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Occurrence of *Tuta absoluta* (Meyrick 1917) on tomato varieties cultivated under protected structures in Lesotho

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Abstract
Tomato leafminer, *Tuta absoluta*, is the most devastating pest of tomato (*Solanum lycopersicum* L.). A study which determined the severity of *T. absoluta* on tomato varieties, population dynamics and the correlation between *T. absoluta* and weather parameters under high tunnel and shade net was conducted in Lesotho. Data were subjected to SPSS and analyzed using descriptive analysis. Results under high tunnel showed that the population of *T. absoluta* on pheromone lures was highest with 29 adults. Tomato leaves had mild damage from *T. absoluta*. There was a positive non-significant correlation between weather parameters and *T. absoluta* with R^2 of 0.649. Under shade net; there was a moderate damage by *T. absoluta*, and the highest population on pheromone traps was 285 adults. *T. absoluta* and temperatures had a negative non-significant correlation, while correlation between relative humidity had a positive and significant relationship with R^2 of 82%.

Keywords: tomato leafminer (*Tuta absoluta*), tomato (*Solanum lycopersicum* L.), severity, pheromone lures, population dynamics

Introduction
Tomato (*Solanum lycopersicum* L.) is the most cultivated and consumed fruit in Africa, in a raw and processed form and its production offers employment opportunities to women and youth [1]. In sub-Saharan Africa tomato is an important vegetable crop for the income and nutrition of smallholder farmers [2]. It is one of the most promising areas for the expansion of horticulture and development in many developing countries [3]. In Lesotho, the tomato is the most cultivated horticultural crop (78%) under protected structures [4].

The recently introduced tomato leafminer, *Tuta absoluta*, has become the most important constraint to tomato production in Lesotho. *T. absoluta* (Meyrick, 1917) is an invasive and highly damaging leaf-mining moth of the family Gelechiidae (Lepidoptera) and is one of the most severe pests of tomato [5]. In Zambia and Tanzania crop losses of 90 – 100% were recorded in the greenhouse and open field conditions where control measures were not applied [6, 7]. Larvae feed on the mesophyll of all above ground parts of tomatoes and other solanaceous species, as well as on the fruit, resulting in significant yield loss through unmarketable tomato fruits [8].

In Lesotho, the presence of *T. absoluta* was detected in 2016 which is the same year it was recorded in South Africa, Zambia and Botswana [9, 10, 11, 12]. Since the appearance of *T. absoluta* in Lesotho, farmers relied on the removal of infested plants and chemicals for the control while some stopped producing tomato as insecticides used were not effective [9]. In South Africa small-scale farmers were recommended to monitor the pest with pheromone traps, use plant material without traces of *Tuta absoluta*, and destroy the infested plant materials as appropriate insecticides were limited in supply [13]. Its high reproductive capacity, mining behavior and rapid development of resistance to different insecticides make conventional chemical control very challenging [14].

Temperature is the most essential abiotic factor influencing direct and indirect effects on population dynamics of *T. absoluta* and thus its invasion success [15]. Heat stress affects *T. absoluta* by decreasing its survival and reproduction and increasing its mortality.

The lower and higher temperature threshold for *T. absoluta* was 7 and 34.6 °C, respectively and it decreases its development at a temperature below 14 °C and has optimum development at 30 °C [16]. On the other hand temperatures of 20.5±2°C and relative humidity of 55±5% are the most suitable for development, maximum survival and minimum mortality of *T. absoluta* [17].

The Ecoclimatic Index (EI) for *Tuta absoluta* modelled using CLIMEX indicates that Lesotho is less unsuitable in the mountains regions and highly suitable in some low lands regions for this pest [18]. Lesotho has temperate climate with hot, wet summers and cool to cold winters [19]. They are highly variable on diurnal, monthly, and annual time scales, generally ranging between 10°C and 30°C [20]. Since *T. absoluta* was detected in 2016 [7], no studies have been conducted to determine the influence of climatic factors on the population dynamics of this pest in Lesotho. Therefore, this study was conducted to determine the severity of *T. absoluta* on tomato varieties, population dynamics and correlation between *T. absoluta* and weather parameters under protected agriculture in Lesotho.

