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Research Article

Influence of biocontrol agents on the population dynamics of pests in strawberry (*Fragaria ananasa*) cv. Sweet Charlie under different growing conditions

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ABSTRACT: Owing to its soft foliage, flowers and colourful sweet berries, strawberry attracts a wide range of insects for nectaring and pollination; nevertheless, it eventually becomes easily target for the destructive insects that have the potential to cause significant economic losses. Continuous and irrational heavy use of chemical pesticides in the last few decades has resulted in negative impacts on the environment and ecosystem. Therefore, the present study aimed to investigate the effectiveness of various biocontrol agents and growing conditions on the population dynamics of the insect pests. The present study consisted of 10 treatments, *viz*., T_1 (*Trichoderma viride* @20 g/L), T_2 (*Bacillus subtilis* @20 g/L), T_3 (*Pseudomonas fluorescens* @20 g/L), T_4 (Copper oxychloride @3 g/L) and T_5 (control) with two growing conditions (mulch and nonmulch), which replicated thrice. Among the biocontrol agents used, plants treated with *Bacillus* spp. were found to be least infested by four important serious insect pests, *Spodoptera exigua, S. litura, Somena scintillans* and snails (*Macrochlamys indica*) reported during the study. In growing conditions, pest infestation was recorded at its maximum in the mulched condition compared to the non-mulched condition.

KEYWORDS: Biocontrol agents, pest population, strawberry

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INTRODUCTION

Strawberry (*Fragaria ananassa*) belonging to the family Rosaceae (Garrido *et al*., 2011) is cultivated mostly in temperate regions. However, in recent times, it has also grown in subtropical regions due to its high market value and demand. Total production and area under cultivation for strawberries are rapidly increasing to meet the growing market demand. Globally, strawberry production increased to 9.00 million kg from 7.60 million kg during 2014 (FAO, 2019). Owing to short crop duration and high yield, strawberry has the potential to double the farmer's income. Nevertheless, the strawberry attracts a variety of insects, including the essential pollinators. Thus, they tend to invite and attract a range of insect pests, making them sensitive and susceptible to crop damage by insect pests.

Application of chemical pesticides to control insect pests in crops not only persists in the soil for long periods, and harms the beneficial microorganisms in the rhizosphere, but also renders fruit unsuitable for consumption. Thus, there is a growing demand for organic, eco-friendly and sustainable cultivation practices. Biological control agents have gained momentum in recent years for managing a variety of damaging insect pests (Syed *et al*., 2018). Biocontrol agents such as *Bacillus* species (Fira *et al*., 2018), *Trichoderma* species (Anwar *et al*., 2023), and *Pseudomonas* species (Flury *et al*., 2016) have been reported to be insect pathogens and control their infestation effectively by releasing different bioactive compounds. The entomopathogenic potential of the Bacillus genus has led to extensive exploration of the species (Mampallil *et al*., 2017).

Therefore, the present study aims at management of insect pests of strawberry *viz*.., *Spodoptera litura, S. exigua, Somena scintillans* and *Macrochlamys indica* through biocontrol agents in different growing conditions.

MATERIAL AND METHODS

Location and details of the experiment

An experiment was conducted in the Horticulture orchard of Assam Agricultural University, Jorhat, located at

26°43′41″ N and 94°12′05″ E from November 2022 to April 2023. The experiment was carried out in a strawberry field following factorial randomised block design, consisting of 10 treatments of different biocontrol agents, a chemical and a control, in two growing conditions (mulch and non-mulched). The biocontrol agents were incorporated in soil along with vermicompost, and Copperoxychloride was applied as a basal dose (soil application) during planting time, and then followed by three foliar applications (maintaining the same dose) at 15-day intervals. The treatment combinations are presented in Table 1.

Sample size and observations

A total of 30 plots, each consisting of 15 plants, were selected for the study (N=450). The plants were tagged with plates, and regular inspection was carried out every fortnight of the month. The pests were identified by the experts in the Department of Entomology, AAU-Jorhat, based on their morphological features, types of mouth parts, feeding habits, and the damage symptoms, including windowing, appearance of skeletonised leaves, shot hole-like and nibbled holes on the fruits and recorded accordingly. The observations started from the month of December when the infestation of the pests became more apparent.

The percentage of infestation

The percentage of plant infestation was calculated by following the formula given by Abott (1925):

$$\%\,\text{inf}\,estation\ of\ \ fruit\,/\,plant = \frac{No.\ of\ \ \text{inf}\,ested\ \ fruits\,/\,plant}{Total\ \ No.\ of\ \ fruits\,/\,plant} \times 100$$

Statistical analysis

The fortnightly collected data were assembled for each month and represented monthly. The data were then subjected to ANOVA using the online statistical analysis tool OPSTAT and analysed for significance level at 5%.

