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Article

Susceptibility of the sweet pepper (*Capsicum annuum* L.) to the infestation of *Tetranychus urticae* (Acari: Tetranychidae) and the different insect pests under greenhouse conditions in Ismailia, Egypt

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ABSTRACT

The sweet pepper, an important export crop in Egypt, has been recently invaded by the two-spotted spider mite (TSSM) in parallel with other insect pests that have the potential to reduce its yield. This study aimed to determine the susceptibility of two sweet pepper cultivars (cv. Mazurka and Cannon) to TSSM infestation. In addition, it aimed to investigate how the cultivar as well as the growing season, might affect the population fluctuations of the pests along with the host plant resistance. Also, enzymatic and non-enzymatic antioxidant activities were determined to distinguish between the two cultivars after natural infestation. The TSSM was identified as the primary pest that invaded both cultivars during the two examined growing seasons. In addition to the TSSM, three insect pests (*Bemisia tabaci*, *Frankliniella occidentalis*, and *Myzus persicae*) and four predators (*Neoseiulus cucumeris*, *Phytoseiulus persimilis*, *Scolothrips longicornis*, and *Orius laevigatus*) were identified. The cv. Cannon was found to have the highest density of TSSM, *B. tabaci*, and *M. persicae* than cv. Mazurka demonstrated the highest density of *P. persimilis* and *O. laevigatus*. Our findings also revealed that the winter-spring season was highly significant in antioxidant enzyme activities than the summer-fall season. Due to the high chlorophyll and phenol contents, and antioxidant enzyme activity in its leaves, the Mazurka cultivar was more resistant to TSSM and other insect pest infestations. The population density of the two-spotted spider mite and the associated pests change based on season and/or cultivar.

KEYWORDS: Antioxidant enzymes, *Myzus persicae*, resistant cultivar, secondary metabolites, two-spotted spider mite.

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INTRODUCTION

The sweet pepper (*Capsicum annuum* L.) is one of three important Solanaceae fruit-bearing vegetable crops (El-Sayed *et al*. 2015). Greenhouse bell pepper cultivars are hybrids with bell-shaped or blocky-type fruits of varying colors (Zayed *et al*. 2013). It is a profitable local and export crop grown in greenhouses in Egypt (El-Laithy *et al*. 2013). According to statistics from the Egyptian Ministry of

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Agriculture for sweet pepper production in 2019, it occupies about a 0.634 million m^2 of the total greenhouse area in Egypt and yields 3,938 tons annually.

Sweet pepper is commonly infested by the whitefly, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae), the Western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), as well as their effective natural enemies, the predatory mite *Amblyseius swirskii* Athias-Henriot (Acari: Phytoseiidae) and *Orius laevigatus* (Fieber) (Hemiptera: Anthocoridae) (Calvo *et al*. 2012). Apart from insect attacks, recently sweet pepper is also susceptible to the attack of a non-insect pest, the two-spotted spider mite (TSSM), *Tetranychus urticae* Koch (Acari: Tetranychidae), inducing a heavy loss to crop yields by reduction of chlorophyll due to it sucking the sap. Both nymphs and adults of this mite primarily feed on the underside of the leaf, forming a large amount of silk webbing that may completely cover infested areas of leaves. This reduces photosynthesis and can lead to a decrease of 50–100 percent in yields (Park and Lee 2002).

In Integrated Pest Management (IPM) programs, the study of the pest's occurrence and its natural enemies is a valuable tool for decision-making (Rahmani *et al*. 2010). Seasonal abundance of the TSSM population is affected by different factors, such as predation by natural enemies, climate changes, and host plant (Kitashima and Gotoh 2003).

