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GROWTH, YIELD AND PEST INFESTATION ASSESSMENT OF *SOLANUM LYCOPERSICUM* UNDER PEST EXCLUSION NET (PEN) TECHNIQUE IN BANGLADESH

MI Hosen[1, 2*#], MN Hoque[2*#], MA Rahim[3], A Hannan[3], T Biswas[2] and K Akter[2]

[1]Department of Agricultural Extension, The Government of the People's Republic of Bangladesh
[2]Khulna Agricultural University, Khulna-9100, Bangladesh
[3]Bangladesh Agricultural University, Maymenshing-2202, Bangladesh
# equally contributed

Abstract

Tomato (*Solanum lycopersicum* L.) is one of the most popular vegetable crops in Bangladesh. The production of this crop in open field is constrained by major pests like fruit borer, yellow striped armyworm and caterpillar. A pest exclusion net (PEN) experiment was carried out to assess the performance of seven varieties of tomato through growth, yield and pest occurrence. The two-factor experiment was carried out in randomized complete block design (RCBD) with three conditions *viz*. under net without pesticide, no net with pesticide, no net without pesticide and three replications. Data were analyzed with MSTAT-Cv. 2.1 software package and means were separated by Duncan's multiple range test (DMRT) at 1% level of significance. The result revealed that crop under PEN had maximum plant height (98.47±1.02 cm), inflorescence number per plant (20.34±0.06), open flowers number per plant (69.34±2.02), fruit number per plant (43.12±0.03), individual fruit weight (49.70±0.02 g), gross yield (50.76±1.06 tons/ha) whereas no net with or without pesticide condition produced the minimum above traits. However, most of the parameters showed decreasing trend under no net condition except pest incidence. This study shows that the use of PEN protect tomato against pests, increases growth and yield which can be considered as a viable technology for tomato production by marginal farmers of Bangladesh.

***Key words*:** PEN, Pest Incidence, Pesticide, Growth, Yield

Introduction

Tomatoes (*Lycopersicon esculentum* L.) are one of the nutritionally most important and popular vegetables in the world. Tomato plants belong to the family Solanaceae and are normally a self-pollinated annual crop. Cultivated tomato is the third most commonly consumed vegetable, just next to potato (FAO 2016), and in Bangladesh, it ranks second, which is next to potato and tops the list of canned vegetables (BBS 2016). In Bangladesh, the area of tomato cultivation is about 67535 acres, with a production of about 368121 metric tons (BBS 2016). Vegetable production can help farmers generate income, which eventually alleviates poverty and malnutrition (Sharmin et al. 2019). It is an important condiment in most diets and a very cheap source of vitamins like A, C, E, fibers, and minerals (Olaniyi 2010).

The production of *Lycopersicon esculentum* has been declining for the last few years in the country (BBS 2016). Infestation by numerous insect-pests is a prominent reason for the decline in the production of *L.*

*Author for correspondence: najmulhaque466@gmail.com

esculentum. Fruit borer (*Helicoverpa armigera*), whitefly (*Bemisia tabaci*), thrips (*Frankliniella occidentalis*), red spider mites (*Tetranychus evansi*), cutworms (*Agrotis segetum*), leafhoppers (*Empoasca fabae*), and aphids (*Aphis gossypii*) are among these pests (Varela et al. 2003). Every year, an attack on tomatoes causes massive economic losses (BBS 2016). Current control strategies are heavily reliant upon insecticide sprays at the farm level, although they are expensive and unbearable for small-scale tomato growers. Globally, agriculture consumes a significant amount of pesticides, around 85% of the estimated 3.5 million tons used each year (Sharma et al. 2019). Awareness among urban consumers about the quality of their food and the harmful effects of poisonous residues has increased greatly. Hence, vegetable growers, especially small-holders, face the challenge of producing more with the reduced use of chemical pesticides (Hoque et al. 2022). The current negative opinion by the general public and by scientists of the non-target toxicity of pesticides on humans (Sellare et al. 2020), on beneficial arthropods and on the environment (Ganguly et al. 2021), stresses the urgency of alternative pest management strategies. More than 242 pesticides have been registered in Bangladesh and more than 87% of the pesticides used are against insect pests and are broad spectrum, applied without considering the consumer's health and surrounding environment (Shammi et al. 2020, Ganguly et al. 2021).