RESULTS AND DISCUSSION

An investigation aimed to evaluate the effectiveness of biocontrol agents on the population dynamics of pest infestation in strawberry compared to chemical and control treatments, showed significant variation ($p \leq 0.05$) among the treatments. The incidence, damage symptoms of infestation, population dynamics throughout the experimentation period, and effectiveness of the treatments against different identified pests are discussed separately.

***Beet armyworm, Spodoptera exigua* (Noctuidae: Lepidoptera) -**

Eminent characteristics of *S. exigua* observed were the colour of the larva is green or brown (Figure 1a). The 2nd instar larva of *S. exigua* feeds on the lower surface of the leaves, causing a symptom called windowing (Figure 1b). Upon severe infestation, they feed on the whole foliage, leaving only the main veins of the leaves (Figure 1c). The *S. exigua* is the main armyworm found in strawberries in California (Zalom *et al*., 2015). Newly hatched armyworms are often green in colour and feed in groups, skeletonising the undersides of leaves (Zalom *et al*., 2015).

Effect of different biocontrol and growing conditions on the incidence of Spodoptera exigua

The incidence of *S. exigua* is presented in Table 2. Significant differences were observed among the treatments for all four months. The maximum infestation of *S. exigua* was recorded in the month of Jan (13.46%) in nonmulch conditions. Meanwhile, in mulching conditions, 11.26% was recorded during the study period. Among the treatments, the average maximum infestation (19.39%) during the study period was recorded in the control, in January, while the least (0.91%) was recorded in *B. subtilis* in December. Likewise, the best treatment combination, interaction effect was seen in treatment G_1B_2, where only 0.75% average infestation was recorded in December, which was significantly different ($p \leq 0.05$) from the rest of the treatments. Meanwhile, the maximum average infestation during the four-month study period was recorded in Jan with 20.23% in G_2B_5, which was found statistically different ($p \leq 0.05$) and higher than all other treatments. It shows that treatment consisting of *B. subtilis* had the minimum pest infestation % throughout the experimentation period. In contrast, control alone and control with nonmulching had the highest level of infestation of *S. exigua*.

Table 1. Treatment combinations of the experiment

Treatments	Treatment combinations	Treatments	Treatment combinations
T_1=*Trichoderma viride* (20 g/L) + mulch	G_1B_1	T_6= *Pseudomonas fluorescens* (20 g/L) + nonmulch	G_2B_3
T_2=*Trichoderma viride* (20 g/L) + nonmulch	G_2B_1	T_7= Copperoxychloride (3 g/L) + mulch	G_1B_4
T_3= *Bacillus subtilis* (20 g/L) + mulch	G_1B_2	T_8= Copperoxychloride (3 g/L) + nonmulch	G_2B_4
T_4= *Bacillus subtilis* (20 g/L) + nonmulch	G_2B_2	T_9= Control + mulch	G_1B_5
T_5= *Pseudomonas fluorescens* (20 g/L) + mulch	G_1B_3	T_{10}= Control + nonmulch	G_2B_5

The *B. subtillis*-treated beds were least affected by the pest. It has been reported that *Bacillus* spp. changes the dynamics of microbiota and the bacterial diversity of the gut of *S. exigua* and affects their metabolic functions (Li *et al*., 2022). In addition, Hernandez-MartÍnez *et al*. (2008) found that Cry1 proteins from *Bacillus* spp. are reported to be toxic to *S. exigua* and thus increase their mortality rate. This might be due to those attributes of *Bacillus* spp. that significantly reduced the infestation or the population of *S. exigua* in the check during the study. Additionally, it was found that *Trichoderma* spp. treated plant had a lower infestation % than other treatments after *B.* spp. treated plants. *Trichoderma* spp. enhances the effectiveness and potential for use in the agrosystem by acting against the insect pest in two ways, directly (by parasitising insects and producing insecticidal secondary metabolites, antifeedant compounds, and repellent metabolites) and indirectly (by attracting natural enemies, activating systemic plant defensive responses, and parasitising insect-symbiotic microorganisms) (Poveda, 2021). Di Lelio *et al.* (2023) findings suggested *Spodoptera littoralis* larvae in their fourth instar displayed an imbalance (dysbiosis) in the functional composition and metabolic activities of the gut microbiota upon ingestion of leaves treated with *Trichoderma.*

Tobacco caterpillar, *Spodoptera litura* (Noctuidae: Lepidoptera)

The mature larva of *Spodoptera litura* is dark brown (Figure 2a). The older larva has a significant characteristic of a Y-shape on the head/thorax shield (Figure 2b). On the first abdominal segment of *S. litura,* there is a large black lateral patch/spot. The spot extends to the point where it interrupts the spiracular line. When the larva reaches the third stage, the mid dorsal line often has a bright yellow or orange dot/spot. There is a small white or light-coloured spot caudal to the spiracle on the abdominal segments. The larvae feed on the leaves, leaving a shot-hole-like symptom. They also feed typically from the outer margin of the leaves (Figure 2c). In the later stage, it feeds voraciously on the whole plant. The larvae feed on the outer margin of the leaves, including veins (Gupta *et al*., 2015).