Materials and Methods

Study Area

The study was conducted at the National University of Lesotho (NUL) Roma campus in 2019 to 2020 under the high tunnel lined with white shade net on top of the plastic and a black shade net of 40% relative shading intensity. Roma is located 34 kilometers from Maseru. Coordinate; Latitude 29º 26 27º42’27E, Altitude is 1610m and Longitude is (WGs84) - 29º11’27’S.

Experimental Procedures and Cultural Practices

High tunnel and shade net structures were erected on a virgin land in 2019. Round-up (active ingredient: glyphosate) was applied to kill all the emerged weeds. Tomato seedlings were produced in the crop science laboratory for six weeks and were hardened for two weeks before transplanting, by exposing them to sunlight from morning until in the evening. Four varieties of tomato, Roma VF, Floradade, Heinz 1370 and Rodade were used.

Plants were cultivated in pots of size 25cm height and 20cm diameter. A total of 80 pots were prepared and filled with soil mixed with well decomposed kraal manure. The seedlings were then transplanted, under both the high tunnel (40 pots) and the black shade net (40 pots). One seedling per pot was transplanted making a total of ten seedlings per variety.

Agronomic practices such as irrigation, fertilization and weeding were performed under both structures. Under high tunnel; irrigation at seedling and vegetative stage was done once per day then reducing irrigation to once every other day when the plants started to flower. Weeding was done fortnightly by cultural practice using hand fork in the pots and spade between the pots. Fertilization was done fortnightly using Seagro organic plant food at 5ml per liter concentration and applying 0.5 liter during vegetative and 1 liter per pot during flowering. Under shade net; during the study there was a lot of rainfall (there was a substantial seasonal distribution of precipitation of about 60 to 80 percent received during February to April 2020) as such under the shade net, irrigation was only done depending on the soil moisture. Both fertilization and weeding were done using the same practice as the high tunnel.

Data collection

Severity of *T. absoluta* on tomato varieties

Data collection on severity of *T. absoluta* was done 90 days after transplanting. The numbers of leaves per plant showing damage due to *T. absoluta* (with mines on the leaves) were counted to determine the severity and averaged. This was done by first counting number of leaves that had mines per branch and the total was averaged.

Insect severity was determined using a 0-4 scale by Khanna [21] as follows;

0 = 0% – Trace (No infection/damage)
1 = 1 – 25% (Mild infection/damage)
2 = 26 – 50% (Moderate infection/damage)
3 = 51 – 75% (High infection/damage)
4 = 76 – 100% (Severe infection/damage)

Population dynamics of *T. absoluta*

Pheromone lures were placed in both high tunnel and shade nets to trap *T. absoluta* adults and were counted fortnightly. During the study period, the microclimate factors; relative humidity and temperatures were also recorded daily (morning and evening) using Thermo Hygrometer H19564, Hanna Instruments. These were recorded after 20 days of transplanting tomatoes in both high tunnel and shade net house.

Table 1: shows the corresponding dates to which *T. absoluta* was counted on the traps.

Fortnightly	Corresponding date
1	26 February 2020
2	12 March 2020
3	26 March 2020
4	09 April 2020
5	23 April 2020
6	07 May 2020
7	21 May 2020

Data analysis

Data on severity and population of *T. absoluta* was analyzed using descriptive statistics and the results were presented in tables and graphs using Microsoft excel.

Data on the impact of weather factors (temperature and relative humidity) on population of *T. absoluta* was subjected to Statistical Package for Social Sciences (SPSS) 20 and the correlation coefficient (r), regression (R^2) and pearson correlation (p) were used to determine correlation between weather parameters and number of *T. absoluta*.

