., Banneville, A.-S., De Zitter, E., & Colletier, J.-P. (2021). How Does *Bacillus thuringiensis* Crystallize Such a Large Diversity of Toxins? *Toxins*, 13(7), 443. https://doi.org/10.3390/toxins13070443

Thapa, R., Nainabasti, A., Lamsal, A., Malla, S., Thapa, B., Subedi, Y., & Ghimire, S. (2022). Pesticide Persistence in Agriculture and its hazardous effects on Environmental Components. *International Journal of Applied Sciences and Biotechnology*, 10(2), 75–83. https://doi.org/10.3126/ijasbt.v10i2.45095

Toledo, J., Liedo, P., Flores, S., Campos, S. E., Villaseñor, A., & Montoya, P. (2007). Use of *Beauveria bassiana* and Metarhizium anisopliae for fruit fly control: a novel approach. *Proceedings of the 7th International Symposium on Fruit Flies of Economic Importance*, 2, 127–132.

Tomar, P., Thakur, P., Singh, S., Shreaz, S., Rustagi, S., Kumar Rai, P., Yadav, A., & Yadav, A. N. (2024). Biological control of tephritid fruit flies *Bactrocera* spp. in Himachal Pradesh, India. *Plant Science Today*, 11(3), 314-319. https://doi.org/10.14719/pst.3215

Wang, H., Peng, H., Li, W., Cheng, P., & Gong, M. (2021). The Toxins of *Beauveria bassiana* and the Strategies to Improve Their Virulence to Insects. *Frontiers in Microbiology*, 12, 1-10. https://doi.org/10.3389/fmicb.2021.705343

Wei, Q.-Y., Li, Y.-Y., Xu, C., Wu, Y.-X., Zhang, Y.-R., & Liu, H. (2020). Endophytic colonization by *Beauveria bassiana* increases the resistance of tomatoes against *Bemisia tabaci*. *Arthropod-Plant Interactions*, 14(3), 289–300. https://doi.org/10.1007/s11829-020-09746-9