Effect of different biocontrol agents and growing conditions on the incidence of Spodoptera litura

Data pertaining to the incidence of *Spodoptera litura* presented in Table 3 showed that there was a significant difference among the treatments during December to March. In terms of growing conditions, the maximum mean occurrence and infestation of *S. litura* was recorded in March in mulching

Table 2. Effect of biocontrol agents and growing conditions on insect incidence (%) of *Spodoptera exigua* species in strawberry

Treatments	Incidence (%)			
	Dec	Jan	Feb	Mar
Growing conditions				
G_1	8.39	11.26	10.79	9.82
G_2	10.54	13.46	12.87	12.14
SE(m)	**0.12**	**0.06**	**0.11**	**0.09**
C.D (5%)	**0.36**	**0.19**	**0.24**	**0.27**
Bioformulations				
T. viride	8.70	12.08	11.32	10.73
B. subtillis	0.91	3.19	2.72	1.69
P. fluorescens	8.35	10.98	10.51	9.94
Copperoxychloride	13.07	16.16	15.69	14.66
Control	16.30	19.39	18.92	17.89
SE(m)	**0.19**	**0.10**	**0.13**	**0.14**
C.D (5%)	**0.57**	**0.31**	**0.38**	**0.43**
Interaction				
G_1B_1	6.30	9.39	8.92	8.18
G_1B_2	0.75	2.71	2.24	1.21
G_1B_3	5.02	8.11	7.64	6.61
G_1B_4	14.46	17.55	17.08	16.05
G_1B_5	15.46	18.55	18.08	17.05
G_2B_1	11.11	14.78	13.73	13.28
G_2B_2	1.07	3.67	3.20	2.17
G_2B_3	11.69	13.85	13.38	13.28
G_2B_4	11.69	14.78	14.31	13.28
G_2B_5	17.14	20.23	19.76	18.73
SE(m)	**0.27**	**0.14**	**0.18**	**0.20**
C.D (5%)	**0.81**	**0.43**	**0.54**	**0.61**

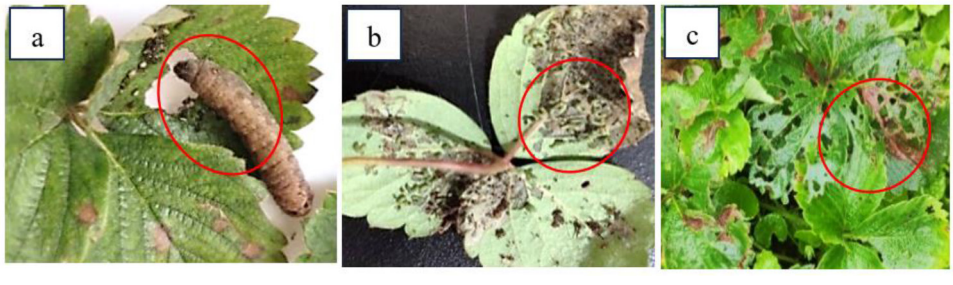


Figure 1. **(a)** *S. exigua* full-grown larvae, **(b)** 2nd instar larvae, **(c)** Damage symptoms of *S. exigua*.

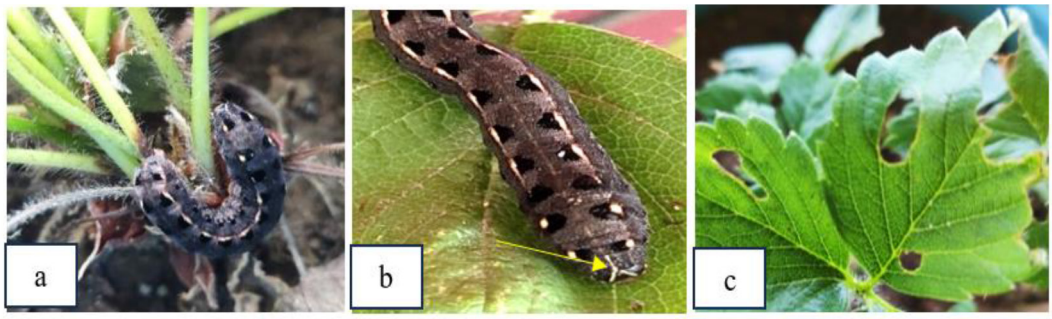


Figure 2. **(a)** *Spodoptera litura adult larva*, **(b)** Y-shaped pattern, **(c)** Damage symptoms of *S. litura*.