Results

Table 2: Severity of *Tuta absoluta* on tomato varieties planted under high tunnel and shade net

Variety of tomato	*T. absoluta* severity per sampled plants (High tunnel)	*T. absoluta* severity per sampled plants (Shade net)
Floradade	4.5%	31.1%
Heinz 1370	11.6%	36.0%
Rodade	14.8%	43.4%
Roma VF	12.0%	39.9%

Key 0 = 0 – Trace (No infestation), 1 = 1 – 25% (Mild infestation), 2 = 26 - 50% (Moderate infestation), 3 = 51 – 75% (High infestation), 4 = 76 -100% (Severe infestation).

Table 2 shows the severity of *T. absoluta* leaf damage on tomato varieties under both high tunnel and shade net. There was a mild damage by *T. absoluta* on all the varieties planted under high tunnel. However, the highest severity was obtained on Rodade variety with 14.8% of leaves damaged. Floradade had the lowest number of leaves damaged. All the varieties had moderate damage by *T. absoluta* under shade net, with

Rodade being the most severely affected variety (43.4%) and Floradade being the least affected variety (31.1%).

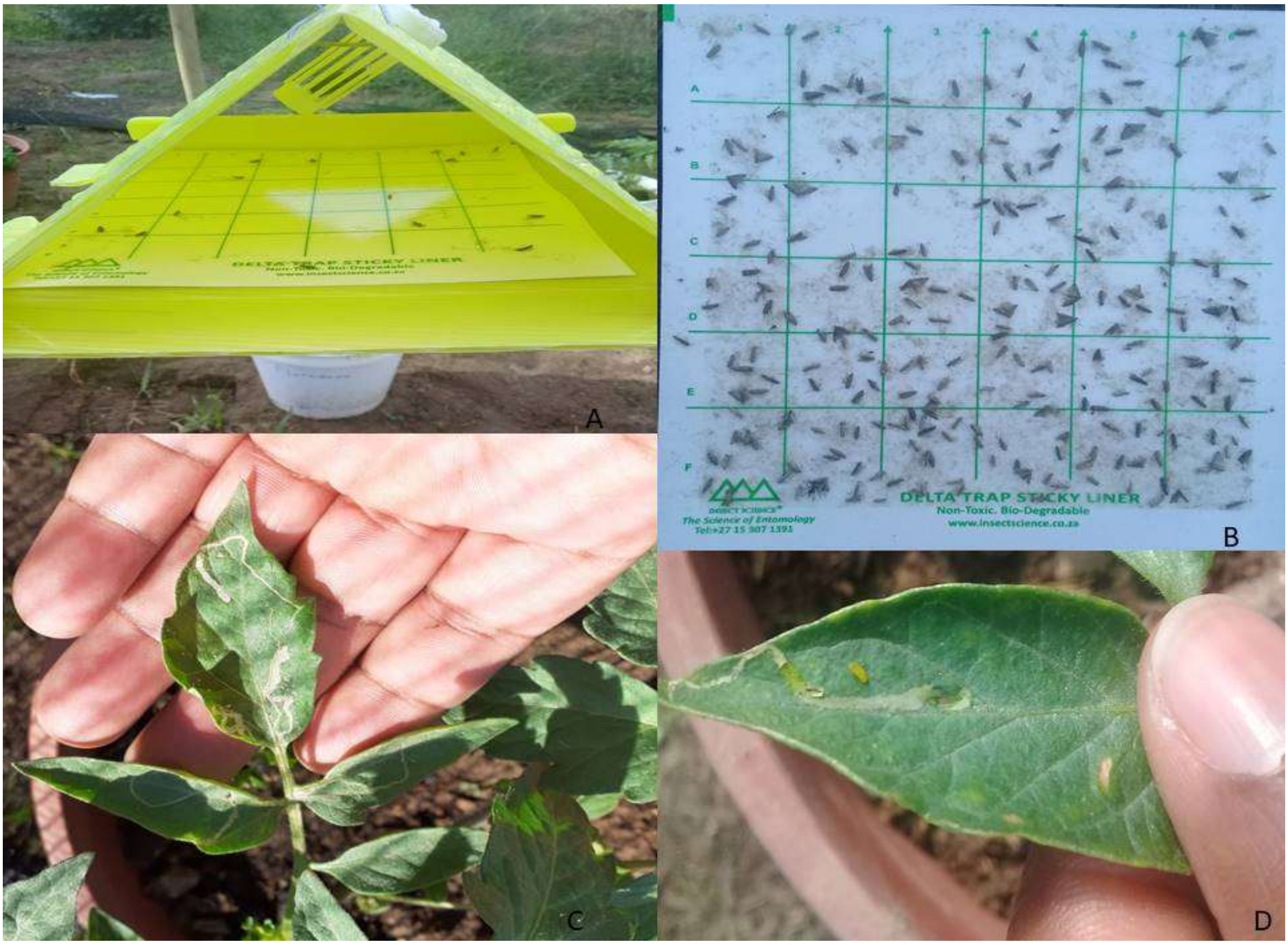

Fig 1: A; delta trap inserted with delta trap sticky liner and T.A Pherolure (Tomato leaf miner), B; Tomato leafminer trapped on delta sticky liner, C and D; tomato leaves damaged by tomato leafminer.

Population of *T. absoluta* trapped on pheromone lures under high tunnel and shade net

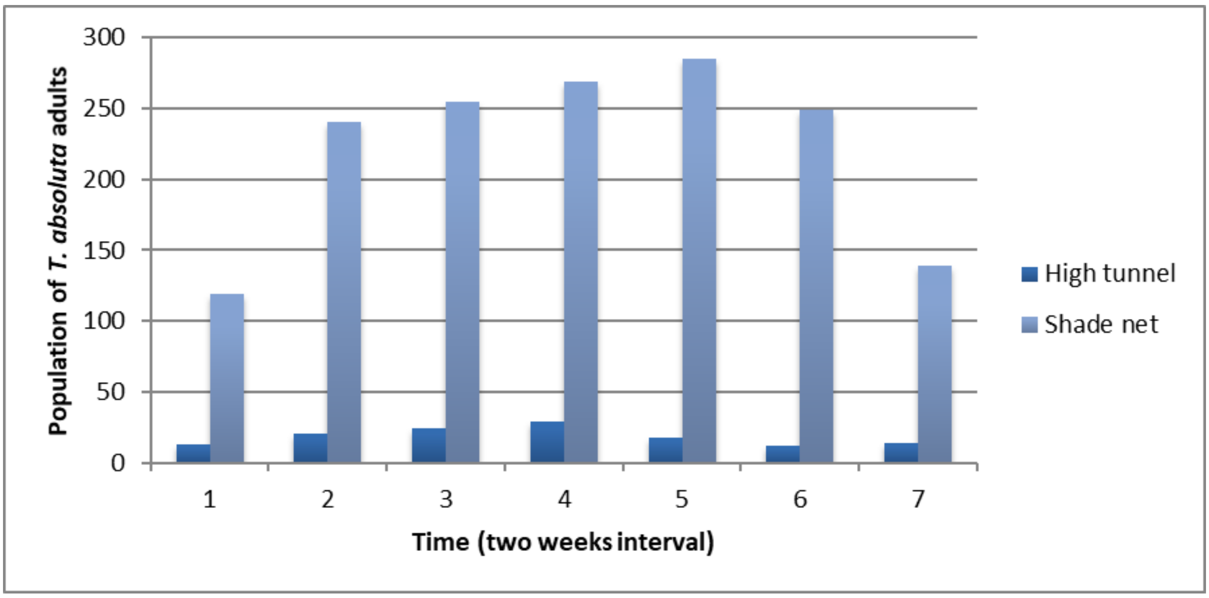

Fig 2: Number of *T. absoluta* adults trapped fortnightly using pheromone lures under both high tunnel and shade net

Population of *T. absoluta* trapped on the pheromone traps is reflected on figure 2, and this was recorded after every two weeks (from 26 February to 21 May). Under high tunnel; Fortnight four recorded the highest number of *T. absoluta* adults of 29 adults and the lowest number was recorded at fortnight six with 12 adults. Shade net recorded the highest number of *T. absoluta* at fortnight six with 285 adults the lowest record was in fortnight 1 with 119 adults.

