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Effectiveness of Microbial and Plant Extracts for Pest and Disease Management in Cucumber Production in Abuja Region of Nigeria

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Abstract

Abstract

Cucumber is an essential crop in Nigeria predominantly produced by smallholder farmers. Its yield is often hindered by pests and diseases and exacerbated by the reliance on chemical treatments that pose environmental risks. This study addresses the research gap regarding the effectiveness of microbial and plant extracts for pest and disease management in Nigeria for cucumber production. A randomised complete block design was employed to compare the performance of T_1 (*Bacillus pumilus*), T_2 (*Isaria fumosorosea*), T_3 (mixture of T_1 and T_2), T_4 (neem oil), T_5 (fermented neem leaf extract), T_6 (mixture of T_4 and T_5) and T_7 (control with water) in field and pot environments. The study observed pest and disease incidence, growth and yield parameters. The best treatments for pest control were T_2 (1.92) and T_5 (2.08) while the least effective treatments were T_1 (4.71) and T_4 (6.17) pest population plant^{-1}, while T_6 was effective in downy mildew and bacterial wilt management with a value of 2.46 and 2.17, respectively, with the highest disease score recorded in T_2 with a value of 3.17 and 2.75 for downy mildew and bacterial wilt respectively. The environmental conditions affected the field (11.99 t ha^{-1} and 3.19) significantly. They favoured higher fruit yield and quality compared to the pot (2.20 t ha^{-1} and 2.44) with T_4 (7.94 t ha^{-1}) and T_1 (10.10 t ha^{-1}) treatments having the highest yield while the lowest of 4.83 t ha^{-1} was recorded in T_6. The study concludes that environmental conditions play crucial role in the efficacy of treatments.

Keywords: *Bacillus*, Bacterial wilt, Cucumber, Downy mildew, *Erwinia*, Neem

Introduction

Originating from India, the cucumber (*Cucumis sativus* L.) is a key cucurbit crop, second only to watermelon in global cultivation (Pal *et al.*, 2020; Yadav *et al.*, 2024). Cucumbers cover 2.2 million hectares worldwide, yielding 94.7 million tons, with China leading at 1.3 million hectares for 77.3 million tons of production (Sallam *et al.*, 2021).

Egypt leads cucumber production with 0.484 million tons, while Cameroon has the largest area at 0.278 million hectares. In Nigeria, smallholder farmers dominate production with sparse production data (Okafor and Yaduma, 2021). It is vital for fresh consumption and cosmetics but suffers low yields due to abiotic and biotic stress causing up to 26% loss (Oke *et al.*, 2020; Okafor and Yaduma, 2021).

Among the biotic stresses, downy mildew and bacterial wilt are key diseases impacting cucumbers (Gabriel-Ortega *et al.*, 2020; Atiq *et al.*, 2022), causing over 40% of global yield losses (Arogundade *et al.*, 2021; Bondarenko *et al.*, 2021). The downy mildew pathogen, *Pseudoperonospora cubensis*, affects over 60 cucurbit species (Salcedo *et al.*, 2020; Sun *et al.*, 2022). High moisture from rainfall and irrigation fosters its spread, a concern given cucumbers' high water needs (Bondarenko *et al.*, 2022).

Cucumber downy mildew symptoms manifest as angular, water-soaked spots on leaf undersides, progressing from chlorosis to necrosis, leading to leaf death and susceptibility

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varies by cultivar (Salcedo *et al.*, 2020).

After downy mildew, bacterial wilt caused by *Erwinia tracheiphila* is another major disease impacting cucumber cultivation, which is spread by striped (*Acalymma vittatum*) and spotted (*Diabrotica undecimpunctata*) cucumber beetles. These beetles feed on infected plants or plant debris harbouring overwintered bacterial inocula, facilitating the disease's rapid spread to healthy plants. The bacteria overwinter in the insects' gut (Acharya *et al.*, 2021). Common symptoms include leaf wilting, dull green leaf colour, flaccid infected leaves, stem and vine wilting and sudden plant death (Atiq *et al.*, 2022).

Insects significantly reduce cucumber yields through leaf damage (chewing, sucking, piercing, *etc.*) (Messelink *et al.*, 2020). They can spread fungal spores (Islam *et al.*, 2021), bacterial inoculum (as in the case of the striped beetle and *Erwinia tracheiphila*) (Kaur, 2023) and viruses (Qi *et al.*, 2021). This weakens the plant and reduces its photosynthetic ability, leading to considerable yield loss. Infested leaves also create a favourable environment for bacterial and fungal pathogen colonization (Balla *et al.*, 2021).

Eco-friendly management methods are crucial for managing diseases like downy mildew, bacterial wilt and insect pests in cucumber production (Jaiswal *et al.*, 2022). Current control methods include synthetic chemicals, disease-resistant varieties and biocontrol (van Lenteren *et al.*, 2020). Chemical control, involving various fungicides and insecticides, is widely used (Srivastava and Joshih, 2021; Uebbing, 2023). However, concerns exist about the emergence of resistant organisms (Yang *et al.*, 2020; Costa *et al.*, 2023) and the cost for farmers in sub-Saharan Africa (Nyambo *et al.*, 2022). Additionally, environmental and food safety issues arise due to pesticide residues.

Eco-friendly pesticides can significantly mitigate pests and diseases in cucumber production (Jaiswal *et al.*, 2022). Safe alternatives to chemicals, such as plant extracts and microbial products, are being explored to control pathogens and disease vectors in cucumbers (Huang *et al.*, 2021). Biocontrol uses competition, antagonism and microbial metabolites to manage pests and diseases (Boro *et al.*, 2022). Bio-control bacteria like *Pseudomonas* species (Fira *et al.*, 2018), *Bacillus* species (Durojaye and Agu, 2019) and fungi like *Trichoderma* species, atoxigenic *Aspergillus flavus* (Ortega-Beltran *et al.*, 2019) have shown efficacy against agricultural pests and diseases. Botanicals also provide farmers with local resources for pest and disease control as those from trees and shrubs contain compounds effective for pest and disease control (Lengai *et al.*, 2020). Trees like neem (Sharma *et al.*, 2023b), bitter leaf, eucalyptus, *etc.* are potential sources of pest repellents, but the correct dosage is unclear (Hossain, 2020). Efficient cucumber pest management can be achieved through integrated approaches like prevention, cultural practices, resistant cultivars, systemic fungicides and biological agents (Haq and Ijaz, 2020).

Research on microbial and plant extracts for pest management in cucumbers is limited in the Nigerian context. This study aims to address this gap by assessing the effectiveness of specific extracts in managing cucumber pests and diseases in Abuja, contributing to sustainable agriculture in the region.

Materials and Methods

Description of the Study Area

The study took place at Be the Help Foundation Agroforestry in Kwali Area Council, Abuja, Nigeria (08°49'24.51" N, 06°56'27.2" E). The field was prepared for cucumber cultivation. For the pot experiment, 35 cm by 20 cm polythene bags were filled with topsoil.

Experimental Design and Layout

This study used a randomized complete block design (RCBD) with seven treatments, each replicated thrice. Treatments were randomly allocated to plots for uniform distribution (Durojaye *et al.*, 2019).

Seedling Preparation and Transplanting

Mid-early maturing Stilo cucumber seeds were sourced from Abuja agro-dealers. Seeds were sown in seedling trays (50 cm × 30 cm × 4 cm) filled with sterilized coco peat and placed in a nursery screenhouse for optimal growth until uniform emergence. After two weeks, seedlings were transplanted on both sides of a 30 cm high ridge, spaced 50 cm apart within rows in the open field (Ansa and Garjila, 2019) and in pots filled with topsoil at other locations, replicated thrice. The cucumbers were trellised (Keinath, 2019), watered, mulched and monitored until disease symptoms and pest invasion occurred naturally.

Treatments

This study used two commercial microbial agents from SCL Nigeria's biopesticide lab: *Bacillus pumilus* (T_1), *Isaria fumosorosea* (T_2) and their mixture (T_3). Two local botanical extracts were also used: neem oil (T_4), fermented neem leaf (T_5) and their mixture (T_6). Water was used as a control (T_7).

Treatment Sources and Preparation

Two kilograms of matured neem leaves were collected, washed, chopped and soaked in 5 litres of water for 48 hours. The mixture was filtered through cheesecloth and the filtrate was diluted to 10 litres for plant spraying (Hossain, 2020). Locally prepared neem oil was sourced from a northern Nigerian agricultural market among rural smallholder farmers and biopesticides were procured from the SCL laboratory in Abuja.

The Application Rate of Treatments

The application rate for T_1 was 4 ml L^{-1} of water, while T_2 was 6 ml L^{-1} of water, T_3 is an equal volume of T_1 and T_2, T_4 was 2 ml L^{-1} of water, T_5 was 16.7% wv^{-1} of neem leaves and water, T_6 was a mixture of equal concentration of T_5 and T_6 and T_7 was water application as a control treatment. The individual treatments were dispensed in a separate sprayer with proper labelling on each cucumber plant as tagged 21 days after planting (DAP) with water only as the treatment on the control cucumber. The treatments were applied using a hand sprayer. All treatments were applied during the late evening hours to lessen potential stress on the microbes and faster acclimatisation to the environment due to longer humidity periods (Singh *et al.*, 2019).

Each of the treatments was applied three times during the cucumber vegetative growth period on the cucumber leaf till run off (Durojaye *et al.*, 2019), at one-week intervals in both locations starting from 7 days after transplanting (DAT). The fields were surveyed daily to monitor signs and symptoms of pest infestation and disease occurrence.

Data Collection and Observation

Specific cucumber plants were chosen and marked for data collection in each trial location. The research parameters fell into three categories: disease and pest infestation, cucumber plant vegetative and reproductive parameters.

Disease Assessment

Disease severity was gauged every 7 days starting 21 DAT. Cucumber leaves were periodically checked for downy mildew and bacterial wilt symptoms.