The host plant resistance is a component of IPM that is typically cultivar-specific and determined by factors like chemical and/or physical defenses (Sharma and Ortiz 2002). In this regard, plants have various defensive chemicals, for example, photosynthetic pigments, proteins, and phenolic compounds, as well as enzymatic antioxidants like peroxidase (POD), catalase (CAT), polyphenol oxidase (PPO) and glutathione-s-transferase (GST) (Sereme *et al*. 2016). These enzymes are among the protective enzymes responsible for plant resistance in response to pest attacks (Constabel *et al*. 2000; Kettles and Kaloshian 2016). Enhancement of these enzymes in plants is correlated with resistance to pests, as in tomato, where overexpression of PPO increases resistance to common cutworms (Li and Steffens 2002). Higher activity of POD and PPO is strongly associated with faba bean *Vicia faba* L. resistance to aphid *Aphis craccivora* (Soffan *et al*. 2014). The increased activities of POD and PPO were positively correlated to the rubber tree germplasm resistance to *Eotetranychus sexmaculatus* (Riley) (Acari: Tetranychidae) (Lu *et al*. 2016). Identifying the pest-resistant cultivars with less suitability for insect and non-insect pests would lead to delaying pest outbreaks (Fahim *et al*. 2020).

Therefore, in this study we sought to determine which of the locally available sweet pepper cultivars in Ismailia Governorate have the greatest TSSM resistance. Second, we aimed to investigate the effect of the seasonal fluctuation of the TSSM, along with the associated insects on the two cultivars. Third, the effect of the leaf contents of photosynthetic pigments, total protein, and phenol contents, as well as the change in the antioxidant enzyme activities on the cultivars infestation with TSSM, associated insects, and predators were identified.

MATERIALS AND METHODS

Experimental design

Plant material

Seeds of red sweet pepper (bell-shaped) cultivars (cv.) Cannon F_1 and Mazurka F_1 were obtained from Syngenta and Rijk-Zwaan Company, respectively. They are the most planted commercial cultivar in Ismailia Governorate, Egypt.

Study site

The present study was conducted for two successive growing seasons; Summer (S) – Fall (F) and Winter (W) – Spring (Sp) seasons 2021–2022 at the greenhouse of the experimental farm of Ismailia Agricultural Research Station, ARC, Ismailia Governorate (30° 35' 30" N, 32° 14' 50" E). The soil type was sandy in texture.

A randomized complete block design (RCBD) with four replications for each cultivar was adopted. The sweet pepper seedlings were transplanted on both sides of the row with a space of 40 cm between seedlings and 60 cm within the rows (40 plants/replica). Seedlings were cultivated in mid-May 2021 for the first growing season and mid-November for the second. Cultivation was carried out using a drip irrigation system, following all recommended agronomic practices with no chemical applications.

Sampling

Sampling started after one month from cultivation, and the major pests were monitored on each cultivar at bi-weekly intervals from transplanting until harvesting. Fifteen leaves were randomly selected from five different plants, covering the top, middle, and bottom parts of each plant. Leaves were collected and moved in polythene bags to the laboratory for examination under a Stereo-Binocular microscope (Olympus SZ-PT, Japan). The number of TSSM (immature and adult stages) was counted and recorded separately in a 2.5 cm^2 area on the underside of each leaf. The number of insect pests and associated predators was counted and recorded on the whole area of the leaf. The associated insects and predators were identified at Insect Classification and Surveying Department, PPRI, ARC, Egypt.

Sweet pepper biochemical analyses

All biochemical analyses were carried out on infested leaves collected from five different plants. All activity measurements were monitored spectrophotometrically using the UV-Vis spectrophotometer (Spectronic, 1201, Milton Roy, USA).

Plant photosynthetic pigments assay

The assessment of photosynthetic pigment contents [chlorophyll (Chl. a + b) and carotenoids (Car.)] was performed as described by Arnon (1949) and Wettstein (1957), respectively. The absorbance was read at 662 and 644 nm for Chl. and at 440 nm for Car., respectively.

Plant total phenol assay

Twenty leaves were washed and then oven-dried at 45 °C for four days. Then, they were grounded in an electric grinder into fine powder. The extraction assay was performed as described by Kähkönen *et al*. (1999). Total phenol content was determined by the Folin-Ciocalteu method (Singleton and Rossi 1965) using gallic acid as the standard. The absorbance was measured at 765 nm.