The overuse of hazardous pesticides by smallholder farmers not only results in negative impacts on human health and the environment but also increases resistance of pests and destroys beneficial insect. In this circumstance, tomato production under pest exclusion net (PEN) could meet this challenge by increasing the production by reducing insect-pests incurred losses and simultaneously decreasing the dependence of small-holders to chemical insecticides. PEN is one kind of mosquito net that creates aphysical barrier against insect pests and associated diseases. This technology simply involves the covering of tomato field by net. The nets are easy to use and can also serve as floating row covers to control temperature, light, relative humidity, and soil moisture for plant production. Therefore, this study was carried out to assess the efficacy of PEN in controlling the major pests of tomato (*Lycopersicon esculentum*) and its effectiveness in sustainable growth and production of tomato in sub-continent conditions and compare the yield of tomato in PEN with other treatments.

Materials and Methods

Planting Materials and Experimental site

The experiment was conducted at the USDA Allium field laboratory of the Horticulture farm at Bangladesh Agricultural University (BAU), Mymensingh, Bangladesh from October, 2016 to March, 2017. The present research work was conducted at 24.60 N latitude and 90.50 E longitudes (Edris et al.1979) with an elevation of approximately 19 m above sea level. On the other hand, the laboratory work was done at the Horticulture Department Laboratory. The tomato varieties used in the experiment were Unnayan tomato, BARI Tomato-16, BARI Tomato-2, BARI Tomato-3, BARI Hybrid Tomato-5, BARI Hybrid Tomato-7 and BARI Tomato-14. The seeds of these varieties were collected from Bangladesh Agricultural Research Institute (BARI). The seeds were sown in the seed bed for raising seedlings. Temperature (°C), relative humidity (%), and light intensity (lux) were measured three times per day in the experimental field. Data was recorded during the experiment season.

Table 1: The average data of the experimental field.

Climatic condition	Net condition	9.00 am	12.00 pm	4.00 pm
Temperature	No net (open)	20.59°C	23.38°C	22.27°C
	White net	23.07°C	26.17°C	23.92°C
Relative humidity (%)	No net (open)	78.25	67.25	60.00
	White net	75.50	65.20	62.25
Light intensity (lux)	No net (open)	295.00	340.20	116.50
	White net	222.00	249.12	97.75

Experimental designs and treatments

The two-factor experiment was carried out in a Randomized Complete Block Design (RCBD) with three replications. There were three treatments assigned randomly to the plot of 4.62 m^2 each. The experimental area was divided into three blocks. Plant spacing was 70 cm x 60 cm per plot. The experimental material consisted of 07 varieties of winter tomato (V1 = Unnayan Tomato, V2 = BARI Tomato-16, V3 = BARI Tomato-2, V4 = BARI Tomato-3, V5 = BARI Hybrid Tomato-5, V6 = BARI Hybrid Tomato-7, V7 = BARI Tomato-14) were planted in healthy plot to assess different growth, yield and pest incidence attributing traits.

The whole plot was covered by white color pest exclusion net according to the experimental design and the size of the plot. The net was brought from the local market. The mesh size was 40 per square inch. The net was tied with bamboo, and the bamboo was 6 feet in height so that data collection or other intercultural operations could easily be done. The netting (T1: PEN without pesticides, T2: No PEN with pesticides, T3: No PEN no pesticides) was done 05 days after the transplantation of tomato seedlings into the main field.