Modified Downy Mildew Severity Scale according to Call (2012) where:

1. No lesions
2. Small chlorotic lesions (1-2 mm), < 10% leaf area, no sporulation
3. Small lesions (2-3 mm), 10% leaf area, negligible sporulation
4. Chlorotic lesions (3-5 mm), 10-20% leaf area, weak sporulation
5. Chlorotic lesions (6-10 mm), 50% leaf area, moderate sporulation
6. Partially necrotic lesions (6-10 mm), 50-75% leaf area, heavy sporulation
7. 75% leaf necrosis, moderate sporulation due to necrosis

Bacterial Wilt Severity Scale Modified from Winstead and Kelman (1952):

1. No wilting
2. One leaf partially wilted
3. Two or three leaves wilted
4. All but two or three leaves wilted
5. All leaves wilted
6. Plant death

Pest Infestation Parameters

Infestation levels were determined by the presence of active insects on a leaf. Data was collected at pre-treatment, 2 and 4 days post-treatment at cycles 7, 14 and 21 DAT. Selected cucumber leaves from each tagged plant were examined. Parameters recorded included counts of aphids, mites, spiders, beetles, mantis and the number of damaged and infested leaves plant^{-1}.

Growth and Yield Parameters Evaluation

Growth parameters such as plant height, leaf count, vine length, primary branch count, leaf length and leaf width were recorded. Yield parameters including fruit counts, fruit count plant^{-1}, fruit length, fruit width and yield (kg plant^{-1}) were also noted. Fruit quality from each treatment plot was assessed physically based on pest and disease damage, attractiveness and bulkiness. It was rated on a scale of 1 to 5 (Akinwole *et al.*, 2019), where:

1. Very Poor
2. Poor
3. Fair
4. Good
5. Excellent

Statistical Analysis

Data from the experiments were analysed using SPSS (Version 26) and R-Studio (Version 4.3.2). Where significant differences were found, means were differentiated using Duncan's Multiple Range Test (DMRT) and Least Significant Difference (LSD) at a significance level of $p \leq 0.05$.

Results and Discussion

Effect of Treatments on the Population of Pest

The observed pooled data on the number of insects before treatment showed no significant difference among the treatments across the two locations, the highest value was observed in T_2, T_7, T_5, T_4, T_3, T_1 and T_6 and these values were found to be statistically at par. There were different infestation levels for the interaction between the individual treatments and the locations before treatment application on the cucumbers at individual plots across the two locations, the insect population at the field was higher than that of the pot studies for each treatment and this also presented a statistical difference for the values recorded for insect for the treatments with interaction to their respective location. However, there were significant differences at $p<0.01$ between the two locations as the pooled average number of insects was 3.29 and 0.60 for the field and pot respectively at pre-application of the first treatment (Table 1).

At two days post-application of the first treatments, there were no significant differences between the treatments and treatments by location interaction. Still, there were substantial differences between the insect population in the locations at $p<0.01$, with the open field having a value of 2.8 and 0.48 for the pot studies. For the pooled mean across the two locations, the highest value was observed in T_3, T_4, T_5, T_7, T_2, T_1 and T_6, which were found to be statistically at par with it (Table 1). This pattern was similar for the three spraying cycles as there were only significant differences at the locations and no differences in the pooled mean of the treatments and treatment by location interaction with T_4 (neem oil), T_1 (*Bacillus pumilus* biopesticide) and T_7 (control) having the highest pest population at three days after the application (DAA) of pesticides during the third spraying cycles, whereas the medium pest population was recorded in T_3 (mixture of *Bacillus pumilus* and *Isaria fumosorosea* biopesticide) and T_6 (mixture of neem oil and neem leaf

Table 1: Effects of different biological and botanical treatments on total insect population in cucumber plants grown in two locations

Factors		1st Application			2nd Application			3rd Application		
		Pre-application	2 DAA	4 DAA	Pre-Application	2 DAA	4 DAA	Pre-application	2 DAA	4 DAA
Location	Open field	3.286±0.2773^{a}	2.821±0.4327^{a}	5.976±0.8443^{a}	6.476±0.7765^{a}	7.452±0.9243^{a}	10.905±1.5448^{a}	7.595±1.7811^{a}	5.238±1.1305^{a}	5.869±1.5019^{a}
	Pot	0.595±0.1124^{b}	0.476±0.1219^{b}	0.738±0.178^{b}	1.643±0.2467^{b}	1.214±0.1603^{b}	1.548±0.2864^{b}	2.143±0.2848^{b}	1.5±0.2012^{b}	0.976±0.1672^{b}
LSD (0.05)		0.6439	0.8465	1.5988	1.6578	1.607	2.72	3.6712	2.2212	2.9215
SEm		0.2215	0.2912	0.55	0.5703	0.5528	0.9357	1.2629	0.7641	1.005
F value		73.743**	32.422**	45.3454**	35.9179**	63.6668**	50.0009**	9.3193**	11.9678**	11.8501**
CV%		52.32	80.95	75.08	64.3744	2.1723	68.8693	118.8639	103.9291	134.5675
Treatment	T_1	1.667±0.6667	1.083±0.5231	5.792±2.5136^{a}	4.417±1.599^{a}	6.458±2.6144^{a}	9.25±3.9492^{ab}	4.833±2.1473^{a}	4.25±1.5097^{a}	4.708±2.06^{a}
	T_2	2.583±0.8002	1.417±0.5069	3.667±1.7638^{ab}	3.417±0.7897^{a}	3.917±1.63^{ab}	4.583±2.1386^{ab}	3.75±1.0859^{a}	1.75±0.7042^{a}	1.917±0.7897^{a}
	T_3	1.833±0.8628	2.417±1.5621	3.083±1.2478^{ab}	2.917±0.9951^{a}	3.333±0.9972^{ab}	3.917±1.5938^{b}	3.25±1.2433^{a}	2.5±1.2042^{a}	2.667±1.4181^{a}
	T_4	1.917±0.5069	2.25±0.8827	2.167±0.9006^{b}	4.083±1.4912^{a}	4.417±1.9934^{ab}	9.833±4.4771^{a}	7.417±4.3597^{a}	5.167±3.0894^{a}	6.167±4.6827^{a}
	T_5	2.083±0.7897	1.708±0.6404	2.292±0.7969^{b}	3.583±1.3627^{a}	2.958±1.0377^{b}	4.167±1.9264^{ab}	3.333±1.1081^{a}	2.083±0.3745^{a}	2.083±0.8002^{a}
	T_6	1.333±0.5725	1.0±0.3416	2.75±1.2093^{ab}	4.25±1.2633^{a}	5.083±2.158^{ab}	6.167±2.7101^{ab}	4.25±1.9181^{a}	3.417±0.9435^{a}	2.417±1.3504^{a}
	T_7	2.167±0.7491	1.667±0.3575	3.75±2.0726^{ab}	5.75±2.5747^{a}	4.167±2.0276^{ab}	5.667±2.1082^{ab}	7.25±4.5767^{a}	4.417±2.5541^{a}	4.0±2.4597^{a}
LSD (0.05)		1.2049	1.584	2.9913	3.1014	3.0064	5.0886	6.8683	4.1552	5.466
SEm		0.4145	0.5449	1.029	1.0669	1.0342	1.7505	2.3627	1.4294	1.8803
F value		0.9124^{NS}	0.9822^{NS}	1.4438^{NS}	0.7275^{NS}	1.2741^{NS}	1.8898^{NS}	0.5606^{NS}	0.8269^{NS}	0.7147^{NS}
CV%										
Treatment × Location	Field T_1	3.0±0.5774^{ab}	1.83±0.8333^{bcd}	11.25±1.299^{a}	7.0±2.3094^{ab}	12.25±0.7217^{a}	18.0±1.1547^{a}	8.0±3.4641^{a}	7.5±0.866^{ab}	8.75±2.1651^{ab}
	Field T_2	4.33±0.3333^{a}	2.333±0.6009^{abcd}	7.0±2.0817^{b}	4.5±0.7638^{abc}	6.5±2.5^{b}	8.0±3.2146^{bc}	4.667±2.0883^{a}	2.667±1.2019^{ab}	3.167±1.1667^{ab}
	Field T_3	3.33±1.2019^{ab}	4.667±2.6667^{a}	5.5±1.3229^{bcd}	4.667±1.3333^{abc}	5.5±0.5^{bc}	6.333±2.6034^{bc}	4.5±2.4664^{a}	3.333±2.4037^{ab}	3.833±2.8916^{ab}
	Field T_4	2.833±0.441^{ab}	4.167±0.3333^{ab}	4.0±0.7638^{bcde}	6.833±1.7638^{ab}	7.667±2.9059^{b}	17.667±6.1734^{a}	12.0±8.544^{a}	8.667±5.9184^{a}	11.167±9.1712^{a}
	Field T_5	3.67±0.727^{ab}	3.083±0.2205^{abc}	3.583±1.0833^{bcde}	6.0±1.7559^{abc}	4.583±1.6223^{bc}	7.667±2.4889^{bc}	5.167±1.4814^{a}	2.167±0.6009^{ab}	3.167±1.424^{ab}
	Field T_6	2.17±0.928^{bc}	1.5±0.2887^{cd}	4.67±1.8559^{bcde}	7.0±0.2887^{ab}	8.833±3.0322^{ab}	10.333±4.3333^{b}	7.5±2.7839^{a}	4.667±1.6915^{ab}	4.167±2.421^{ab}
	Field T_7	3.67±0.6667^{ab}	2.167±0.6009^{bcd}	5.833±4.0859^{bc}	9.333±4.4845^{a}	6.833±3.6553^{b}	8.333±3.7565^{bc}	11.333±9.3734^{a}	7.667±4.6756^{ab}	6.833±4.6934^{ab}
	Pot T_1	0.333±0.333^{c}	0.333±0.3333^{d}	0.333±0.3333^{e}	1.833±0.8819^{c}	0.667±0.3333^{c}	0.5±0.2887^{c}	1.667±1.0138^{a}	1.0±0.2887^{b}	0.667±0.441^{b}
	Pot T_2	0.833±0.167^{c}	0.5±0.2887^{d}	0.333±0.3333^{e}	2.333±1.1667^{bc}	1.333±0.6009^{c}	1.167±0.928^{c}	2.833±0.8333^{a}	0.833±0.441^{b}	0.667±0.441^{b}
	Pot T_3	0.333±0.167^{c}	0.167±0.1667^{d}	0.667±0.441d^{e}	1.167±0.3333^{c}	1.167±0.1667^{c}	1.5±0.2887^{c}	2.0±0.2887^{a}	1.667±0.8819^{b}	1.5±0.5774^{b}
	Pot T_4	1.0±0.5^{c}	0.333±0.3333^{d}	0.333±0.3333^{e}	1.333±0.6667^{c}	1.167±0.928^{c}	2.0±0.866^{c}	2.833±1.0138^{a}	1.667±0.6667^{b}	1.167±0.7265^{b}

Table 1: Continue...