Plant total protein and antioxidant enzyme activity assays

Fresh leaves (0.5 g) were stored at −20 °C and then handled as described by Hildebrand *et al*. (1986). Total protein content was determined by the dye-binding method of Bradford (I976) with bovine serum albumin as the standard. The absorbance was estimated at 595 nm. The enzymes GST, PPO, POD, and CAT activities were detected spectrophotometrically according to Habig *et al*. (I974), Ishaaya (1971), Langcake and Wickins (1975), and Aebi (1984), respectively. GST activity was monitored by assaying the formation of the conjugate reaction product at 340 nm by using 1-chloro-2,4-dinitrobenzene (CDNB) as a substrate. The PPO and POD activity was determined by monitoring the increase in absorbance at 420 nm. For CAT activity, the decomposition of hydrogen peroxide was followed spectrophotometrically at 240 nm.

Statistical analysis

The monthly abundance of total TSSM, associated insects, and predators were analyzed using a one-way analysis of variance (ANOVA). Two-way analysis of variance (ANOVA) was used to assess the significant effects between cultivar and season using SPSS 23.0 software. Means ± SE were compared using Tukey's HSD test (p = 0.05).

RESULTS

Seasonal activity of the TSSM on the two sweet pepper cultivars

The population fluctuations of the TSSM motile stages on the two sweet pepper cultivars (cv. Cannon and Mazurka) were studied during the Summer - Fall (S-F) and Winter - Spring (W-Sp) growing seasons 2021–22. Our results revealed that the incidence of TSSM nymph and adult stages was significantly affected by the growing season, sweet pepper cultivar, and their interaction (Table 1). During the S-F season, there were fewer adults, nymphs, and larvae than during the W-Sp season. The cv. Cannon had the highest abundance of TSSM adults, nymphs, and larvae (13.72 ± 1.55, 50.58 ± 7.96, and 2.61 ± 0.24, respectively) than cv. Mazurka (9.09 ± 1.13, 30.15 ± 4.51, and 1.70 ± 0.29, respectively). The interaction effect between growing season and cultivar showed that the highest adult number was found in cv. Cannon during the W-Sp season (17.70 ± 0.56), while the lowest numbers were found in cv. Mazurka during the S-F season (6.20 ± 0.59). The nymph stage displayed an identical pattern. However, there were no significant differences in the interaction effects concerning the larval stage.

Table 1. Seasonal incidence of the TSSM motile stages on the two sweet pepper cultivars during the two growing seasons 2021–2022.

	Adult		Mean season	Nymph		Mean season	Larva		Mean season
	Mazurka	Cannon		Mazurka	Cannon		Mazurka	Cannon	
Summer-Fall	6.20 ± 0.59^{c}	9.73 ± 0.47^{b}	**7.96 ± 0.75^{B}**	18.47 ± 1.51^{d}	29.92 ± 1.44^{c}	**24.20 ± 2.37^{B}**	0.96 ± 0.07^{a}	2.02 ± 0.08^{a}	**1.49 ± 0.21^{B}**
Winter-Spring	11.97 ± 0.30^{b}	17.70 ± 0.56^{a}	**14.84 ± 1.12^{A}**	41.83 ± 1.34^{b}	71.24 ± 3.02^{a}	**56.53 ± 5.76^{A}**	2.44 ± 0.12^{a}	3.21 ± 0.14^{a}	**2.83 ± 0.18^{A}**
Mean cultivar	**9.09 ± 1.13^{B}**	**13.72 ± 1.55^{A}**		**30.15 ± 4.51^{B}**	**50.58 ± 7.96^{A}**		**1.70 ± 0.29^{B}**	**2.61 ± 0.24^{A}**	
	F	***P***		F	***P***		F	***P***	
Season	195.47	0.000		274.03	0.000		163.62	0.000	
Cultivar	88.57	0.000		109.37	0.000		75.81	0.000	
Season × Cultivar	5.04	0.040		21.13	0.001		1.95	0.188	

Means followed by the same letter in the same row or column are not significantly different using Tukey's Test at P < 0.05.