Table 3. Effect of biocontrol agents and growing conditions on insect incidence (%) of *Spodoptera litura* species in strawberry

Treatments	Incidence (%)			
	Dec	**Jan**	**Feb**	**Mar**
Growing conditions				
G_1	9.03	10.29	11.30	12.02
G_2	7.70	8.95	10.01	10.74
SE(m)	**0.13**	**0.16**	**0.07**	**0.02**
C.D (5%)	**0.40**	**0.48**	**0.21**	**0.05**
Bioformulations				
T. viride	6.33	7.58	8.58	9.29
Bacillus subtillis	0.53	1.89	2.82	3.57
P. fluorescens	6.34	7.25	8.43	9.18
Copperoxychloride	12.50	13.75	14.63	15.36
Control	16.14	17.63	18.81	19.49
SE(m)	**0.21**	**025**	**0.11**	**0.03**
C.D (5%)	**0.64**	**0.76**	**0.34**	**0.09**
Interaction				
G_1B_1	5.22	6.47	7.28	7.99
G_1B_2	0.78	1.90	2.95	3.70
G_1B_3	7.46	8.37	9.55	10.31
G_1B_4	15.33	16.58	17.43	18.18
G_1B_5	16.39	18.12	19.31	19.92
G_2B_1	7.44	8.69	9.87	10.59
G_2B_2	0.29	1.87	2.69	3.45
G_2B_3	5.22	6.14	7.32	8.06
G_2B_4	9.67	10.92	11.84	12.55
G_2B_5	15.89	17.14	18.32	19.07
SE(m)	**0.30**	**0.36**	**0.16**	**0.04**
C.D (5%)	**0.90**	**1.08**	**0.48**	**0.13**

conditions (12.02%). Meanwhile, 10.74% in the non-mulching condition was recorded. Among the treatments, the average maximum infestation during March was recorded in the control (19.49%), while the least (0.53%) was recorded in *B. subtilis*.

Likewise, the best treatment combination, interaction effect was seen in treatment G_2B_2, where only 0.29% average infestation was recorded in December, which was significantly different ($p \leq 0.05$) from the rest of the treatments. Meanwhile, the maximum average infestation during the four-month study period was recorded as 19.92% in G_1B_5 in March, which was found statistically different ($p \leq 0.05$) and higher than all other treatments. It shows that treatment consisting of *B. subtilis* had the minimum pest infestation % throughout the experimentation period. In contrast, control alone and control with mulching had the highest level of infestation of *S. litura*.

The results showed that the biocontrol treatment *B. subtillis* had the lowest incidence of *S. litura* infestation. This might be due to the production of lipopeptide biosurfactant by *Bacillus* spp. that binds and affects the midgut of larvae and destroys the epithelial cells and their boundaries (Ghribi *et al*., 2011 and Ghribi *et al*., 2012), thus affecting the population. Chandrasekaran *et al*. (2012) further reported that extracellular chitinase from *Bacillus* spp. had the potential to reduce the food consumption, digestion, growth rate, and weight and increase the mortality rate of *S. litura* when applied to host leaves. Also, Vineela *et al*. (2016) observed that Bt particles ranging from 105 to 210 nm had better insecticidal activity against *Spodoptera litura* compared to synthetic pesticides. Remarkably, Abd El-Salam *et al*. (2011) documented *B. subtilis* as a biological control agent that inhibits *Spodoptera littoralis,* which outperformed *Bacillus thuringiensis* in terms of efficiency. *Trichoderma* can activate plant defences against pathogen and pest attacks by colonising the roots. These defensive mechanisms can be activated both locally and systemically, primarily through the plant hormones Jasmonic Acid (JA) and Salicylic Acid (SA) (Poveda *et al*., 2020a, b). Tomato plants colonised by *T. atroviride* activate JA-mediated defensive responses, leading to proteinase inhibitor production in leaves, causing 100% cotton leafworm mortality in 25 days, while *Lansium domesticum* plants produce tannins, alkaloids and flavonoids in leaves, preventing mealybug feeding (Silva *et al*., 2019).

Hairy caterpillar, *Somena scintillans* Walker (Lymantriidae: Lepidoptera)

The characteristic feature of this insect is the dark brown larva with a black or yellow line with a tuff of black hair

covering the whole body and anal covered in bright orange turf (Figure 3a). The hairy caterpillar feeds on the green foliage of the plant, leading to defoliation. The damage symptoms of *S. scintillans* are shown in Figure 3b. The larvae feed on the soft green layers of the leaves, leaving an appearance of a skeletonised form (Figure 3c). This hampers photosynthesis, eventually leading to the death of the plant. The caterpillars passed through four instars. The second larva is the most active stage (Gupta *et al*., 2013).