Factors		1st Application			2nd Application			3rd Application		
		Pre-application	2 DAA	4 DAA	Pre-Application	2 DAA	4 DAA	Pre-application	2 DAA	4 DAA
	Pot T_5	0.5±0.2887[c]	0.333±0.3333[d]	1.0±0.5774[de]	1.167±0.6009[c]	1.333±0.3333[c]	0.667±0.3333[c]	1.5±0.7638[a]	2.0±0.5774[ab]	1.0±0.1[b]
	Pot T_6	0.5±0.2887[c]	0.5±0.5[d]	0.833±0.441[de]	1.5±0.5774[c]	1.333±0.1667[c]	2.0±0.7638[c]	1.0±0.2887[a]	2.167±0.1667[ab]	0.667±0.441[b]
	Pot T_7	0.667±0.3333[c]	1.167±0.1667[cd]	1.667±0.6667[cde]	2.167±0.441[bc]	1.5±0.2887[c]	3.0±1.0[bc]	3.167±0.441[a]	1.167±0.441[b]	1.167±0.441[b]
SEm		0.5861	0.7706	1.4553	1.5088	1.4626	2.4756	3.3414	2.0215	2.6591
F value		0.6931[NS]	1.6305[NS]	1.8529[NS]	0.5613[NS]	1.7435[NS]	2.1177[NS]	0.3586[NS]	0.9809[NS]	0.6896[NS]
CV%										

[Means followed by different letters within each column are significantly different, DMRT (p≤0.05). DAA: Days after application, LSD: Least significant difference, Sem: Standard error mean, CV: Coefficient of variation, *Significant at 5% level of significance, **Significant at 1% level of significance, NS: Not-significant] extract) with the lowest pest population recorded in T_5 (fermented neem leaf extract) and T_2 (*Isaria* biopesticide) (Table 1).

In the studies of Saleem *et al.* (2019), where neem oil was used with other biopesticides to control aphids and mite infestations in hydroponic cucumbers, it was reported that neem oil has the lowest efficacy among the considered treatments indicating that the efficacy of neem oil as a potential biopesticide is low which was also confirmed in this study as it has the highest population of pests than other treatments and the control as well. Kahia *et al.* (2021) reported *Bacillus pumilus* as one of the most effective biopesticides used in controlling aphids in cucumber plants; however, findings in this study do not agree with that as the pest population in T_1 (*Bacillus pumilus* biopesticide) is even greater than the control T_7. A combination of two different biopesticides as we have in T_3 (mixture of *Bacillus pumilus* and *Isaria fumosorosea* biopesticide) and T_6 (mixture of neem oil and fermented neem leaf extract) offer a moderate population reduction in pests as this was in support of the study of Kahia *et al.* (2021), where the treatment that combined *Bacillus pumilus* and *Bacillus subtilis* had a moderate effect on aphid population and mortality, this same observation was reported by Ahmed *et al.* (2020) that combination of *Coccinella septempunctata* and *Chrysoperla carnea* biopesticides was moderately effective in pest population reduction compared to a single application. The combination of plant extracts was also reported by Ali *et al.* (2015) to offer moderate protection to plants against wheat aphids when compared with single extracts. The reason for this can be attributed to the non-synergistic properties of some of the botanical extracts and biopesticides' bioactive metabolites when combined (Dassanayake *et al.*, 2021).

The efficacy of *Isaria* biopesticide in reducing pest population from this study is also similar and aligns with the studies of Tian *et al.* (2015), who reported that *Isaria fumosorosea* is a good entomopathogenic fungus of whiteflies.

The fermented neem leaf extract has been reported to be a potential source of bioinsecticide to combat aphids, thrips and mites in cucumber and vegetable production, from this study it can be confirmed that the usage of neem leaf extract is a good alternative and eco-friendly material which can be considered in integrated pest control as it was reported in the studies of Alam *et al.* (2019) and Sultana *et al.* (2020) that neem leaf is the best among their considered treatments for the control of tomato leaf miners and cucurbit fruit fly (*Bactrocera cucurbitae*) in cucumber and the findings from this study are also in agreement.

However, it was discovered that the pest population was lower in both locations at 2 DAA of treatments at spraying cycles 1 and 3, while there was a peak in pest population at spraying cycle 2 as shown in figure 1. These results suggest that the locations (field vs. pot) play a significant role in the pest population. The treatments, on the other hand, did not show a significant difference in their effect on the pest population. It would be interesting to further investigate why the pest population peaked at spraying cycle 2 and whether this pattern holds for other crops or conditions.

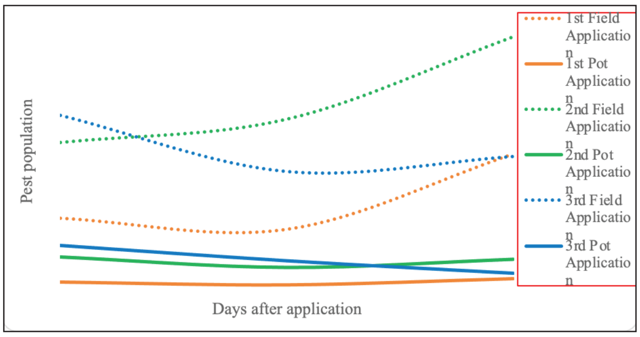

Figure 1: Pest population trend in three cycles of treatment application in cucumber plants across two locations

The initial lack of significant differences among treatments suggests that the pest population may be influenced by factors other than the biopesticides and botanical extracts alone. The observed peak in pest population at the second spraying cycle could be due to a variety of factors, including pest life cycles, environmental conditions, or even the development of resistance. The findings that neem oil and *Bacillus pumilus* did not perform as effectively as expected when compared to previous studies highlight the complexity of pest control and the potential influence of local conditions on treatment efficacy. This discrepancy warrants further investigation into the local pest populations, their resistance mechanisms and the specific strains of biopesticides used.

The moderate reduction in pest population by combined treatments suggests that there may be non-synergistic interactions at play. Investigating the biochemical pathways and interactions between the bioactive compounds could provide valuable insights into optimizing these combinations for better pest control. The effectiveness of *Isaria* biopesticide aligns with previous research, reinforcing its potential as an entomopathogenic agent. Further studies could focus on its application rates, frequency and combination with other biocontrol agents to maximize its efficacy. The confirmation of neem leaf extract as an effective and eco-friendly option for pest control is promising. Given its accessibility and low cost, it could be a viable option for smallholder farmers.

Effects of Different Treatments on Downy Mildew and Bacterial Wilt Disease Severity

The severity of downy mildew after the application of different biopesticides in three different phases showed that there is no significant difference between the treatments, locations and interaction between the location and treatment at the first and second application cycles, but there is a significant difference after the third treatment application as shown in table 2. For the mildew severity rating after the first treatment application, the average severity rating recorded in the field and pot were both 2.51 and not statistically different from each other. The highest severity value was observed in T_3, T_5, T_7, T_2, T_6, T_4 and T_1 without any statistical difference at the first and second cycles of application.

At the third rating, the highest downy mildew severity value of 3.2 was observed in the field while the pot was lower with a value of 2.6 and there are significant differences

Table 2: Effects of different biological and botanical treatments on disease severity in cucumber plants grown in two locations

Factors		DM 21 DAT	DM 28 DAT	DM 35 DAT	BW 35 DAT
Location	Open field	2.51±0.16^{a}	2.69±0.16^{a}	3.20±0.17^{a}	1.07±0.05^{b}
	Pot	2.51±0.09^{a}	2.60±0.08^{a}	2.60±0.08^{b}	3.82±0.21^{a}
LSD (0.05)		0.3381	0.3613	0.4279	0.4828
SEm		0.1163	0.1243	0.1472	0.1661
F value		0.0002^{NS}	0.2599^{NS}	8.3441**	137.1155**
CV%		21.2156	21.579	23.2956	31.1068
Treatment	T_1	2.08±0.19^{a}	2.25±0.13^{a}	2.75±0.13^{a}	2.33±0.63^{a}
	T_2	2.58±0.14^{a}	2.79±0.21^{a}	3.17±0.44^{a}	2.75±0.68^{a}
	T_3	2.79±0.24^{a}	2.92±0.23^{a}	3.04±0.25^{a}	2.29±0.72^{a}
	T_4	2.25±0.20^{a}	2.33±0.19^{a}	2.75±0.21^{a}	2.75±0.74^{a}
	T_5	2.79±0.34^{a}	2.81±0.34^{a}	3.02±0.33^{a}	2.58±0.74^{a}
	T_6	2.29±0.16^{a}	2.38±0.14^{a}	2.46±0.15^{a}	2.17±0.56^{a}
	T_7	2.79±0.26^{a}	3.00±0.26^{a}	3.08±0.30^{a}	2.25±0.66^{a}
LSD (0.05)		0.6326	0.6762	0.8006	0.9032
SEm		0.2176	0.2326	0.2754	0.3107
F value		1.9038^{NS}	1.7736^{NS}	0.8338^{NS}	0.6157^{NS}
CV%					
	Field T_1	1.75±0.14^{c}	2.0±0.0^{b}	3.0±0.0	1.0±0.0^{b}
	Field T_2	2.42±0.22^{abc}	2.83±0.44^{ab}	3.58±0.87	1.33±0.33^{b}
	Field T_3	2.92±0.08^{ab}	3.08±0.22^{ab}	3.33±0.17	1.0±0.0^{b}
	Field T_4	2.08±0.36^{bc}	2.17±0.36^{b}	3.0±0.38	1.17±0.17^{b}
	Field T_5	2.92±0.68^{ab}	2.96±0.65^{ab}	3.38±0.56	1.0±0.0^{b}
	Field T_6	2.33±0.33^{abc}	2.42±0.30^{ab}	2.58±0.30	1.0±0.0^{b}
	Field T_7	3.17±0.44^{a}	3.33±0.44^{a}	3.50±0.50	1.0±0.0^{b}
	Pot T_1	2.42±0.22^{abc}	2.5±0.14^{ab}	2.50±0.14	3.67±0.44^{a}
	Pot T_2	2.75±0.14^{abc}	2.75±0.14^{ab}	2.75±0.1443	4.17±0.44^{a}
	Pot T_3	2.67±0.51^{abc}	2.75±0.43^{ab}	2.75±0.433	3.58±0.96^{a}
	Pot T_4	2.42±0.22^{abc}	2.5±0.14^{ab}	2.5±0.1443	4.33±0.44^{a}
	Pot T_5	2.67±0.33^{abc}	2.67±0.33^{ab}	2.667±0.3333	4.17±0.44^{a}
	Pot T_6	2.25±0.14^{abc}	2.33±0.08^{ab}	2.333±0.0833	3.33±0.44^{a}
	Pot T_7	2.42±0.08^{abc}	2.67±0.17^{ab}	2.67±0.1667	3.50±0.76^{a}
LSD (0.05)		0.8945	0.9561	1.1323	1.2773
SEm		0.3077	0.3289	0.3895	0.4394
F value		1.1982^{NS}	0.7398^{NS}	0.145^{NS}	0.2699^{NS}
CV%					