Effect of temperature and relative humidity on the population of *T. absoluta* under High tunnel

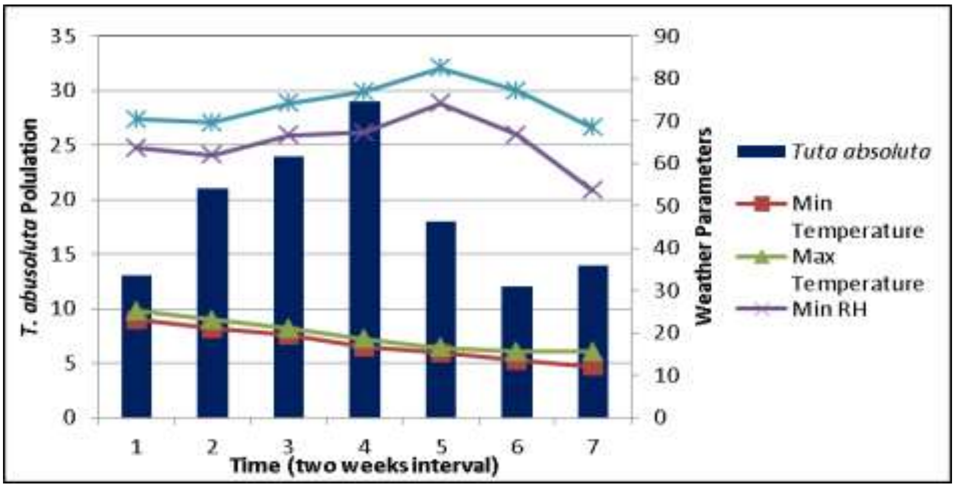

Fig 3: *T. absoluta* population in relation to early morning and evening temperatures and relative humidity under high tunnel

Figure 3 shows correlation between *T. absoluta* and weather parameters (temperatures and relative humidity). During the initial infestation, *T. absoluta* population captured was 13 adults and the average maximum and minimum temperatures that prevailed were 23.0 ºC and 25.2 ºC respectively, whereas the minimum and maximum relative humidity were 63.6% and 70.3%. At fortnight four (09 April) the population of *T. absoluta* was at the highest peak (29 *T. absoluta* adults) which then gradually reduced until fortnight six (07 May).

Effect of temperature and relative humidity on the population of *T. absoluta* under Shade net