Effect of different biocontrol agents and growing conditions on the incidence of Somena scintillans

Data pertaining to the incidence of *Somena scintillans* presented in Table 4 showed that there is a significant difference among the treatments during the months. The maximum damage to strawberries was recorded in the first week of December, and eventually, the population of *S. scintillans* declined drastically in the following months. In terms of growing conditions, the maximum mean occurrence and infestation of *S. scintillans* (8.51%) was recorded in mulch conditions during the study period. Meanwhile, in non-mulching conditions, 7.43% was recorded. Among the treatments, the average maximum infestation (10.81%) during the study period was recorded in the control, while the least (0.91%) was recorded in *B. subtilis*.

Likewise, the best treatment combination, interaction effect was seen in treatment G_2B_2, where only 0.44% average infestation was recorded, which was significantly different ($p \leq 0.05$) from the rest of the treatments. Meanwhile, the maximum average infestation during the four-month study period was recorded as 10.90% in G_1B_5, which was found statistically different ($p \leq 0.05$) and higher than all other treatments. It shows that treatment consisting of *B. subtilis* had the minimum pest infestation % throughout the experimentation period. In contrast, control alone and control with mulching had the highest level of infestation of *S. scintillans*. It has been reported that *T. viride* and *T. citrinoviride* can produce distinct molecules or compounds with antifeedant activity against various insects. Lepidoptera are the primary target of chitinases, which significantly reduce feeding by acting on the larvae's peritrophic membrane. resulting in detrimental effects on larval growth and development, potentially causing mortality in the cotton bollworm (*Helicoverpa armigera*) (Chinnaperumal *et al*., 2018) and the silkworm (*Bombyx mori*) (Berini *et al*., 2016).

Macrochlamys indica (Snail)

The *Macrochlamys indica* population was found at its peak during the rainy season. The adult snail had a soft brown shell with concentric like lines on the shell (Figure 4a). The

Table 4. Effect of biocontrol agents and growing conditions on Insect incidence (%) *Somena scintillans* species in strawberry

Treatments	Incidence (%)			
	Dec	Jan	Feb	Mar
Growing conditions				
G_1	8.51	7.70	7.57	7.07
G_2	7.43	6.42	6.18	5.68
SE(m)	**0.07**	**0.05**	**0.09**	**0.00**
C.D (5%)	**0.22**	**0.15**	**0.12**	**0.00**
Bioformulations				
T. viride	8.38	7.57	7.44	6.95
B. subtillis	2.34	1.53	1.40	0.91
P. fluorescens	8.75	8.41	8.28	7.78
Copperoxychloride	9.58	7.79	7.66	7.17
Control	10.81	9.99	9.57	9.07
SE(m)	**0.11**	**0.08**	**0.06**	**0.00**
C.D (5%)	**0.34**	**0.24**	**0.19**	**0.00**
Interaction				
G_1B_1	9.49	8.68	8.55	8.06
G_1B_2	2.82	2.01	1.88	1.39
G_1B_3	9.33	9.20	9.07	8.57
G_1B_4	10.00	8.52	8.39	7.90
G_1B_5	10.90	10.07	9.95	9.45
G_2B_1	7.27	6.46	6.33	5.84
G_2B_2	1.87	1.06	0.93	0.44
G_2B_3	8.18	7.61	7.49	6.99
G_2B_4	9.15	7.06	6.94	6.44
G_2B_5	10.72	9.91	9.20	8.70
SE(m)	**0.16**	**0.11**	**0.09**	**0.00**
C.D (5%)	**0.49**	**0.34**	**0.27**	**0.00**



Figure 3. **(a)** Adult *Somena scintillans*, **(b)** *S. scintillans* feeding on strawberry leaves, **(c)** Damage symptoms.

snail feeds on the soft foliage of strawberry leaves, starting from the edge of the leaves, petioles and nibbles on the fruit, making holes in it (Figure 4b). The nibbling of snails on the strawberry fruit made it unsuitable for marketing, resulting in economic loss (Figure 4c) (Wilen *et al*., 2018).

Effect of different biocontrol agents and growing conditions on the incidence of Macrochlamys indica

The incidence of *Macrochlamys indica* is shown in Table 5. Significant differences were observed among the treatments for all months. In terms of growing conditions, the maximum mean occurrence and infestation of *Macrochlamys indica* (6.00%) was recorded in mulching conditions during the study period. Meanwhile, in non-mulching conditions, 5.10% was recorded for Feb. Among the treatments, the average maximum infestation (6.54%) during the study period was recorded in the control, while the least (0.68%) was recorded in *B. subtilis*. Likewise, the best treatment combination, interaction effect was seen in treatment G_2B_2 in Dec, where only 0.46% average infestation was recorded, which was significantly different ($p \leq 0.05$) from the rest of the treatments. Meanwhile, the maximum average infestation during the four-month study period was recorded as 7.27% in G_1B_5 during Feb, which was found statistically different ($p \leq 0.05$) and higher than all other treatments. It shows that treatment consisting of *B. subtilis* had the minimum pest infestation % throughout the experimentation period. In contrast, control alone and control with mulching had the highest level of infestation of *M. indica*.