[Means followed by different letters within each column are significantly different, DMRT (p≤0.05). DM: Downy mildew, BW: Bacterial wilt, LSD: Least significant difference, SEm: Standard error mean, CV: Coefficient of variation, *Significant at 5% level, **Significant at 1% level, NS: Not significant]

between the values recorded in the two locations. The highest mildew severity value was observed in T_2 (*Isaria* biopesticide), T_7 (control), T_3 (mixture of *Bacillus pumilus* and *Isaria fumosorosea* biopesticide), T_5 (neem leaf extract), T_1 (*Bacillus pumilus* biopesticide), T_4 (neem oil) and T_6 (mixture of neem oil and neem leaf extract) without any statistical differences in the treatments.

However, the bacterial wilt rating was severe and significant between the cucumber plants in the pot location and the field at a value of 3.82 and 1.07 respectively. The highest bacterial wilt severity value was observed in T_2 (*Isaria* biopesticide), T_4 (neem oil), T_5 (neem leaf extract), T_1 (*Bacillus pumilus* biopesticide), T_3 (mixture of *Bacillus pumilus* and *Isaria fumosorosea* biopesticide), T_7 (control) and T_6 (mixture of neem oil and neem leaf extract) without any statistical differences in the treatments. *B. pumilus* biopesticide (T_1) is moderately effective in suppressing the symptoms of downy mildew and bacterial wilt, while the fungal treatment (T_2) is very weak in the treatment of both diseases as the highest severity was recorded in the usage of T_2, while a combination of T_1 and T_2 (T_3) offers a moderate result in the control of bacterial wilt alone and poor for downy mildew control, this same scenario was observed in T_4 where it was only effective in controlling downy mildew and not bacterial wilt, while T_5 was also a weak treatment for both diseases and T_6 was the most suitable and consistent treatment in both scenarios as it was having the least severity score for both diseases. The control treatment had a high score for the mildew rating but not a very low score for bacterial wilt.

In general, T_2 (*Isaria* biopesticide) and T_5 (neem leaf extract) were not effective in reducing the severity of both bacterial wilt and downy mildew disease across the two locations, while a combination of neem oil and neem leaf extract (T_6) was very effective in reducing the effect of both bacterial wilt and downy mildew of cucumber. These results suggest that the location (field vs. pot) and the type of treatment play significant roles in the severity of downy mildew and bacterial wilt diseases. The effectiveness of the treatments varied, with the combination of neem oil and neem leaf (T_6) showing the most promising results.

The *B. pumilus* biopesticide (T_1) used in this study is moderately effective in suppressing the symptoms of downy mildew and bacterial wilt, this finding was in support of Ni and Punja (2021) and Safaei *et al.* (2022), where *Bacillus subtilis* was reported as being the best biopesticide for managing downy mildew of cucumber among the considered options and its effectiveness against the management of bacterial wilt was also reported by Mahmood *et al.* (2023). Several reports have reported the usage of *Isaria fumosorocea* as an effective entomopathogenic fungus, but little information is available on its success in plant disease suppression aside from the studies of Folorunso *et al.* (2022), where it was reported to be very effective by 65-73% in powdery mildew disease management, however, the result from this study is not in support of the efficacy of *I. fumosorocea* biopesticide in managing either downy mildew or bacteria wilt as the fungus has also been previously reported by Rogers *et al.* (2017) to be ineffective in controlling cucumber beetles in the laboratory.

The difference in this may be attributed to the diversity in biocontrol strains used and field environmental conditions which are mostly harsh and always affect the acclimatisation and efficacy of biological control agents (Bardin and Pugliese, 2020).

For disease control, a mixture of two unrelated microbes (T_3) was only effective in bacterial wilt management and not useful for downy mildew severity reduction, this was not in support of the findings of Dania and Omidiora (2019), where it was reported that a combination of *Trichoderma viride*, *T. harzianum* and *Bacillus subtilis* with *Allium sativum* extract reduced the severity of damping-off disease of tomato, but in agreement with the findings of Mahmood *et al.* (2023) that related biocontrol agents are more effective than unrelated ones in managing cucumber bacterial wilt.

Neem oil has been used in several studies to manage pests and diseases effectively, this is due to the presence of some compounds like azadiractin, alkaloids, saponins, tannins, phenols, flavonoids and terpenoids in neem which repels, deters feeding and impairs growth and reproduction rather than rapid killing (Adusei and Azupio, 2022). In this study, neem oil is the second most effective treatment in controlling downy mildew and this is in support of the findings of Choudhary *et al.* (2020), where neem oil is also the second most effective botanical among the seven treatments considered; however, unlike the oil, the fermented neem leaf extract was not effective in disease management for both mildew and bacterial wilt, this may be due to the concentration, different processing and extraction methods for both neem oil and fermented neem leaf extract as it was reported in the study of Keta *et al.* (2019) that aqueous neem extract was reported to be less effective than ethanol extract.

The significant difference in downy mildew severity after the third treatment application suggests a delayed response to the treatments. This delayed efficacy could be due to the time required for the biopesticides to affect the pathogen or for the plant's defence mechanisms to be activated. Understanding this timing could be crucial for developing effective application schedules. The varied efficacy of treatments across different diseases and locations underscores the complexity of biological control. The effectiveness of T_6 (mixture of neem oil and fermented neem leaf extract) in reducing the severity of both bacterial wilt and downy mildew is particularly noteworthy, suggesting that certain combinations of treatments can be more effective than others. The moderate effectiveness of T_1 (*B. pumilus* biopesticide) in suppressing symptoms aligns with previous studies, reinforcing the potential of *Bacillus* species as biocontrol agents. However, the variability in effectiveness between studies suggests that local environmental conditions and strain diversity play significant roles in biocontrol success. The lack of support for the efficacy of T_2 (*I. fumosorosea* biopesticide) in this study compared to others could be due to differences in the strains used, application methods, or environmental conditions. This highlights the need for context-specific research when deploying biocontrol agents. The findings suggest that neem oil (T_4) is more effective than fermented neem leaf extract (T_5) in controlling downy mildew, which may be attributed to the different active compounds and their concentrations in the oil versus the extract. This supports the idea that the method of extraction and formulation can significantly impact the efficacy of botanical treatments.

The significant role of the environment, as indicated by the differences in disease severity between field and pot locations suggests that microclimate and soil conditions can greatly influence disease development and the success of biocontrol treatments. The study's results on the combination treatments indicate that synergistic and antagonistic interactions between biocontrol agents and botanical extracts can affect their overall efficacy. This is an important consideration for developing integrated pest management strategies.

Effects of Different Treatments on the Growth and Yield of Cucumber

The number of leaves recorded in the study across the three treatment application cycles showed that there are no differences between the location, treatment and treatment-by-location interaction as the highest number of leaves at 8 DAT was observed in the field to be 4.01 and 4.0 in Pot, while the 15 and 22 DAT values were 9.02, 12.88 for field and 9.81,13.07 respectively without any statistical difference between them and the highest values were observed in T_4 (neem oil) and T_7 (control) with the lowest value recorded in T_2 (*Isaria* biopesticide) and T_5 (fermented neem leaf extract) and were all found to be statistically insignificant (Table 3). The neem oil treatment contributes to the leaf number positively and this is in support of the studies of Chowdhury and Talukder (2019), while the low leaf numbers recorded in the neem leaf extract treatment agree with the study of Sriraj *et al.* (2022), where it was discovered that neem leaf extract addition does not have any significant effect on lettuce growth parameters.

The leaf length and width were significant at the locations at 9 and 16 DAT only, with a leaf length value of 9.60, 9.93 for pot and 8.06, 8.18 for field and 10.93, 11.15 and 9.13, 9.33 for leaf width at pot and field, respectively; while the 23 DAT values were not significant. From the treatments, T_4, T_5 and T_2 have the highest number for leaf length consistently while the lowest number of leaves were recorded in T_3, T_6 and T_1, but the highest leaf width was recorded in T_4 with T_1 having the lowest leaf width which is significantly different from T_4 (Table 3).