Data collection and statistical analysis

Growth and pest infestation data were collected 15 days after transplanting up to 57 or 71 days after transplanting at 7-days interval. The fruits were harvested at 7-days intervals at their mature and ripening stages. The maturity of the crop was determined on the basis of the red coloring of the fruits. Data were recorded on the following parameters from the sampled plants during the experiment at period. Five plants were randomly selected from each plot to record data. The collected data were analyzed by analysis of variance (ANOVA table). A statistical computer package MSTAT-C v. 2.1 was used for analyzing data. The analysis was performed F-test and significance of the difference between pairs of lines was evaluated by the Least Significant Difference (LSD) test at 1% level of probability (Gomez and Gomez 1984).

Results

Effect of PEN on growth and yield parameters of studied tomato varieties

The combined effects of both treatments and varieties were statistically significant. The plant height of tomatoes was gradually increased at 57 DAT (Table 2). The height of the plant was significantly influenced by the net. At 57 DAT, the maximum plant height (107.13±1.02 cm) was obtained from T1V5 (PEN without pesticides in BARI Hybrid Tomato-5) and the minimum plant height (73.73±0.03 cm) was obtained from T2V4 (BARI Tomato-3 where no net with pesticide was used) (Table 2). The maximum number of inflorescence was observed in T1V1 (25.05±0.02) where PEN without pesticides was practiced in Unnayan

Tomato and the lowest number of inflorescence was produced (T2V4 = 16.47) in case of BARI Tomato-3 where treatment was no net with pesticide (Table 3).

The combined effects of both treatments and varieties were also significant in respect of number of opened flowers, fruits and individual fruit weights (g) per plant. The maximum number of opened flowers per plant was found in PEN without pesticides condition from Unnayan Tomato combination (T1V1 = 81.13±0.02) where the minimum was obtained from BARI Tomato-16 under control condition (T3V2 = 48.92±0.02) combination (Table 3). The maximum number of fruits were obtained from PEN without pesticide condition from the Unnayan Tomato (T1V1 = 52.50±0.06) and the minimum number of fruits were obtained from BARI Tomato-16 under control condition (T3V2 = 29.24±0.01) (Table 3). Similarly, PEN without pesticides treatment in BARI Hybrid Tomato-5 gave maximum individual fruit weight (T1V5 = 56.77±0.02 g) and the lowest single fruit weight (T2V1 = 37.25±0.03 g) was observed in combination of Unnayan Tomato with no net with pesticide (Table 3). Moreover, the maximum yield of tomato per plot (T1V5 = 30.04±1.06 kg) was observed in PEN without pesticides in BARI Hybrid Tomato-5 and the minimum yield of tomato was found on BARI Tomato-16 under control conditions (T3V2 =12.64±1.06 kg) (Table 4). Similar results were obtained in thecase of gross and marketable yield per hectare (Table 4).

Table 2. Combined effects of pest exclusion net conditions and variety on plant height at different days after transplanting (DAT) of tomato.

Treatment combination	Plant height (cm) at DAT						
	15	22	29	36	43	50	57
T_1V_1	23.87±0.02	31.20±0.06	51.33±0.06	63.67±0.06	89.20±0.03	106.20±0.06	106.53±0.01
T_1V_2	23.20±1.02	29.07±0.02	50.93±0.06	59.87±0.03	83.67±2.01	98.27±0.02	98.27±1.02
T_1V_3	22.60±2.01	28.40±0.06	49.93±0.02	61.80±0.03	78.47±1.5	95.93±0.06	96.60±1.01
T_1V_4	20.27±0.02	26.33±1.5	48.53±0.03	63.33±1.06	75.40±2.01	88.07±0.06	89.60±1.5
T_1V_5	24.97±0.06	31.27±0.06	52.47±0.06	65.67±0.03	89.27±1.5	107.00±0.02	107.13±1.02
T_1V_6	20.67±1.5	26.33±0.02	49.53±0.02	67.47±0.03	78.33±1.5	89.87±0.03	91.00±0
T_1V_7	23.40±1.02	30.13±1.5	51.27±0.06	67.27±1.06	87.20±2.01	99.60±0.03	100.13±0.03
T_2V_1	20.87±0.03	28.33±0.02	46.93±0.03	58.20±0.03	72.93±2.01	82.60±0.03	83.13±0.02
T_2V_2	18.80±0.05	26.47±1.5	45.07±0.06	55.93±1.06	69.53±0.03	78.47±0.02	77.93±1.02
T_2V_3	18.80±0.12	26.00±0.02	44.40±0.02	54.67±0.03	66.87±0.06	76.47±0.03	77.33±0.02
T_2V_4	16.47±0.03	22.00±0.06	42.67±0.02	51.00±0	63.33±0.03	72.40±0.02	73.73±0.03
T_2V_5	22.20±0.02	30.33±1.5	48.07±0.02	62.33±0.03	77.53±1.5	89.20±0.03	89.53±1.02
T_2V_6	17.80±0.02	24.27±0.06	43.73±0.01	53.13±0.06	64.53±0.03	74.53±0.06	75.27±0.03
T_2V_7	19.47±0.06	27.20±1.5	45.80±0.01	56.93±0.06	71.27±0.03	81.73±0.02	82.67±0.03