Additionally, the Volatile Organic Compounds (VOCs) of many *Trichoderma* species (*T. citrinoviride, T. viride*, and *T. harzianum*) serve as insect repellents, lessening the detrimental impacts on plant resources. By functioning as a repellent against one of the primary storage pests affecting stored common beans, *Trichoderma* spores applied to stored beans can reduce the number of seeds consumed by the beetle *A. obtectus* to 10% (Rodríguez-Gonz´alez *et al*., 2019, 2020).

The population of *M. indica* rose drastically from December, and the maximum incidence (%) was recorded in the month of February. The incidence (%) decreased by March. This is in line with Sallam and El-Wakeil (2012), who

Table 5. Effect of biocontrol agents and growing conditions on insect incidence (%) of snail (*Macrochlamys indica*) species in strawberry

Treatments	Incidence (%)			
	Dec	Jan	Feb	Mar
Growing conditions				
G_1	2.94	5.67	6.00	4.96
G_2	1.98	4.71	5.10	4.05
SE(m)	**0.09**	**0.00**	**0.04**	**0.00**
C.D (5%)	**0.29**	**0.00**	**0.12**	**0.00**
Bioformulations				
T. viride	2.21	4.94	5.33	4.28
B. subtillis	0.68	3.41	3.80	2.75
P. fluorescens	2.57	5.30	5.69	4.64
Copperoxychloride	3.42	6.15	6.40	5.35
Control	3.42	6.15	6.54	5.50
SE(m)	**0.06**	**0.00**	**0.06**	**0.00**
C.D (5%)	**0.20**	**0.00**	**0.19**	**0.00**
Interaction				
G_1B_1	2.92	5.65	6.04	4.99
G_1B_2	0.90	3.63	4.02	2.97
G_1B_3	2.68	5.41	5.80	4.75
G_1B_4	4.05	6.78	6.89	5.84
G_1B_5	4.15	6.88	7.27	6.22
G_2B_1	1.50	4.23	4.62	3.57
G_2B_2	0.46	3.19	3.58	2.53
G_2B_3	2.46	5.19	5.58	4.53
G_2B_4	2.79	5.52	5.91	4.86
G_2B_5	2.70	5.43	5.82	4.77
SE(m)	**0.09**	**0.00**	**0.09**	**0.00**
C.D (5%)	**0.29**	**0.00**	**0.27**	**0.00**

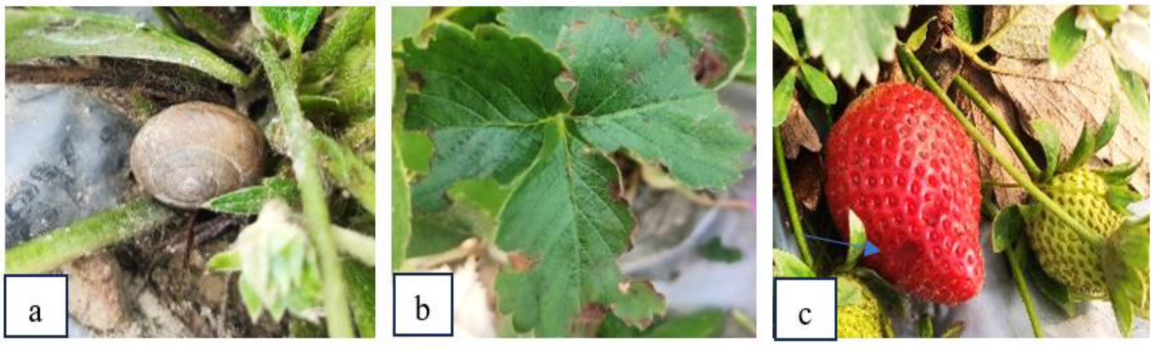


Figure 4. **(a)** Snail, **(b)** damage symptoms on leaves, **(c)** damage symptoms on fruits.

reported the fecundity rate, hatchability of eggs and longer life span of ground snails during December to October when the temperature remained moderately cool, while it decreased as the temperature rose, which our findings supported.

CONCLUSION

The study shows that the biocontrol agents greatly impacted the pest infestation. The *Bacillus subtilis*-treated plot recorded less infestation of insect pests, followed by *Trichoderma viride* and *Pseudomonas flourescens* treatments. In terms of growing conditions, pest infestation was recorded highest in the mulched condition, as the mulching materials harboured pests by providing a safe haven inside. Given the paucity of appropriate research on strawberry pests in northeastern India, we believe that this is most likely the first report of ecologically conscious pest management in strawberry from the area.