From this study it is evident that neem extracts (oil and aqueous extract) have a good impact on the length and width of cucumber leaf, this process will also increase the rate of photosynthesis by the plant as higher leaf area index has been reported to increase photosynthesis rate (Huang *et al.*, 2019). This may be because it has been suggested that neem extract increases the K, Ca and Mg in soil (Sriraj *et al.*, 2022) and this might have contributed to the early peak in leaf length and width recorded in neem treatments. These nutrients are essential for plant growth and development and their increased availability can influence leaf growth. Neem leaf extract acts as a natural nitrification inhibitor. It increases soil NH_4^+ concentrations and inhibits nitrification, but decreases soil NO_3^- concentrations and net nitrification rates.

This alteration in soil nutrient availability can affect plant growth, including leaf dimensions. This suggests that neem extract may have a growth-regulating effect on plants and potentially influence leaf size (Sriraj *et al.*, 2022). *I. fumosorosea* primarily targets insects, not plants. It's used as a biological control agent against many insect pests (Weng *et al.*, 2019). Therefore, its primary mode of action is unlikely to directly influence plant growth parameters such as leaf length and width. While *Isaria fumosorosea* can colonize plant tissues as an endophyte, its main function in this role is to protect against insect pests (Sani *et al.*, 2023). This protective effect could influence plant health and vigour, but not necessarily specific growth parameters like leaf size. Unlike some other fungi, *Isaria fumosorosea* is not known to possess plant growth-promoting traits such as fixing nitrogen, solubilising phosphate, or producing plant growth-promoting hormones. These are typically the mechanisms by which microorganisms influence plant growth parameters (Abdelaal *et al.*, 2021). The effects of *I. fumosorosea* on plants may vary depending on the specific plant species and environmental conditions (Rogers *et al.*, 2017). Therefore, while it might not increase leaf length and width in some plants, it could affect others differently.

The vine length was not significant at 12 DAT in the locations but was significant at 19 and 26 DAT with a value of (43.48, 69.57) cm and (33.44, 56.07) cm for pot and field respectively. The highest values were recorded in T_7 (control), T_4 (neem oil), T_2, T_6, T_3, T_5 and T_1 as the least. However, the number of branches was not significant at the locations for the two data taking periods. There was a significant difference between T_7 and (T_6, T_5) at 16 DAT, but differences only existed between T_7 and T_6 at 23 DAT. The highest vine length in the control group is consistent with the expectation that, in the absence of any treatment, plants will grow optimally under suitable conditions. The highest vine length observed in the control treatment suggests that the growth conditions were optimal for cucumber vine growth without any additional treatments. This serves as a baseline against which the effects of other treatments were compared.

Neem oil is known to have growth-promoting effects on plants. It can improve nutrient availability and moisture retention, which could explain the increased vine length observed in your experiment. The high value recorded for plants treated with neem oil is in line with previous research, which has shown that neem oil can have growth-promoting effects on plants agrees with the findings of Joshiya *et al.* (2020), where treatments containing neem oil recorded the highest heights. It can improve nutrient availability and moisture retention, which could explain the increased vine length observed in this study (Joshiya *et al.*, 2020). The fact that *Isaria fumosorosea* resulted in the third-highest vine length could be due to its role as a biological control agent against insect pests (Reddy and Chowdary, 2021). The application of *I. fumosorosea* might have protected the cucumber plants from pest damage, indirectly promoting plant health and potentially influencing vine length and this was also in support of the findings of Sani *et al.* (2023), where the inoculation of tomato seed with *I. javanica* increases the growth of tomato plants.

The effect of combined treatments (T_3 and T_6) on vine length could be attributed to the combined action of various biopesticides and botanicals. Each component might have contributed to plant health and growth in different ways, leading to an overall positive effect on vine length. Fermented neem leaf extract has been found to influence plant growth parameters. In this study, it appears that the fermented neem leaf extract may have had a less pronounced effect on vine length compared to other treatments. However, its effect can vary depending on factors such as the concentration of the extract and the method of application (Ghongade and Sangha, 2021), as this study is also in support of the findings of Sultana *et al.* (2020), where neem leaf extract was reported to be among

Table 3: Effects of different biological and botanical treatments on the growth parameters of cucumbers grown in two locations

Factors		Leaf Number			Leaf Length		
		8 DAT	15 DAT	22 DAT	9 DAT	16 DAT	23 DAT
Location	Open field	4.01±0.12^{a}	9.02±0.48^{a}	12.88±1.17^{a}	8.06±0.21^{b}	8.18±0.21^{b}	9.78±0.30^{a}
	Pot	4.00±0.04^{a}	9.81±0.2^{4a}	13.07±0.23^{a}	9.60±0.16^{a}	9.93±0.17^{a}	9.82±0.15^{a}
LSD (0.05)		0.2721	1.1139	2.457	0.5334	0.541	0.6642
SEm		0.0936	0.3832	0.8452	0.1835	0.1861	0.2285
F value		0.0107^{NS}	2.1025^{NS}	0.0254^{NS}	35.3738**	43.9745**	0.0161^{NS}
CV%		10.7124	18.6458	29.8482	9.529	9.4201	10.6852
Treatment	T_1	3.92±0.15^{a}	9.42±0.91^{a}	14.17±2.25^{a}	8.51±0.50^{a}	8.43±0.45^{a}	8.88±0.29^{b}
	T_2	3.92±0.08^{a}	8.83±0.53^{a}	11.50±0.75^{a}	9.05±0.58^{a}	9.42±0.56^{a}	10.12±0.34^{ab}
	T_3	4.00±0.29^{a}	9.00±0.56^{a}	12.58±1.02^{a}	8.95±0.37^{a}	8.98±0.52^{a}	9.74±0.42^{ab}
	T_4	4.08±0.08^{a}	10.50±0.68^{a}	14.67±2.21^{a}	9.21±0.62^{a}	9.55±0.47^{a}	10.35±0.39^{a}
	T_5	3.88±0.09^{a}	8.75±0.38^{a}	11.67±0.60^{a}	8.77±0.30^{a}	9.15±0.15^{a}	10.14±0.31^{ab}
	T_6	4.17±0.17^{a}	9.17±0.46^{a}	11.75±1.07^{a}	8.29±0.42^{a}	8.74±0.51^{a}	9.39±0.60^{ab}
	T_7	4.08±0.20^{a}	10.25±1.18^{a}	14.50±2.10^{a}	9.02±0.55^{a}	9.09±0.79^{a}	9.99±0.51^{ab}
LSD (0.05)		0.5093	2.0837	4.5965	0.9982	1.0122	1.2427
SEm		0.1752	0.7168	1.5812	0.3434	0.3482	0.4275
F value		0.3856^{NS}	0.9371^{NS}	0.8098^{NS}	0.8996^{NS}	1.2226^{NS}	1.4348^{NS}
CV%							
Treatment × Location	Field T_1	4.00±0.29^{a}	10.00±1.73^{a}	16.00±4.62^{a}	8.15±0.88^{bc}	7.87±0.34^{de}	8.81±0.11^{a}
	Field T_2	3.83±0.17^{a}	8.17±0.93^{a}	10.50±1.26^{a}	8.05±0.79^{bc}	8.31±0.52^{c-e}	10.07±0.70^{a}
	Field T_3	3.83±0.60^{a}	8.00±0.58^{a}	11.83±1.97^{a}	8.33±0.33^{bc}	7.95±0.39^{de}	9.33±0.80^{a}
	Field T_4	4.17±0.17^{a}	10.67±1.48^{a}	16.17±4.70^{a}	7.99±0.59^{bc}	8.74±0.63^{b-e}	10.43±0.85^{a}
	Field T_5	3.75±0.14^{a}	8.00±0.29^{a}	10.50±0.29^{a}	8.25±0.14^{bc}	8.83±0.10^{b-e}	10.66±0.38^{a}
	Field T_6	4.33±0.33^{a}	8.50±0.76^{a}	10.00±1.61^{a}	7.53±0.52^{c}	7.84±0.60^{de}	9.32±1.31^{a}
	Field T_7	4.17±0.44^{a}	9.83±2.32^{a}	15.17±4.60^{a}	8.07±0.79^{bc}	7.72±1.09^{e}	9.83±1.13^{a}
	Pot T_1	3.83±0.17^{a}	8.83±0.88^{a}	12.33±0.83^{a}	8.87±0.58^{a-c}	8.98±0.77^{a-e}	8.95±0.63^{a}
	Pot T_2	4.00±0.00^{a}	9.50±0.29$_{a}$	12.50±0.5^{a}	10.04±0.18^{a}	10.54±0.18^{a}	10.17±0.32^{a}
	Pot T_3	4.17±0.17^{a}	10.00±0.50$_{a}$	13.33±0.93^{a}	9.56±0.45a^{b}	10.01±0.35^{ab}	10.14±0.29^{a}
	Pot T_4	4.00±0.00^{a}	10.33±0.33$_{a}$	13.17±0.44^{a}	10.42±0.36^{a}	10.36±0.12^{ab}	10.27±0.21^{a}
	Pot T_5	4.00±0.00^{a}	9.50±0.29$_{a}$	12.83±0.60^{a}	9.29±0.40^{ab}	9.47±0.06^{a-d}	9.62±0.22^{a}
	Pot T_6	4.00±0.00^{a}	9.83±0.17$_{a}$	13.50±0.29^{a}	9.04±0.23^{a-c}	9.65±0.38^{a-c}	9.46±0.31^{a}
	Pot T_7	4.00±0.00^{a}	10.67±1.20^{a}	13.83±0.60^{a}	9.96±0.11^{a}	10.47±0.21^{a}	10.14±0.11^{a}
LSD (0.05)		0.7203	2.9468	6.5005	1.4116	1.4314	1.7575
SEm		0.2478	1.0137	2.2362	0.4856	0.4924	0.6046
F value		0.5356^{NS}	0.6204^{NS}	0.7985^{NS}	0.7447^{NS}	1.0241^{NS}	0.4335^{NS}
CV%							

Table 3: Continue...