Contd. (Table 2)

T_3V_1	21.47±0.01	30.00±0	48.20±0.03	59.80±1.06	76.53±0.06	88.93±0.01	89.00±0
T_3V_2	20.93±0.03	28.73±0.02	45.07±0.06	58.20±0.03	71.87±1.5	83.80±0.03	84.40±2.05
T_3V_3	19.20±0.12	26.73±0.02	44.93±0.03	56.67±1.06	70.13±0.06	83.33±0.01	84.33±1.02
T_3V_4	17.40±0.02	24.00±0	43.33±0.01	54.07±0.06	66.13±0.03	73.27±0.06	73.80±0.03
T_3V_5	22.47±0.06	31.07±0.02	48.87±0.03	64.20±0.03	79.20±0.06	89.20±0.03	89.93±1.02
T_3V_6	18.00±0.02	25.13±1.5	44.33±0.06	56.53±1.06	67.93±1.5	74.73±0.01	75.40±0.03
T_3V_7	21.13±0.05	30.00±0.02	46.20±0.06	59.73±1.02	75.93±0.03	84.47±0.03	86.13±0.02
$LSD_{0.05}$	0.62	1.04	0.44	0.96	1.21	1.42	1.22
$LSD_{0.01}$	0.83	1.39	0.58	1.28	1.61	1.90	1.63
Level of significance	**	**	**	**	**	**	**

T1 = Net without pesticide, T2 = No net with pesticide, T3 = No net no pesticide (control). V1 = Unnayan Tomato, V2 = BARI Tomato-16, V3 = BARI Tomato-2, V4 = BARI Tomato-3, V5 = BARI Hybrid Tomato-5, V6 = BARI Hybrid Tomato-7, V7 = BARI Tomato-14, ** = Significant at 1% level of probability.

Table 3. Combined effects of pest exclusion net conditions and variety on yield contributing characters of tomato at different days after transplanting.

Treatment combination	Inflorescence number/plant	Open flowers number /plant	Fruit number/plant	Individual fruit wt. (g)
T_1V_1	25.05±0.02	81.13±0.02	52.50±0.06	38.85±0.02
T_1V_2	17.07±1.02	60.94±0.06	36.29±0.02	43.62±0.01
T_1V_3	18.51±2.01	65.67±0.02	39.61±0.06	50.33±0.02
T_1V_4	17.71±0.03	63.22±0.03	36.71±0.06	47.88±0.03
T_1V_5	22.49±0.06	75.40±0.02	48.10±0.02	56 .77±0.06
T_1V_6	22.11±0.02	70.74±0.03	47.64±0.06	55.76±0.02
T_1V_7	19.41±0.03	68.26±1.02	40.97±0.03	52.75±0.06
T_2V_1	22.89±0.01	79.95±0.02	49.12±0.02	37.59±0.06
T_2V_2	15.96±0.02	50.43±0.01	31.58±0.03	42.33±0.02
T_2V_3	17.90±2.01	56.03±0.02	34.84±1.02	46.00±0.06
T_2V_4	17.03±0.02	54.00±0.03	32.18±0.02	44.89±0.03