Seasonal activity of the associated predators on the two sweet pepper cultivars

We recorded four predators: *Neoseiulus cucumeris* (Oudemans), *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae), and *Scolothrips longicornis* Priesner (Thysanoptera: Thripidae) during the S-F season in addition to *Orius laevigatus* in the W-Sp season (Table 2).

Neoseiulus cucumeris **–** Our study showed that the incidence of *N. cucumeris* was significantly affected by the growing season, with the highest abundance during the S-F season (2.59 ± 0.12) compared to the W-Sp season (0.06 ± 0.03). However, the effect of cultivar and the interaction effect between growing season and cultivar was not significant.

Scolothrips longicornis **–** The incidence of *S. longicornis* was significantly affected by both the growing season and the interaction between growing season and cultivar, with the highest abundance (1.30 ± 0.10) during the S-F season compared to the W-Sp season (0.04 ± 0.01). The cultivar alone did not have a significant effect on the abundance of *S. longicornis*.

Phytoseiulus persimilis – The growing season and cultivar had a significant effect on the incidence of *P. persimilis*, but the interaction effect between them was not significant. The abundance of *P. persimilis* was higher in the W-Sp season (1.85 ± 0.16) compared to the S-F season (1.07 ± 0.09). It was observed that cv. Mazurka was found to have the highest *P. persimilis* abundance (1.70 ± 0.21) compared to cv. Cannon (1.22 ± 0.12).

Orius laevigatus – The incidence of *O. laevigatus* was significantly affected by the growing season, cultivar, and their interaction. The highest abundance of *O. laevigatus* was 0.19 ± 0.03, followed by 0.10 ± 0.02 on cv. Mazurka and Cannon, respectively, at W-Sp season, and it did not appear in both cultivars during the S-F season.

Seasonal activity of the associated insect on the two sweet pepper cultivars

We recorded three insect pests on both cultivars: whitefly, *Bemisia tabaci*, thrips, *Frankliniella occidentalis*, and aphid, *Myzus persicae* (Hemiptera: Aphididae) (Table 3).

Table 2. Seasonal incidence of the associated predators recorded on the two sweet pepper cultivars during the two growing seasons 2021–22.

	Neoseiulus cucumeris		**Mean season**	***Scolothrips longicornis***		**Mean season**	***Phytoseiulus persimilis***		**Mean season**	***Orius laevigatus***		**Mean season**
	Mazurka	**Cannon**		**Mazurka**	**Cannon**		**Mazurka**	**Cannon**		**Mazurka**	**Cannon**	
Summer-Fall	2.48 ± 0.18^{a}	2.70 ± 0.16^{a}	**2.59 ± 0.12^{A}**	1.13 ± 0.09^{b}	1.47 ± 0.13^{a}	**1.30 ± 0.10^{A}**	1.20 ± 0.13^{a}	0.94 ± 0.08^{a}	**1.07 ± 0.09^{B}**	0.00 ± 0.00^{c}	0.00 ± 0.00^{c}	**0.00 ± 0.00^{B}**
Winter-Spring	0.03 ± 0.01^{a}	0.10 ± 0.06^{a}	**0.06 ± 0.03^{B}**	0.05 ± 0.02^{c}	0.03 ± 0.01^{c}	**0.04 ± 0.01^{B}**	2.20 ± 0.17^{a}	1.50 ± 0.11^{a}	**1.85 ± 0.16^{A}**	0.19 ± 0.03^{a}	0.10 ± 0.02^{b}	**0.14 ± 0.02^{A}**
Mean cultivar	**1.25 ± 0.47^{A}**	**1.40 ± 0.50^{A}**		**0.59 ± 0.21^{A}**	**0.75 ± 0.28^{A}**		**1.70 ± 0.21^{A}**	**1.22 ± 0.12^{B}**		**0.09 ± 0.04^{A}**	**0.05 ± 0.02^{B}**	

	F	***P***	**F**	***P***	**F**	***P***	**F**	***P***
Season	418.02	0.000	259.81	0.000	39.12	0.000	68.53	0.000
Cultivar	1.42	0.256	4.00	0.069	14.94	0.002	6.57	0.025
Season × Cultivar	0.419	0.530	5.54	0.037	2.95	0.112	6.57	0.025

Means followed by the same letter in the same row or column are not significantly different using Tukey's Test at P < 0.05.