Factors		Leaf width			Vine length		
		9 DAT	16 DAT	23 DAT	12 DAT	19 DAT	26 DAT
Location	Open field	9.13±0.23[b]	9.33±0.20[b]	10.93±0.32[a]	22.86±1.02[a]	33.44±1.5[b]	56.07±2.63[b]
	Pot	10.93±0.18[a]	11.15±0.18[a]	11.25±0.16[a]	22.14±0.53[a]	43.48±1.63[a]	69.57±1.89[a]
LSD (0.05)		0.6105	0.5474	0.7046	2.55	4.9494	7.1282
SEm		0.21	0.1883	0.2424	0.8772	1.7026	2.4521
F value		36.7299[**]	46.7962[**]	0.8871[NS]	0.3315[NS]	17.3717[**]	15.1548[NS]
CV%		9.5908	8.4294	10.0147	17.8666	20.2877	17.8873
Treatment	T_1	9.73±0.59[a]	9.44±0.46[a]	10.10±0.3[b]	21.33±1.82[a]	35.83±3.44[a]	57.13±4.92[a]
	T_2	10.30±0.66[a]	10.52±0.59[a]	11.29±0.41[ab]	22.50±1.68[a]	38.83±3.51[a]	64.25±4.49[a]
	T_3	10.19±0.36[a]	10.36±0.46[a]	10.92±0.47[ab]	21.33±1.20[a]	37.42±4.43[a]	61.67±6.79[a]
	T_4	10.34±0.68[a]	10.56±0.55[a]	11.69±0.37[a]	23.25±1.43[a]	40.25±2.79[a]	66.58±3.22[a]
	T_5	9.80±0.32[a]	10.32±0.18[a]	11.44±0.34[ab]	21.75±1.04[a]	35.21±1.59[a]	59.13±2.73[a]
	T_6	9.59±0.53[a]	9.93±0.66[a]	10.82±0.71[ab]	23.58±1.21[a]	38.58±2.84[a]	62.92±5.61[a]
	T_7	10.28±0.71[a]	10.54±0.67[a]	11.37±0.50[ab]	23.75±2.29[a]	43.08±6.02[a]	68.08±7.24[a]
LSD (0.05)		1.1419	1.0241	1.318	4.7709	9.2595	13.3357
SEm		0.3928	0.3523	0.453[4]	1.6412	3.1853	4.5875
F value		0.6337[NS]	1.3822[NS]	1.36[NS]	0.4074[NS]	0.7112[NS]	0.7233[NS]
CV%							
Treatment × Location	Field T_1	9.20±1.01c[d]	8.72±0.25[e]	9.84±0.12[a]	22.00±3.46[a]	33.50±4.91[bc]	49.75±4.48[c]
	Field T_2	9.17±0.92[cd]	9.37±0.54[de]	10.93±0.79[a]	22.33±3.66[a]	34.00±6.11[bc]	57.00±6.82[a-c]
	Field T_3	9.65±0.27[b-d]	9.62±0.48[c-e]	10.51±0.82[a]	20.17±1.30[a]	29.33±2.91[c]	50.33±5.46[c]
	Field T_4	8.96±0.53[cd]	9.52±0.61[c-e]	11.77±0.79[a]	24.00±2.93[a]	36.33±4.05[bc]	64.83±5.37[a-c]
	Field T_5	9.31±0.18[cd]	10.01±0.2[b-e]	10.10±0.33[a]	23.00±1.44[a]	32.25±1.88[bc]	54.75±3.61[bc]
	Field T_6	8.56±0.54[d]	8.74±0.77[e]	10.49±1.55[a]	24.17±2.59[a]	34.83±4.53[bc]	56.67±10.04[a-c]
	Field T_7	9.06±0.97[cd]	9.32±0.78[de]	11.07±1.04[a]	24.33±4.70[a]	33.83±6.93[bc]	59.17±12.74[a-c]
	Pot T_1	10.25±0.66[a-d]	10.16±0.69[a-e]	10.36±0.67[a]	20.67±2.05[a]	38.17±5.45[a-c]	64.50±6.83[a-c]
	Pot T_2	11.42±0.29[ab]	11.68±0.37[a]	11.66±0.30[a]	22.67±0.93[a]	43.67±1.01[a-c]	71.50±1.26[a-c]
	Pot T_3	10.72±0.55[a-c]	11.10±0.52[a-c]	11.34±0.50[a]	22.50±2.02[a]	45.50±4.93[ab]	73.00±8.51[ab]
	Pot T_4	11.71±0.32[a]	11.60±0.29[ab]	11.61±0.25[a]	22.50±1.04[a]	44.17±2.68a[-c]	68.33±4.49[a-c]
	Pot T_5	10.29±0.49[a-d]	10.63±0.04[a-d]	10.98±0.33[a]	20.50±1.32[a]	38.17±0.60[a-c]	63.50±2.26[a-c]
	Pot T_6	10.63±0.19[a-c]	11.12±0.40[a-c]	11.15±0.15[a]	23.00±0.58[a]	42.33±2.40[a-c]	69.17±4.19[a-c]
	Pot T_7	11.50±0.25[a]	11.76±0.40[a]	11.67±0.30[a]	23.17±1.92[a]	52.33±6.89[a]	77.00±4.51[a]
LSD (0.05)		1.6148	1.4485	1.8642	6.7468	13.095	18.8595
SEm		0.5555	0.4983	0.6413	2.3209	4.5047	6.4877
F value		0.905[NS]	0.907[NS]	0.4841[NS]	0.2318[NS]	0.6835[NS]	0.4532[NS]
CV%							

Table 3: Continue...

Factors		No of branches		No of tendrils		Damaged leaf		
		16 DAT	23 DAT	16 DAT	23 DAT	15 DAT	22 DAT	29 DAT
Location	Open field	0.86±0.29^{a}	1.36±0.36^{a}	4.62±0.39^{a}	8.04±0.45^{a}	1.50±0.27^{a}	2.70±0.36^{a}	4.14±0.49^{a}
	Pot	0.67±0.21^{a}	1.17±0.18^{a}	5.21±0.29^{a}	8.62±0.22^{a}	1.86±0.22^{a}	2.36±0.17^{a}	1.26±0.15^{b}
LSD (0.05)		0.6994	0.8183	1.011	1.1102	0.7241	0.8296	1.1259
SEm		0.2406	0.2815	0.3478	0.3819	0.2491	0.2854	0.3873
F value		0.3133^{NS}	0.2289^{NS}	1.4641^{NS}	1.1664^{NS}	1.0283^{NS}	0.7317^{NS}	27.6699**
CV%		144.7133	102.2319	32.4197	21.0184	67.9932	51.7017	65.6717
Treatment	T_1	1.17±0.56^{ab}	1.46±0.63^{ab}	4.33±0.57^{a}	7.96±0.78^{a}	1.92±0.33^{a}	2.58±0.33^{a}	2.46±0.64^{a}
	T_2	0.67±0.33^{ab}	0.83±0.28^{ab}	5.42±0.58^{a}	8.50±0.68^{a}	2.5±0.41^{a}	3.33±0.48^{a}	3.67±1.40^{a}
	T_3	0.50±0.26^{ab}	1.33±0.38^{ab}	4.67±0.77^{a}	8.17±0.76^{a}	1.83±0.33^{a}	2.08±0.33^{a}	1.83±0.56^{a}
	T_4	1.00±0.65^{ab}	1.92±0.83^{ab}	5.33±0.56^{a}	8.83±0.57^{a}	1.42±0.40^{a}	3.08±0.51^{a}	3.08±1.08^{a}
	T_5	0.00±0.00^{b}	0.88±0.20^{ab}	3.92±0.35^{a}	7.92±0.35^{a}	1.08±0.38^{a}	2.13±0.20^{a}	3.13±0.76^{a}
	T_6	0.25±0.17^{b}	0.33±0.21^{b}	5.17±0.69^{a}	8.42±0.78^{a}	1.58±0.5^{4a}	2.67±0.86^{a}	2.67±1.25^{a}
	T_7	1.75±0.63^{a}	2.083±0.64^{a}	5.58±0.85^{a}	8.5±0.93^{a}	1.41±0.68^{a}	1.83±0.60^{a}	2.08±0.38^{a}
LSD (0.05)		1.3084	1.5311	1.8916	2.0773	1.3544	1.5523	2.1061
SEm		0.4501	0.5267	0.6507	0.7146	0.4659	0.534	0.7245
F value		1.7415^{NS}	1.4077^{NS}	0.9183^{NS}	0.2136^{NS}	0.9642^{NS}	1.065^{NS}	0.7788^{NS}
CV%								
Treatment × Location	Field T_1	1.50±0.87^{a}	1.75±1.01^{a}	4.50±0.87^{a}	7.75±1.59^{a}	2.00±0.58^{ab}	3.00±0.58^{ab}	3.75±0.43^{a-d}
	Field T_2	0.67±0.33^{a}	0.83±0.44^{a}	4.83±1.01^{a}	8.50±1.50^{a}	2.83±0.73^{a}	4.00±0.76^{a}	6.00±2.0^{a}
	Field T_3	0.50±0.50^{a}	1.50±0.76^{a}	3.67±0.88^{a}	7.00±1.00^{a}	1.50±0.50^{ab}	2.00±0.58^{ab}	2.83±0.60^{a-d}
	Field T_4	1.83±1.17^{a}	2.50±1.61^{a}	5.67±1.09^{a}	9.50±1.00^{a}	1.33±0.73^{ab}	3.67±0.60^{a}	4.83±1.64^{ab}
	Field T_5	0.00±0.00^{a}	0.75±0.43^{a}	3.50±0.58^{a}	7.50±0.58^{a}	1.00±0.58^{ab}	2.25±0.43^{ab}	4.75±0.43^{a-c}
	Field T_6	0.00±0.00^{a}	0.000.00^{a}	5.17±1.17^{a}	8.00±1.53^{a}	1.50±1.04^{ab}	3.00±1.89^{ab}	4.17±2.32^{a-d}
	Field T_7	1.50±1.26^{a}	2.17±1.42^{a}	5.00±1.76^{a}	8.00±1.76^{a}	0.33±0.17^{b}	1.00±0.58^{ab}	2.67±0.33^{a-d}
	Pot T_1	0.83±0.83^{a}	1.17±0.93^{a}	4.17±0.93^{a}	8.17±0.67^{a}	1.83±0.44^{ab}	2.17±0.17^{ab}	1.17±0.44^{d}
	Pot T_2	0.67±0.67^{a}	0.83±0.44^{a}	6.00±0.58^{a}	8.50±0.29^{a}	2.17±0.44^{ab}	2.67±0.33^{ab}	1.33±0.60^{cd}
	Pot T_3	0.50±0.29^{a}	1.17±0.33^{a}	5.67±1.09^{a}	9.33±0.73^{a}	2.17±0.44^{ab}	2.17±0.44^{ab}	0.83±0.44^{d}
	Pot T_4	0.17±0.17^{a}	1.33±0.73^{a}	5.00±0.50^{a}	8.17±0.44^{a}	1.50±0.50^{ab}	2.50±0.76^{ab}	1.33±0.33^{cd}
	Pot T_5	0.00±0.00^{a}	1.00±0.00^{a}	4.33±0.33^{a}	8.33±0.33^{a}	1.17±0.60^{ab}	2.00±0.00^{ab}	1.50±0.29^{b-d}
	Pot T_6	0.50±0.29^{a}	0.67±0.33^{a}	5.17±1.01^{a}	8.83±0.73^{a}	1.67±0.60^{ab}	2.33±0.17^{ab}	1.17±0.44^{d}
	Pot T_7	2.00±0.58^{a}	2.00±0.00^{a}	6.17±0.44^{a}	9.00±1.00^{a}	2.50±1.04^{ab}	2.67±0.88^{ab}	1.50±0.50^{b-d}
LSD (0.05)		1.8506	2.1651	2.6753	2.9375	1.9154	2.195	2.9785
SEm		0.6366	0.7448	0.9203	1.0105	0.6589	0.7551	1.0246
F value		0.7133^{NS}	0.3144^{NS}	0.5404^{NS}	0.6041^{NS}	0.9215^{NS}	0.9223^{NS}	0.5973^{NS}
CV%								