Contd. (Table 3)

T_2V_5	20.55±0.02	73.17±0.01	46.06±1.02	56.66±0.06
T_2V_6	19.99±1.02	69.64±0.02	41.42±0.02	52.83±0.02
T_2V_7	18.65±2.02	59.70±2.02	38.02±1.02	47.59±2.02
T_3V_1	21.21±0.02	71.50±0.01	41.74±2.02	55.30±0.02
T_3V_2	15.03±0.01	48.92±0.02	29.24±0.01	39.29±0.02
T_3V_3	16.43±1.02	52.98±0.06	31.56±0.02	42.52±1.02
T_3V_4	15.56±0.01	50.44±0.02	30.23±0.01	39.71±0.02
T_3V_5	19.25±0.02	60.95±1.02	37.43±0.01	53.13±1.02
T_3V_6	18.68±1.02	59.13±2.03	32.94±0.03	50.64±0.02
T_3V_7	18.36±1.02	56.51±0.02	32.13±1.03	43.96±1.02
$LSD_{0.05}$	1.07	1.84	0.94	1.89
$LSD_{0.01}$	1.43	2.46	1.26	2.53
Level of significance	**	**	**	**

T1 = Net without pesticide, T2 = No net with pesticide, T3 = No net no pesticide (control). V1 = Unnayan Tomato, V2 = BARI Tomato-16, V3 = BARI Tomato-2, V4 = BARI Tomato-3, V5 = BARI Hybrid Tomato-5, V6 = BARI Hybrid Tomato-7, V7 = BARI Tomato-14, ** = Significant at 1% level of probability.

Table 4. Combined effects of pest exclusion net conditions and variety on yield and marketable yield of tomato.

Treatment combination	Gross yield/plot (kg)	Gross yield (t ha^{-1})	Marketable yield/plot (kg)	Marketable yield (t ha^{-1})
T_1V_1	22.44±0.02	48.56±2.01	20.42±0.03	44.19±0.06
T_1V_2	17.41±0.03	37.69±1.06	15.85±1.06	34.30±1.03
T_1V_3	21.93±1.02	47.47±2.02	19.96±2.02	43.19±0.02
T_1V_4	19.33±2.02	41.85±1.03	17.59±1.01	38.08±0.03
T_1V_5	30.04±1.06	65.02±0.01	27.33±0.06	59.16±1.02
T_1V_6	29.22±1.02	63.25±0.06	26.59±0.02	57.56±0.03
T_1V_7	23.77±0.06	51.46±0.01	21.63±0.08	46.83±1.02
T_2V_1	20.31±0.03	43.96±0.02	17.26±0.03	37.37±0.06

Contd. (Table 4)

T_2V_2	14.70±0.06	31.83±0.01	12.50±0.02	27.05±2.02
T_2V_3	17.63±0.06	38.16±0.03	14.98±3.02	32.43±0.03
T_2V_4	15.89±0.02	34.39±0.01	13.51±1.01	29.24±0.02
T_2V_5	28.71±2.02	62.14±0.08	24.40±0.06	52.82±0.01
T_2V_6	24.07±1.05	52.10±1.5	20.46±1.06	44.29±2.02
T_2V_7	19.90±2.06	43.08±0.06	16.92±0.02	36.62±1.06
T_3V_1	25.39±1.02	54.96±1.5	20.57±2.06	44.52±2.03
T_3V_2	12.64±1.06	27.35±1.06	10.24±1.06	22.16±2.02
T_3V_3	14.76±1.05	31.95±0.02	11.96±1.01	25.88±3.02
T_3V_4	13.20±0.02	28.58±1.05	10.70±0.08	23.15±1.06
T_3V_5	21.88±1.05	47.35±2.02	17.72±0.06	38.35±1.03
T_3V_6	18.35±2.02	39.72±1.05	14.86±2.02	32.17±3.02
T_3V_7	15.54±3.06	33.63±0.02	12.58±1.03	27.24±2.02
$LSD_{0.05}$	2.24	2.99	2.33	2.90
$LSD_{0.01}$	2.99	4.00	3.11	3.87
Level of significance	**	**	**	**