Table 3. Seasonal incidence of the associated insect pests recorded on the two sweet pepper cultivars during the two growing seasons 2021–22.

	Bemisia tabaci		**Mean season**	***Frankliniella occidentalis***		**Mean season**	***Myzus persicae***		**Mean season**
	Mazurka	**Cannon**		**Mazurka**	**Cannon**		**Mazurka**	**Cannon**	
Summer-Fall	2.53 ± 0.22^{a}	4.76 ± 0.17^{a}	**3.64 ± 0.44^{A}**	0.83 ± 0.12^{a}	1.18 ± 0.12^{a}	**1.00 ± 0.10^{A}**	7.88 ± 0.65^{b}	10.33 ± 0.57^{a}	**9.10 ± 0.61^{A}**
Winter-Spring	3.25 ± 0.33^{a}	5.39 ± 0.54^{a}	**4.32 ± 0.50^{A}**	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	**0.00 ± 0.00^{B}**	0.00 ± 0.00^{c}	0.00 ± 0.00^{c}	**0.00 ± 0.00^{B}**
Mean cultivar	**2.89 ± 0.23^{B}**	**5.07 ± 0.29^{A}**		**0.41 ± 0.17^{A}**	**0.59 ± 0.23^{A}**		**3.941 ± 1.52^{B}**	**5.17 ± 1.97^{A}**	

	F	***P***	**F**	***P***	**F**	***P***
Season	3.79	0.075	143.06	0.000	445.53	0.000
Cultivar	39.26	0.000	4.43	0.057	8.10	0.015
Season × Cultivar	0.017	0.899	4.43	0.057	8.10	0.015

Means followed by the same letter in the same row or column are not significantly different using Tukey's Test at P < 0.05.

Bemisia tabaci – The study revealed that the incidence of *B. tabaci* was significantly influenced by the cultivar, while the effect of the growing season and the interaction effect between growing season and cultivar were not significant. The cv. Cannon exhibited a higher abundance of *B. tabaci* (5.07 ± 0.29) than cv. Mazurka (2.89 ± 0.23).

Frankliniella occidentalis – The findings showed that the incidence of *F. occidentalis* was significantly influenced by the growing season, while the effect of cultivar and the interaction between growing season and cultivar were not significant. The abundance of *F. occidentalis* was 1.18 ± 0.12 and 0.83 ± 0.12 in cv. Cannon and Mazurka, respectively, during the S-F season, and it did not appear in both cultivars during the W-Sp season.