[Means followed by different letters within each column are significantly different, DMRT ($p \leq 0.05$). DAA: Days after application, LSD: Least significant difference, Sem: Standard error mean, CV: Coefficient of variation, *Significant at 5% level, **Significant at 1% level, NS: Not significant]

the treatments that recorded the lowest height in cucumber.

Bacillus pumilus is a bacterium known for its plant growth-promoting properties. However, its effect on plant growth can vary depending on factors such as the strain of the bacterium, the method of application and the specific plant species. This study agrees with the findings of Sharma *et al.* (2023a), where *B. subtilis* was only better than the control among the used biocontrol agents.

The number of tendrils was insignificant for the location and treatments during the growth phase. At the same time, the damaged leaf count was only significant at 29 DAT, where the field has a value of 4.14 and a count of 1.26 for the pot indicating that more insects feed on the cucumber leaf in the field. Damaged leaves were a result of insect feeding and it was discovered that the high values obtained for leaves treated with biocontrol agents like *I. fumosorosea* agree with the findings of Rogers *et al.* (2017), where the application of *I. fumosorosea* and *Beauveria bassiana* strains did not result in increased mortality or reduced leaf feeding when compared to control treatments.

Insects generally have easier access to plants grown in the field compared to those grown in pot (Saleem *et al.*, 2019) due to some insects overwintering on plant debris and living on alternative hosts. As recorded in this study, this could lead to a higher incidence of insects feeding on field-grown cucumber leaves, resulting in a higher damaged leaf count. The microclimate conditions in a field can be quite different from those in a pot (Srivastava and Joshih, 2021). Factors such as temperature, humidity, light intensity and wind speed can vary significantly and these can influence insect activity and feeding behaviour (Rogers *et al.*, 2017; Kumar *et al.*, 2021). The health and vigour of plants can influence their susceptibility to insect damage (Matumba *et al.*, 2021) as plants grown in the field may experience more stress due to competition with weeds, variations in soil fertility, *etc*. compared to those grown in pots, which could make them more susceptible to insect damage. The insignificant difference in the number of tendrils across locations and treatments suggests that this growth parameter may be relatively stable under varying conditions. However, the significant difference in damaged leaf count between field and pot environments highlights the influence of external factors on plant health.

The number of days to first flowering was significant in the three factors (location, treatment and treatment by location interactions) at 1%, 5% and 5% respectively, with the field having an average of 17.42 DAT and the pot having an average of 15.24 DAT to first flowering. The neem leaf extract (T_5) and the mixed biopesticides (T_3) have the longest number of days to first flowering at 17.71 and 17.0 DAT with no differences between the two treatments, but there are differences between T_5 and all others, while T_3 is different from T_1 and T_4. The treatments having medium days to flowering include T_7, T_2 and T_6, while the fastest days to flowering were recorded in T_1 and T_4 (Table 4). Regarding the days to first flowering, the significant differences observed suggest that both environmental conditions and the type of treatment can influence this important growth milestone. The earlier flowering observed with *B. pumilus* (T_1) and neem oil (T_4) treatments aligns with their known plant growth-promoting properties. Conversely, the delayed flowering associated with fermented neem leaf extract (T_5) and mixed biopesticides (T_3) could be due to allelopathic effects or the specific interactions between the combined agents and the plant's physiological processes.

B. pumilus is known to promote plant growth, which could explain the earlier flowering observed in this study as it aligns with that of Dobrzyński *et al.* (2023). Similarly, neem oil has been reported to improve plant growth and prevent certain pests, potentially leading to earlier flowering. *I. fumosorosea* is a fungus that has been used to control insect pests (Xu *et al.*, 2017) and its impact on plant growth and flowering might be indirect through pest control. The control treatment had a medium number of days to flowering, suggesting that the treatments had a significant impact on the flowering time.

The neem leaf extract treatment resulted in the longest number of days to first flowering. This aligns with a study that found that neem leaf extract can inhibit the germination of some vegetable crops (Khanam *et al.*, 2020). The allelopathic effects of neem leaf extract could be the reason for the delayed flowering in this study. However, it's important to note that the concentration and application method of the neem leaf extract can significantly influence its effects on plant growth. The mixed biopesticides also resulted in a longer time to first flowering. This could be due to the specific combination of biopesticides used, which might have affected the plant's growth and development. However, more research is needed to understand the exact mechanisms. From this study the single application of either biopesticide or botanical extract seems to be independently effective in contributing to the early flowering of cucumber as seen with the neem oil extract and *B. pumilus* treatments were reported to enhance the early flowering of cucumber in this study.

The average number of flowers and days to first fruit was not significant at the location, treatment and location by treatment interaction, whereas the number of fruits plant^{-1} was significant only at the location with the field having 6.94 and the pot having an average of 1.86 fruits plant^{-1}. The number of fruits plant^{-1} was significantly affected by the location, with the field yielding an average of 6.94 fruits plant^{-1} and the pot yielding an average of 1.86 fruits plant^{-1}. The number of fruits plant^{-1} also varied depending on the treatment used.

However, the number of flowers varied depending on the treatment used, with T_4 (neem oil) resulting in the highest number of flowers (13.4), followed by the control (T_7) with 12.7, T_1 (*B. pumilus*) with 10.04, T_3 (mixed biopesticide) with 9.42, T_2 (*I. fumosorosea*) with 9.33, T_5 (neem leaf extract) with 8.42 and lastly T_6 (mixture of neem oil and neem leaf extract) with 8.42. A study by Joshiya *et al.* (2020) found that the application of neem oil significantly increased the number of fruits plant^{-1}, which is related to an increase in the number of flowers. This aligns with the findings of this study where neem oil resulted in the highest number of flowers and third highest fruit number.

B. pumilus has been found to promote plant growth and suppress phytopathogens (Dobrzyński *et al.*, 2023). However, its specific effect on flower number and fruit number has not been mentioned in previous studies. This result provides valuable data in this regard, showing a moderate number of flowers with *Bacillus pumilus* treatment. While specific studies on mixed biopesticides and cucumber flower yield are limited, a study by Pan *et al.* (2022) found that the mixed use of pesticides and foliar fertilizer improved the physiological indexes of cucumber plants. This suggests that mixed biopesticides could potentially influence flower yield, although this result disagrees and indicates a lower medium flower and lowest fruit number compared to some other treatments.

I. fumosorosea has been used as a biocontrol agent against various pests (Pan *et al.*, 2022). While its effect on flower yield is not explicitly mentioned in the literature, this result shows a slightly lower flower and fruit yield with this treatment compared to others, which points to the fact that the treatment does not affect the plants directly. Fermented neem leaf extract (T_5) and a mixture of neem oil and neem leaf extract (T_6) results show the lowest flower yield with these treatments, suggesting that they might not be as effective as others in promoting flower yield. While specific studies on these treatments and cucumber flower yield and fruit numbers are limited, neem-based treatments are generally known to have insecticidal properties and could potentially affect plant growth and flower yield (Joshiya *et al.*, 2020). The fruit length and width were significant in the location at 1% with a value of 13.26 cm, 8.31 cm in the field and 12.25 cm, 7.44 cm in the pot for fruit length and width respectively. However, there was also a significant difference between the fruit length of T_3 and T_6.

A study on cucumber fruit size and shape variations found that fruit length had a strong positive correlation to the cell number in the longitudinal section of fruit throughout the four stages of 0, 6, 12 and 30 days after anthesis. However, significant negative correlations were found between fruit length and the fruit cell size at 12 and 30 DAA (Liu *et al.*, 2020). This suggests that the variations in fruit length in this study could be due to differences in cell number and size, which might be influenced by the different treatments.

While there's no direct study on mixed biopesticides' effect on cucumber fruit size, research has shown that plant growth-promoting rhizobacteria can improve plant height, stem diameter, root length, secondary roots, biomass, fruit size, fruit diameter and yield (Zapata-Sifuentes *et al.*, 2022). This could explain the larger fruit length observed in T_3.