T1 = Net without pesticide, T2 = No net with pesticide, T3 = No net no pesticide (control). V1 = Unnayan Tomato, V2 = BARI Tomato-16, V3 = BARI Tomato-2, V4 = BARI Tomato-3, V5 = BARI Hybrid Tomato-5, V6 = BARI Hybrid Tomato-7, V7 = BARI Tomato-14.

** = Significant at 1% level of probability.

Effect of PEN on pest infestation in studied tomato varieties

Significant differences were observed in total insect-pest incidence for different treatments with different varieties. The combination of net and variety resulted in the highest insect-pest incidence (T3V3 = 33.33±0.06%) in BARI Tomato-2 under control, while net without pesticide resulted in the lowest insect-pest incidence (Table 5). Similarly, significant differences were observed in total disease infection for different treatments with different conditions. The effect of PEN showed that maximum disease infection was in control condition and minimum disease infection in plants was observed in the case of net without pesticide (Table 6).

Table 5. Combined effects of pest exclusion net conditions and variety on percentage of insect infected plants per plot.

Treatment combination	% Inset infected plants/plot at DAT						
	29	36	43	50	57	64	71
T_1V_1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T_1V_2	0.00	0.00	0.00	0.00	0.00	3.03±0.01	3.03±0.06
T_1V_3	0.00	0.00	0.00	0.00	3.03±0.02	6.06±0.05	9.09±0.02
T_1V_4	0.00	0.00	0.00	0.00	0.00	0.00	3.03±0.03
T_1V_5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T_1V_6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T_1V_7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T_2V_1	0.00	0.00	0.00	0.00	3.03±0.03	9.09±0.06	15.15±0.01
T_2V_2	0.00	0.00	0.00	3.03±0.02	6.06±0.03	12.12±0.06	18.18±0.02
T_2V_3	0.00	3.03±0.02	3.03±0.05	3.03±0.02	6.06±0.05	12.12±0.01	18.18±0.02
T_2V_4	0.00	0.00	0.00	3.03±0.01	6.06±0.06	12.12±0.03	18.18±0.05
T_2V_5	0.00	0.00	0.00	0.00	0.00	6.06±0.05	12.12±0.02
T_2V_6	0.00	0.00	0.00	0.00	3.03±0.06	9.09±0.01	15.15±0.03
T_2V_7	0.00	0.00	0.00	3.03±0.02	3.03±0.02	9.09±0.03	15.15±0.02
T_3V_1	0.00	0.00	0.00	0.00	3.03±0.05	12.12±0.01	27.27±0.06
T_3V_2	0.00	3.03±0.01	3.03±0.05	3.03±0.01	6.06±1.02	15.15±3.03	30.30±2.01
T_3V_3	0.00	3.03±0.02	3.03±0.05	3.03±0.01	6.06±2.06	15.15±1.02	33.33±0.06
T_3V_4	0.00	0.00	3.03±0.01	3.03±0.02	6.06±0.03	15.15±1.02	30.30±1.03
T_3V_5	0.00	0.00	0.00	0.00	3.03±1.02	9.09±0.06	27.27±1.03
T_3V_6	0.00	0.00	0.00	0.00	6.06±0.01	12.12±0.1	27.27±0.01
T_3V_7	0.00	0.00	0.00	3.03±0.02	6.06±0.05	12.12±0.06	30.30±0.05
$LSD_{0.05}$	-	-	-	-	0.17	0.80	1.23
$LSD_{0.01}$	-	-	-	-	0.23	1.07	1.65
Level of significance	-	-	-	-	**	**	**

T1 = Net without pesticide, T2 = No net with pesticide, T3 = No net no pesticide (control). V1 = Unnayan Tomato, V2 = BARI Tomato-16, V3 = BARI Tomato-2, V4 = BARI Tomato-3, V5 = BARI Hybrid Tomato-5, V6 = BARI Hybrid Tomato-7, V7 = BARI Tomato-14. ** = Significant at 1% level of probability.