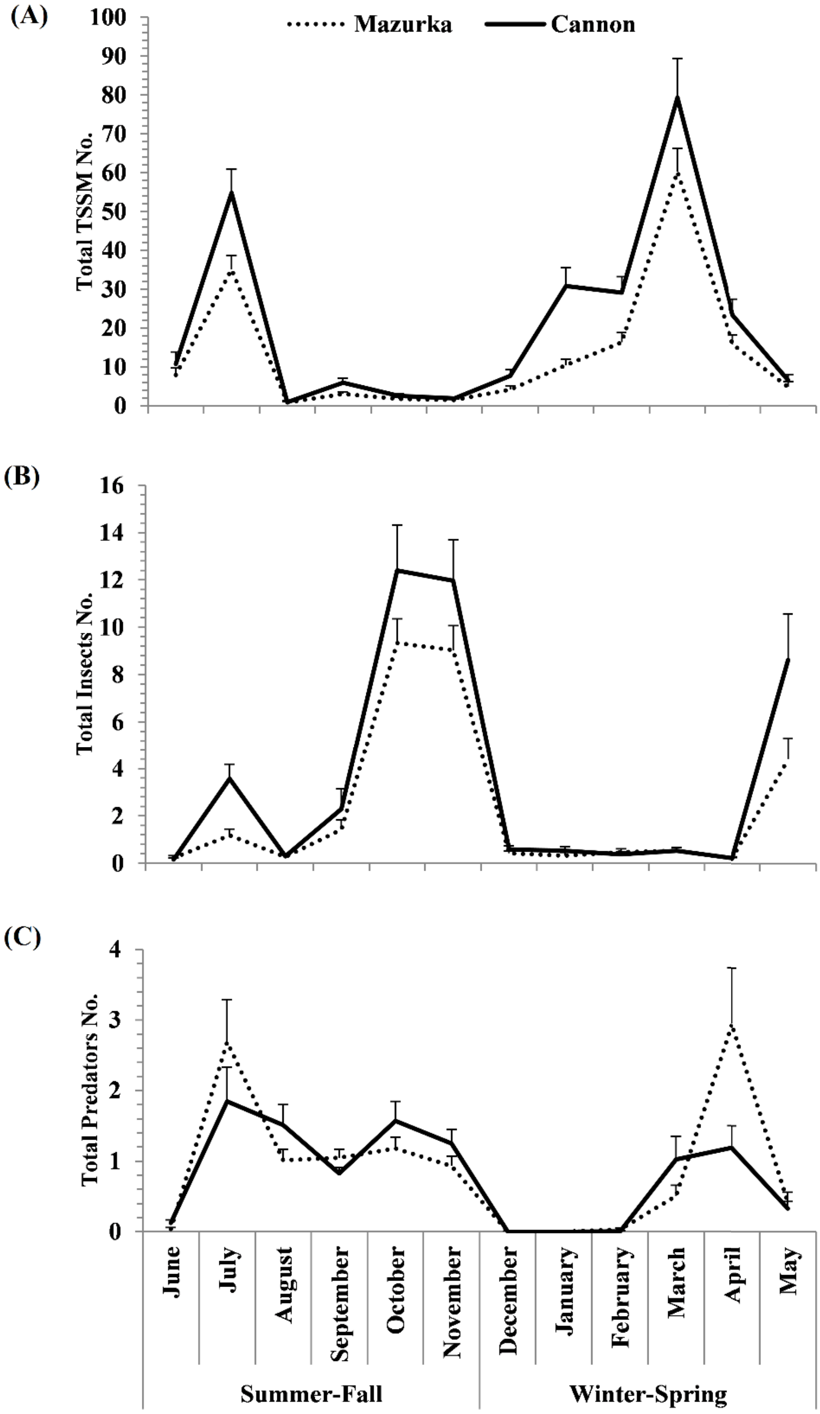

Figure 1. Monthly abundance of total TSSM (A), associated insect pest (B), and predator (C) numbers on the two sweet pepper cultivars during the two growing seasons 2021–22.