REFERENCES

Abott, W. S. 1925. A method of computing the effectiveness of insecticide. *J Eco Ent*, **18**: 265- 267. https://doi.org/10.1093/jee/18.2.265a

Abd El-Salam, A. M. E., Nemat, A. M., and Magdy, A. 2011. Potency of *Bacillus thuringiensis* and *Bacillus subtilis* against the cotton leafworm, *Spodoptera littoralis* (Bosid.) Larvae. Arch. *Phytopathol Plant Protec*, **44**(3): 204-215. https://doi.org/10.1080/03235400902952129

Anwar, W., Amin, H., Khan, H. A. A., Akhter, A., Bashir, U., Anjum, T., and Zohaib, K. A. 2023. Chitinase of *Trichoderma longibrachiatum* for control of *Aphis gossypii* in cotton plants. *Sci Rep*, **13**(1): 131-181. https://doi.org/10.1038/s41598-023-39965-y PMCid:PMC10425378

Berini, F., Caccia, S., Franzetti, E., Congiu, T., Marinelli, F., Casartelli, M., and Tettamanti, G. 2016. Effects of *Trichoderma viride* chitinases on the peritrophic matrix of Lepidoptera. *Pest Manag Sci,* **72**(5): 980-989. https://doi.org/10.1002/ps.4078

Chandrasekaran, R., Revathi, K., Nisha, S., Kirubakaran, S. A., Sathish-Narayanan, S., and Senthil-Nathan, S. 2012. Physiological effect of chitinase purified from *Bacillus subtilis* against the tobacco cutworm *Spodoptera litura* Fab. *Pesti Biochem Physio*, **104**(1): 65-71. https://doi.org/10.1016/j.pestbp.2012.07.002

Chinnaperumal, K., Govindasamy, B., Paramasivam, D., Dilipkumar, A., Dhayalan, A., Vadivel, A., *...,* Pachiappan, P. 2018. Bio-pesticidal effects of *Trichoderma viride* formulated titanium dioxide nanoparticle and their physiological and biochemical changes on *Helicoverpa armigera* (Hub.). *Pestic Biochem Physiol*, **149**: 26-36. https://doi.org/10.1016/j.pestbp.2018.05.005

Di Lelio, I., Forni, G., Magoga, G., Brunetti, M., Bruno, D., Becchimanzi, A., …, Pennacchio, F. 2023. A soil fungus confers plant resistance against a phytophagous insect by disrupting the symbiotic role of its gut microbiota. *Proc Natl Acad Sci*, **120**(10): e2216922120. https://doi.org/10.1073/pnas.2216922120 PMCid:PMC10013743

FAO. 2019. FAOSTAT agricultural statistics database. https://www.fao.org/3/ca6463en/ca6463en.pdf

Fira, D., Dimkic, I., Beric, T., Lozo, J., and Stankovic, S. 2018. Biological control of plant pathogens by *Bacillus* species. *J Biotec*, **285**: 44-55. https://doi.org/10.1016/j.jbiotec.2018.07.044

Flury, P., Aellen, N., Ruffner, B., Péchy-Tarr, M., Fataar, S., Metla, Z., and Maurhofer, M. 2016. Insect pathogenicity in plant-beneficial pseudomonads: phylogenetic distribution and comparative genomics. *ISME J*, **10**(10): 2527-2542. https://doi.org/10.1038/ismej.2016.5 PMCid:PMC5030700

Garrido, C., Carbú, M., Fernández-Acero, F. J., González-Rodríguez, V. E., and Cantoral, J. M. 2011. New insight in the study of strawberry fungal pathogens. In: Husaini AM, Mercado JA (eds). Genomics, transgenics, molecular breeding and biotechnology of strawberry (pp. 24-39). Global Science Books, Japan/UK.

Ghribi, D., Elleuch, M., Abdelkefi, L., and Ellouze-Chaabouni, S. 2011. Evaluation of larvicidal potency of *Bacillus subtilis* SPB1 biosurfactant against *Ephestia kuehniella* (Lepidoptera: Pyralidae) larvae and influence of abiotic factors on its insecticidal activity. *J Stor Prod Res*, **48**: 68-72. https://doi.org/10.1016/j.jspr.2011.10.002

Ghribi, D., Abdelkefi-Mesrati, L., Boukedi, H., Elleuch, M., Ellouze-Chaabouni, S., and Tounsi, S. 2012. The impact of the *Bacillus subtilis* SPB1 biosurfactant on the midgut histology of *Spodoptera littoralis* (Lepidoptera: Noctuidae) and determination of its putative receptor. *J Inverte Pathol,* **109**: 183-186. https://doi.org/10.1016/j.jip.2011.10.014

Gupta, R., Tara, J. S., and Pathania, P. C. 2013. First report of yellow tail tussock moth, *somena scintillans* Walker (Lepidoptera: Lymantriidae) on apple plantations in Jammu. *J Inst Sci*, **26**(1): 130-133.