Neem has been widely used for its medicinal properties and as a natural pest control solution. It has been found to protect plants against garden pests and enhance the quality and quantity of crops. This might have contributed to the relatively large fruit length in T_5 (Kumari *et al.*, 2020). *I. fumosorosea* has been used to control insect pests of plants grown for the production of cut flowers, ornamentals growing in greenhouses and nurseries and vegetable crops. Its effect on cucumber fruit size is not directly studied, but its pest control properties might have contributed to the fruit length in T_2. *B. pumilus* has been found to promote plant growth (Dobrzyński *et al.*, 2023), which could explain the fruit length in T_1.

Neem oil is known to protect plants against pests and diseases, but it can also cause phytotoxicity in some plants, including cucumber plants, resulting in stunted growth, leaf damage and even death of the plants. This might have contributed to the smaller fruit length in T_4. The combination of neem leaf extract and neem oil might have similar effects as T_4 and T_5, but the potential phytotoxicity of neem oil might have led to the smallest fruit length in T_6.

The yield was also significant only at the location with the field having 11.99 t ha^{-1}; while the pot had a value of 2.20 t ha^{-1}. There were no differences among the treatment, but the highest yield was recorded in T_1 and T_7 while the medium yield was recorded in T_4 and T_5 and the least yield was recorded in T_2, T_3 and T_6 (Table 4). The quality of the fruits was only significant at the locations with the field having a value of 3.19 while the pot was 2.44 indicating a fair quality in the field and a poor quality in the pot location. The highest fruit quality was recorded in T_5 while the lowest quality was observed in T_7, T_2 and T_1 (Table 4).

The findings from the cucumber yield and fruit quality study present an interesting comparison to previous research in the field. The significant yield difference between the field (11.99 t ha^{-1}) and pot (2.20 t ha^{-1}) locations aligns with the consensus that field conditions often provide a more conducive environment for crop growth due to factors such as soil structure and microclimate, which are difficult to replicate in pot culture.

In terms of treatment effects, the highest yield recorded for T_1 (*Bacillus pumilus*) at 10.10 t ha^{-1} and the control T_7 at 9.03 t ha^{-1} suggests that *B. pumilus* may have a positive impact on yield, which is supported by previous studies indicating that certain Bacillus strains can enhance plant growth and yield. However, the fact that there were no significant differences among the treatments could imply that other factors, such as environmental conditions or the genetic potential of the cucumber variety played a more pivotal role in determining yield (Gebretsadik *et al.*, 2021). The medium yields observed for T_4 (neem oil) and T_5 (neem leaf extract) are particularly interesting as they suggest the potential for these natural products to be used as biopesticides without significantly compromising yield. This is in line with research that has highlighted the efficacy of neem-based products in pest management (Zapata-Sifuentes *et al.*, 2022).

The lower yields for T_2 (*I. fumosorosea*), T_3 (mixed biopesticide) and T_6 (mixture of neem oil and neem leaf extract) indicate that these treatments may not be as effective in promoting growth or may even have a negative impact on yield. This could be due to a variety of reasons, including phytotoxicity or inadequate pest control, which warrants further investigation. Regarding fruit quality, the study's findings that the field location produced fruits of fair quality (3.19) compared to poor quality in the pot location (2.44) are consistent with the notion that field-grown crops often have better quality attributes. This could be attributed to the more balanced nutrient availability and stress conditions in the field, which can enhance the development of desirable fruit traits.

The highest fruit quality recorded for T_5 (neem leaf extract) and T_4 (neem oil) suggests that these treatments may have a role in improving fruit quality, possibly through the reduction of pest and disease damage, which is corroborated by other

Table 4: Effects of different biological and botanical treatments on yield parameters of cucumber plants grown in two locations

Factors		Days to 1st flower	No. of fruits	Fruit length (cm)	Fruit width (cm)	Yield (t ha^{-1})	Fruit quality
Location	Open field	17.42±0.39[a]	6.94±0.81[a]	13.26±0.26[a]	8.31±0.21[a]	11.99±1.55[a]	3.19±0.09[a]
	Pot	15.24±0.14[b]	1.86±0.17[b]	12.251±0.23[b]	7.44±0.15[b]	2.20±0.24[b]	2.44±0.15[b]
LSD (0.05)		0.661	1.5927	0.6453	0.541	3.2134	0.3651
SEm		0.2274	0.5479	0.222	0.1861	1.1054	0.1256
F value		45.9104**	43.0404**	10.221**	10.928**	39.2679**	17.5883**
CV%		6.3811	57.0783	7.9779	10.8333	71.4178	20.429
Treatment	T_1	15.58±0.20[c]	6.33±2.16[a]	12.63±0.41[ab]	7.72±0.39[a]	10.10±3.97[a]	2.71±0.33[a]
	T_2	16.17±0.78[bc]	3.33±1.07[a]	12.79±0.48[ab]	7.80±0.24[a]	5.34±2.10[a]	2.74±0.38[a]
	T_3	17.00±0.79[ab]	3.08±0.60[a]	13.75±0.38[a]	8.13±0.34[a]	5.34±1.29[a]	2.77±0.26[a]
	T_4	15.42±0.40[c]	4.92±1.58[a]	12.45±0.38[ab]	8.14±0.64[a]	7.94±3.01[a]	2.87±0.37[a]
	T_5	17.71±0.95[a]	4.04±1.26[a]	13.00±0.54[ab]	8.07±0.34[a]	7.07±2.77[a]	3.09±0.16[a]
	T_6	16.08±0.27[bc]	3.50±0.89[a]	11.93±0.66[b]	7.54±0.40[a]	4.83±1.74[a]	2.79±0.24[a]
	T_7	16.33±0.96[bc]	5.58±2.40[a]	12.73±0.48[ab]	7.72±0.32[a]	9.03±4.65[a]	2.75±0.25[a]
LSD (0.05)		1.2363	2.9796	1.2076	1.0122	6.0113	0.6828
Sem		0.4253	1.025	0.4154	0.3482	2.0679	0.2349
F value		3.5265*	1.4618	1.7833[NS]	0.4677[NS]	0.9662[NS]	0.3047[NS]
CV%							
Treatment × Location	Field T_1	15.50±0.29[e]	11.00±1.16[a]	13.44±0.10[ab]	8.44±0.42[ab]	18.45±2.97[a]	3.23±0.07[a-c]
	Field T_2	17.50±1.04[b-d]	4.67±1.97[b-d]	13.07±0.88[ab]	7.67±0.52[ab]	8.09±3.77b[c]	3.32±0.26[ab]
	Field T_3	18.50±0.87[ab]	4.17±0.73[b-d]	14.25±0.53[a]	8.45±0.54[ab]	7.91±1.24b[c]	2.96±0.38[a-c]
	Field T_4	16.17±0.33[c-e]	8.17±1.20[ab]	12.90±0.31[ab]	9.26±0.86[a]	14.01±2.77[ab]	3.55±0.22[a]
	Field T_5	19.75±0.43[a]	6.75±0.72[a-c]	13.74±0.63[ab]	8.46±0.39a[b]	12.81±2.18[ab]	3.17±0.31[a-c]
	Field T_6	16.67±0.17[b-e]	5.00±1.16[b-d]	12.04±1.1[5b]	7.53±0.60[b]	7.32±2.89[bc]	2.95±0.32[a-c]
	Field T_7	17.83±1.48[bc]	8.83±4.21[ab]	13.34±0.61[ab]	8.36±0.24[ab]	15.34±8.21[ab]	3.14±0.14[a-c]
	Pot T_1	15.67±0.33[de]	1.67±0.44[d]	11.82±0.43[b]	6.99±0.26[b]	1.76±0.52c	2.19±0.50[bc]
	Pot T_2	14.83±0.44[e]	2.00±0.29[d]	12.50±0.52[ab]	7.92±0.04[ab]	2.59±0.51[c]	2.16±0.57[c]
	Pot T_3	15.50±0.29[e]	2.00±0.29[cd]	13.26±0.44[ab]	7.81±0.44[ab]	2.77±0.29[c]	2.58±0.38[a-c]
	Pot T_4	14.67±0.33[e]	1.67±0.67[d]	11.99±0.65[b]	7.02±0.28[b]	1.87±0.89[c]	2.19±0.44[bc]
	Pot T_5	15.67±0.33[de]	1.33±0.33[d]	12.27±0.72[b]	7.70±0.54[ab]	1.33±0.73[c]	3.00±0.14a[-c]
	Pot T_6	15.50±0.00[de]	2.00±0.58[cd]	11.82±0.92[b]	7.55±0.65[b]	2.33±0.73[c]	2.63±0.40[a-c]
	Pot T_7	14.83±0.44[e]	2.33±0.67[cd]	12.12±0.63[b]	7.08±0.25[b]	2.72±0.84[c]	2.36±0.36[bc]
LSD (0.05)		1.7485	4.2139	1.7075	1.4317	8.5014	0.9657
SEm		0.6015	1.4496	0.5874	0.4925	2.9245	0.3322
F value		2.8098*	1.621[NS]	0.3503[NS]	1.5407[NS]	1.2376[NS]	0.9586[NS]
CV%							

[Means followed by different letters within each column are significantly different, DMRT (p≤0.05). DAA: Days after application, LSD: Least significant difference, Sem: Standard error mean, CV: Coefficient of variation, *Significant at 5% level, **Significant at 1% level, NS: Not significant]

studies of Zapata-Sifuentes *et al.* (2022). The lower quality observed in the control and other treatments could be indicative of the importance of effective pest and disease management in achieving high-quality produce.

Conclusion

The research conducted provides substantial evidence that the application of biopesticides and botanical extracts can have a positive impact on cucumber cultivation. The field environment proved to be more conducive to cucumber growth, yielding a higher number of fruits plant^{-1} and superior fruit quality compared to pot cultivation.

Neem oil and *B. pumilus* emerged as effective treatments for promoting early flowering and increasing fruit yield. However, the study also revealed that the efficacy of treatments is highly dependent on environmental conditions and the specific combinations used. The findings underscore the importance of tailoring pest and disease management strategies to local conditions and suggest that sustainable agricultural practices can be optimized by incorporating natural biocontrol agents.

Future research should focus on elucidating the mechanisms behind the observed effects and exploring the long-term impacts of these treatments on soil health and ecosystem sustainability.

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