Table 6. Combined effects of pest exclusion net conditions and variety on percentage of disease infestation in plants per plot.

Treatment combination	Disease infected plant/plot (%) at DAT						
	29	36	43	50	57	64	71
T_1V_1	0.00	0.00	3.03±0.01	6.06±0.03	9.09±0.03	9.09±0.01	9.09±0.05
T_1V_2	0.00	3.03±0.02	9.09±0.04	18.18±0.06	18.18±0.02	21.21±0.02	21.21±0.03
T_1V_3	0.00	3.03±0.06	12.12±0.03	24.24±0.01	27.27±0.02	30.30±1.02	30.30±0.01
T_1V_4	0.00	0.00	9.09±0.01	15.15±0.03	18.18±0.02	18.18±2.02	18.18±1.02
T_1V_5	0.00	0.00	0.00	0.00	3.03±0.02	6.06±0.02	6.06±0.01
T_1V_6	0.00	0.00	9.09±0.03	9.09±0.02	9.09±0.02	12.12±0.06	15.15±0.02
T_1V_7	0.00	0.00	9.09±0.01	15.15±0.02	15.15±1.02	15.15±0.03	15.15±1.02
T_2V_1	0.00	0.00	6.06±0.1	9.09±0.06	12.12±0.03	15.15±0.01	15.15±0.06
T_2V_2	3.03±0.02	9.09±0.05	21.21±0.2	24.24±0.03	36.36±0.06	39.39±0.03	39.39±1.02
T_2V_3	3.03±0.06	9.09±0.01	21.21±0.06	27.27±0.02	42.42±0.01	45.45±0.02	48.48±3.02
T_2V_4	3.03±0.03	6.06±0.02	18.18±0.02	24.24±0.02	30.30±0.03	33.33±0.02	36.36±1.02
T_2V_5	0.00	0.00	0.00	3.03±0.02	6.06±0.02	6.06±0.01	9.09±0.03
T_2V_6	0.00	3.03±0.04	9.09±0.02	15.15±0.02	15.15±0.02	18.18±0.02	18.18±0.06
T_2V_7	0.00	3.03±0.01	18.18±0.02	21.21±1.02	27.27±0.02	30.30±0.01	30.30±0.06
T_3V_1	0.00	0.00	6.06±0.02	9.09±0.02	15.15±0.02	18.18±0.01	18.18±0.01
T_3V_2	3.03±0.03	6.06±0.01	21.21±1.06	27.27±1.01	45.45±1.02	51.52±0.04	51.52±2.06
T_3V_3	3.03±0.01	9.09±0.01	30.30±3.01	33.33±1.03	45.45±2.06	51.52±2.02	51.52±2.02
T_3V_4	3.03±0.02	6.06±0.05	21.21±1.02	27.27±0.02	42.42±0.02	45.45±0.03	45.45±3.02
T_3V_5	0.00	0.00	6.06±0.03	6.06±0.01	6.06±0.02	9.09±0.02	9.09±0.02
T_3V_6	0.00	3.03±0.01	15.15±0.01	12.12±0.06	15.15±0.02	18.18±0.02	18.18±0.01
T_3V_7	0.00	3.03±0.01	18.18±0.02	21.21±0.03	39.39±0.02	39.39±0.01	42.42±3.02
$LSD_{0.05}$	-	0.07	0.23	0.24	0.52	0.58	0.42
$LSD_{0.01}$	-	0.10	0.31	0.33	0.70	0.78	0.57
Level of significance	-	**	**	**	**	**	**

T1 = Net without pesticide, T2 = No net with pesticide, T3 = No net no pesticide (control). V1 = Unnayan Tomato, V2 = BARI Tomato-16, V3 = BARI Tomato-2, V4 = BARI Tomato-3, V5 = BARI Hybrid Tomato-5, V6 = BARI Hybrid Tomato-7, V7 = BARI Tomato-14.