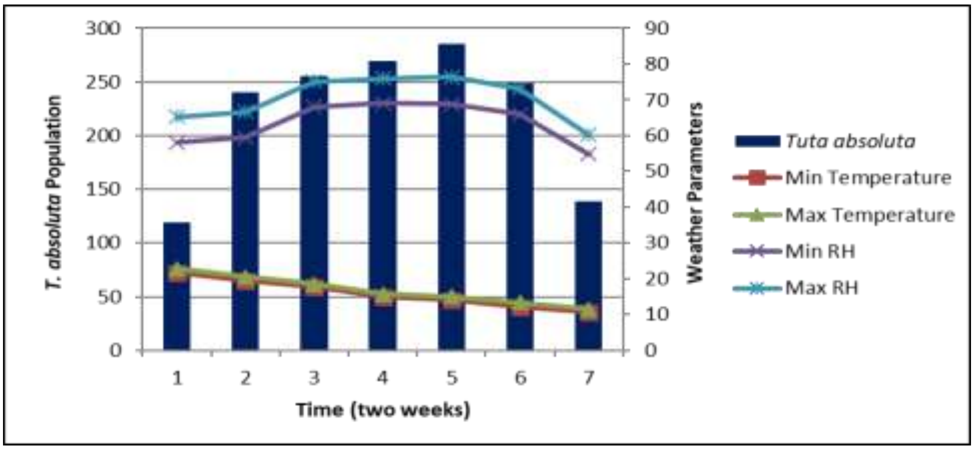

Fig 4: *T. absoluta* population in relation to early morning and evening temperatures and relative humidity under shade net house

Figure 4 shows the population of *T. absoluta* captured in relation to temperature and relative humidity. *T. absoluta* population during the initial infestation was 119 and the average maximum and minimum temperatures that prevailed were 22.9 ºC and 21.7 ºC respectively. The minimum and maximum relative humidity was 58.0% and 65.3% respectively. The peak population of *T. absoluta* was reached at fortnight five (23 April). The temperatures were average minimum 14.0 ºC and the maximum 15.1 ºC and the average minimum and maximum relative humidity were 68.8% and 76.4% respectively.

Table 3: Analysis of *T. absoluta* population dynamics collected on the pheromone traps in the tunnel and shade net in relation to abiotic factors.

	T. absoluta			
Weather parameters	**Correlation coefficient (r) under high tunnel**	**P values under high tunnel**	**Correlation coefficient (r) under Shade net**	**P values under Shade net**
Minimum temperatures	0.201	0.666^{NS}	-0.185	0.691^{NS}
Maximum temperatures	0.145	0.756^{NS}	-0.192	0.680^{NS}
Minimum relative humidity	0.287	0.533^{NS}	0.873	0.010*
Maximum relative humidity	0.213	0.647^{NS}	0.872	0.010*
Coefficient of determination (R^2)	High tunnel = 0.649		Shade net = 0.820	

*significant at 0.05; and NS: non-significant

Table 3 shows the correlation coefficient, regression (R^2) and pearson correlation between weather parameters and number of *T. absoluta* collected from the pheromone traps. Coefficient of determination between weather factors and *T. absoluta* was 0.649 and 0.820 in the high tunnel and shade net respectively. In the high tunnel, correlation between both temperatures (minimum and maximum) and *T. absoluta* was positive with 0.201 and 0.145 respectively and their p values were 0.666 (minimum temperatures) and 0.756 (maximum temperatures). Minimum and maximum relative humidity also had the positive r of 0.287 and 0.213 respectively, and their p values were 0.533 (minimum relative humidity) and 0.647 (maximum relative humidity). Under shade net, both minimum and maximum temperature had a negative r with p values of 0.691 and 0.680 respectively. Minimum and maximum relative humidity had a positive r of 0.873 and 0.872 and had the same p value of 0.010.

Discussion

Tomato leafminer is the major pest of tomato plants [22]. Tomato varieties grown under both high tunnel and shade net were all affected by tomato leafminer. Infestation started two weeks after transplanting and continued until harvesting (Fig 2, 3 and 4). The rating scale showed that the severity of *T. absoluta* in all varieties in the high tunnel was mild while moderate in the shade net (Table 2). Mild damage in the high tunnel might have been due to closing of the high tunnel at night which prohibited entry for the pest. *T. absoluta* is nocturnal, and during the day adults hide between leaves, and this was when the high tunnel would be opened to regulate temperatures and relative humidity [5]. However, the holes of shade nets allowed entry to this pest during the night [23] which may have let to moderate damage and high population of trapped adults. The use of *T. absoluta* pheromone traps control the pest by mating disruption [24]. This leads to reduced pest population and therefore low leaf damage. The results were in line with those found by Cocco *et al*. [25] where the use of pheromone traps significantly reduced leaf damage and *T. absoluta* population from 57% to 85% under high tunnels.