Gupta, M., Tara, J. S., Sharma, S., and Bala, A. 2015. Biology and morphometry of *Spodoptera litura* Fabricus, a

serious defoliator of Mango (*Mangifera indica*) in Jammu Region (J and K). *Munis Ent Zool*, **10**: 215-221.

Hernandez-Martınez, P., Ferre, J., and Escriche, B. 2008. Susceptibility of *Spodoptera exigua* to 9 toxins from *Bacillus thuringiensis*. *J Inverte Patho*, **97**: 245-250. https://doi.org/10.1016/j.jip.2007.11.001

Li, Y., Zhao, D., Wu, H., Ji, Y., Liu, Z., Guo, X., Guo, W., and Bi, Y. 2022. Bt GS57 interaction with gut microbiota accelerate *Spodoptera exigua* mortality. *Front Microbiol,* **13**: 835227. https://doi.org/10.3389/fmicb.2022.835227 PMCid:PMC8989089

Mampallil, L. J., Faizal, M. H., and Anith, K. N. 2017. Bacterial bioagents for insect pest management. *J Entomol Zool Stud*, **5**(6): 2237-2244.

Poveda, J. 2020a. *Trichoderma parareesei* favors the tolerance of rapeseed (*Brassica napus* L.) to salinity and drought due to a chorismate mutase. *Agrono*, **10**: 118. https://doi.org/10.3390/agronomy10010118

Poveda, J. 2020b. Use of plant-defense hormones against pathogen-diseases of postharvest fresh produce. *Physiol Mol Plant Path*, **111**: 101521 https://doi.org/ 10.1016/j.pmpp.2020.101521

Poveda, J. 2021. Trichoderma as biocontrol agent against pests: New uses for a mycoparasite. *Bio Cont*, **159**: 104634. https://doi.org/10.1016/j.biocontrol.2021.104634

Rahman, S. F. S. A., Singh, E., Pieterse, C. M. J., and Schenk, P. M. 2018. Emerging microbial biocontrol strategies for plant pathogens. *Pl Sci*, **267**: 102-111. https://doi.org/10.1016/j.plantsci.2017.11.012

Rodríguez-Gonz´alez, A., Casquero, P. A., Cardoza, R. E., and Gutiérrez, S. 2019. Effect of trichodiene synthase encoding gene expression in *Trichoderma* strains on their effectiveness in the control of *Acanthoscelides obtectus*. *J Stored Prod Res*, **83**: 275-280. https://doi.org/10.1016/j.jspr.2019.07.006

Rodríguez-González, Á, Campelo, M. P., Lorenzana, A., Mayo-Prieto, S., González-López, Ó, Álvarez-García, S., …, Casquero, P. A. 2020. Spores of *Trichoderma* strains sprayed over *Acanthoscelides obtectus* and *Phaseolus vulgaris* L. beans: effects in the biology of the bean weevil. *J Stored Prod Res*, **88**: 101666. https://doi.org/10.1016/j.jspr.2020.101666

Sallam, A., and El-Wakeil, N. 2012. Biological and ecological studies on land snails and their control. In: Soloneski S (ed.). Integrated pest management and pest control - current and future tactics (413-444). Tech Europe University Campus Step Ri Slavka Krautzeka 83/A 51000 Rijeka, Croatia. https://doi.org/10.5772/29701

Silva, B. B., Banaay, C. G., and Salamanez, K. 2019. *Trichoderma*-induced systemic resistance against the scale insect (*Unaspis mabilis* Lit and Barbecho) in lanzones (*Lansium domesticum* Corr.). *Agric For*, **65**(2): 59-78. https://doi.org/10.17707/ AgricultForest.65.2.05

Vineela, V., Thiyagarajan, N., Reddy, G., and Devi, P. 2016. Enhanced bioefficacy of *Bacillus thuringiensis* var. kurstaki against *Spodoptera litura* (Lepidoptera: Noctuidae) through particle size reduction and formulation as a suspension concentrate. *Biocon Sci Techno*, **27**(1): 1-12. https://doi.org/10.1080/09583157.2016.1247433

Wilen, C. A., and Flint, M. L. 2018. *Snails and slugs*. University of California. IPM Pest Notes Publication, 7427.

Zalom, F. G., Bolda, M. P., Dara, S. K., and Joseph, S. U. C. 2015. IPM pest management guidelines: Strawberry. UC ANR Publication 3468. https://ipm.ucanr.edu/legacy_assets/pdf/pmg/pmgstrawberry.pdf