** = Significant at 1% level of probability.

Discussion

The growth and yield attributes of a plant are influenced by several factors. For example, plant height, which is an important growth parameter may alter crop growth attributing characters and subsequently yield (Roy et al. 2014). The results of this study revealed that plant height increased steadily with the advancement of time. This was fluctuated significantly with the diverse varieties and treatments. PEN without pesticides contributed to maximum plant height (T1) whereas the minimum heights were recorded from T2 and T3which means without net implementation. Gogo et al. (2014) and Ramesh and Arumugam (2010) reported that PEN modifies microclimatic conditions within the net house which may enhance photosynthesis and respiration due to the favorable growth environment. These results were also obtained in the study where temperature, soil moisture, and light intensity were favorable in net compared to open conditions for proper plant growth accompanying the rapid increase and expansion of plant cells.

The insect pest infestation in tomatoes was lowest in PEN without pesticides, whereas without net implementation, it was troubled with severe pest infestation in open condition. PEN uninterruptedly eliminates the destructive insects like fruit borer, yellow striped armyworm, caterpillar, silver leaf whitefly, aphids, thrips and mites. Therefore, insects can't lay egg on the leaves surface and consequently, the larvae are unable to damage the leaves or shoots of tomato. But in open conditions, the tomato plants were severely attacked by insects, even after applying insecticides or pesticides several times. Chouinard et al. (2016) PEN covers have been described as an effective physical barrier, eliminating a wide range of lepidopteron pests from growing plants. These results were observed in this study that the net system supported tremendous safeguard from all major fruit pests. Similarly, the tomato plant was infested by various diseases like tomato back eye disease, late blight of tomato, tomato bushy stunt virus disease under open air conditions. The modified microclimatic condition maintains the environment better for winter tomato. Light interception is lower in the netting condition than in the open condition. Thus, photosynthetic active radiation (PAR) is lower in PEN. The higher plant height, inflorescence, and lowered pest incidence significantly enhanced yield in tomato due to better microclimate and fruit weight (wt.). So, a higher fruit yield per plot was reported under PEN, whereas the poorer yield was perceived under no net condition. This might be due to the favorable climatic conditions such as optimal temperature, light intensity and relative humidity that prevailed inside the shade net, resulting in greater vegetative growth, favorable to more numbers of flowers, inflorescences, higher percentage of fruit set, added numbers of fruits and greater fruit weight. The individual number and weight of tomato fruits were higher in PEN compared to the no PEN condition. This may be due to the greater uptake of nutrients, the accumulation of sufficient photosynthesis, the increase in fruit size and shape, the thickening of the shoots and the weight of the fruit. To sum up, having better microclimatic conditions and less pest incidence under the PEN protected plots enhances seedling growth, which further results in better yields.

Conclusion

The results of this study revealed that PEN is a sustainable technique for improving tomato yields by reducing the population of major pests and contributing to improved growth and yield attributes. PEN offers several advantages in the production of tomatoes, where it reduces the number of chemical pesticide applications and improves fruit production and quality. The use of white net is recommended for tomato production in areas with similar climates to the current study site. The performance between pest exclusion net (PEN) and no net condition was observed to be different. It was observed that netting without pesticide

gave maximum plant height, diameter of fruit and marketable yield, whereas this condition gave minimum pest infestation in plants, minimum number of pest incidence and higher individual fruit weight. However, further research on different crops and climatic regions has been proposed to assess the applicability and flexibility of this technology on a global scale. Results from the above study; it is advisable to investigate the techniques for quantifying the reduction of pesticides and their residues in the crop cycle.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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