The tomato leafminer can develop over a wide range of temperatures [26]. The optimum temperature for its development ranges from 19 to 23 °C [27]. However, on the present findings, population of *T. absoluta* trapped on the pheromone traps was on highest peak on fortnight 5 when the temperatures ranged between 14.0 ºC and 15.1 ºC and relative humidity ranged between 68.8% and 76.4% under shade net. The population starter to decrease as temperatures dropped from 14 ºC and below (figure 4). Martins *et al*. [16] also indicated that tomato leafminer decreases its development at a temperature below 14 °C. Under the high tunnel the highest population was obtained on fortnight 4 (April) (figure 2 and 3). This coincided with period of high rainfall and few crops were still flowering while most of them were at fruiting stage normally at this time of the year it starts to get cooler in Lesotho (recorded temperatures ranged from 17 ºC to 19 ºC). Our results were in agreement with those obtained by Sylla *et al*. [28] who observed that *T absoluta* incidence increased during the rainy season, suggesting that rainfall might not have negative effects.

The relationship between the population of *T. absoluta* and weather parameters (minimum and maximum temperatures and minimum and maximum relative humidity) showed a positive non-significant relation under the high tunnel (Table 3). These observations were in agreement with those found by Ata and Megahed [29] who indicated that the correlations between the climatic factors (daily range, daily mean of temperature and daily relative humidity) and insect population activities were positive but non-significant. Studies by Negi *et al*. [30] demonstrated that *T. absoluta* was able to develop between 15^0 and 35^0. Thermal tolerance assays conducted in Botswana [15] showed higher critical thermal maxima (CT_{max}) and the lower thermal critical minima (CT_{min}) ranged from 37 ^{0}C–43 ^{0}C and -1 ^{0}C to -12 ^{0}C respectively. The minimum and maximum temperatures in Lesotho during tomato production season in the tunnels range from to 2 ^{0}C to over 28 ^{0}C respectively [31]. This indicates that *T. absoluta* can survive in a wide range of environments in Lesotho, where hosts plants are available. The weather parameters were found to contribute around 65% impact on population of *T. absoluta* when acted together under the high tunnel. This indicated that interactions of abiotic factors with the population fluctuation of *T. absoluta* pest of tomato failed to show any significant relationship.

Under the shade net; weather factors, minimum and maximum temperatures showed a negative non-significant correlations with *T. absoluta* population. The results of the present findings did not match with those found by Masry and Saad [32] who found that the occurrence and the trapping intensity and the captures depended on the temperature. However, both minimum and maximum relative humidity had a positive significant relation with *T. absoluta* population. The percentage contribution of all the weather factors on *T. absoluta* population fluctuations was 82%.

Conclusion

Protected structures such as high tunnels can provide an ideal environment for both vegetable crops grown within them and also for insect pests. Tomato varieties were all found to be susceptible to attack by *T. absoluta*. However, damage on tomato varieties by this pest was mild and moderate both under high tunnel and shade net respectively. This may have been due to control of male adults by use of pheromone traps to disrupt their mating with female adults. Correlation of weather parameters (temperatures and relative humidity) with *T. absoluta* showed a positive non-significant relationship. This indicated that interactions of these abiotic factors with the population fluctuation of *T. absoluta* pest of tomato failed to show any significant relationship under the high tunnel. Moreover, these weather parameters were found to contribute 65% impact on population of *T. absoluta* when acted together. The structure of shade net has pores that allow entry for some of the insect pests that affect tomato production. This gained entry for *T. absoluta* as a nocturnal pest. However, the use of pheromone traps that controlled the population of this pest may have led to reduced (moderate) leaf damage on the varieties. Minimum and maximum temperatures showed a negative but non-significant correlation with *T. absoluta* population. However, both minimum and maximum relative humidity had a positive and significant correlation with *T. absoluta* population. The weather parameters were found to contribute around 82% impact on population of *T. absoluta* when acted together.

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