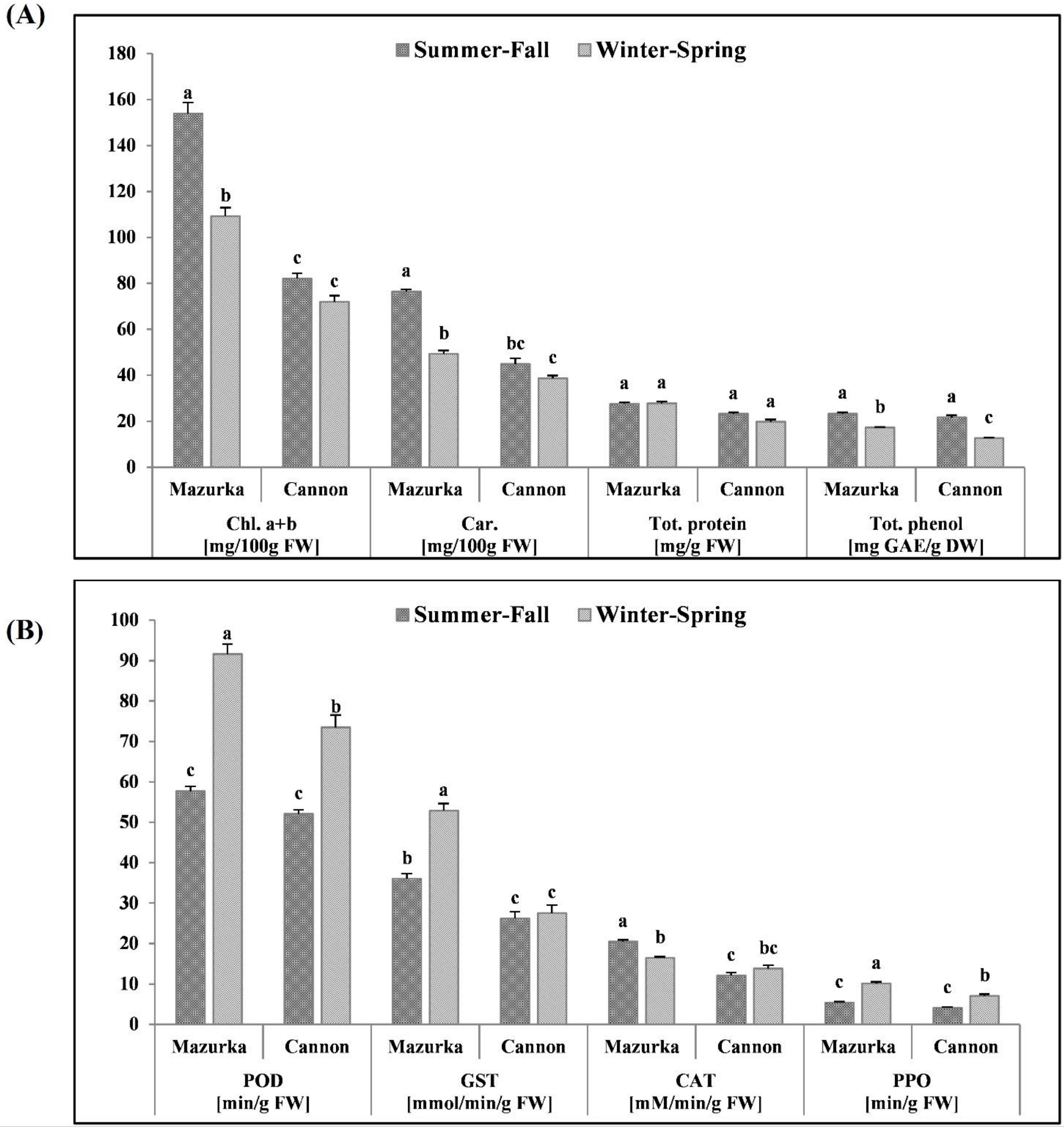

Figure 2. The interaction effects of seasons and cultivars on the Chl., Car., total protein and phenol contents (A) and the activity of the antioxidant enzymes (B) of the two sweet pepper cultivars during the two growing seasons 2021–22.

Myzus persicae – The effect of growing season, cultivar, and their interaction significantly affect the incidence of *M. persicae*. The abundance of *M. persicae* was 10.33 ± 0.57, followed by 7.88 ± 0.65 in cv. Cannon and Mazurka, respectively, during the S-F season, and it did not appear in any of the cultivars during the W-Sp season.

During the two growing seasons, the population of TSSM reached two peaks for both cultivars, as displayed in Figure 1. The first TSSM peak was in the S-F season (July), where the predators were the most abundant and showed a similar population pattern. The second TSSM peak was in the W-Sp season (March), where the predators showed two peaks (March and April). Regarding the associated insect pests, they reached three peaks. The first two peaks were in the S-F season (October and November) and the third at the end of the W-Sp season (May), where the TSSM and the predators were the lowest in abundance, reflecting their negative relationship.

Determination of the non-enzymatic and enzymatic antioxidant activities of the two cultivars during the two growing seasons

The effects of the growing season, cultivar, and their interaction on Chl. (a + b) and Car. was found significant ($P \leq 0.05$) (Fig. 2A). Concerning the interaction effect between growing season and cultivar, the results showed the highest Chl. (a + b) content 153.85 ± 4.83 mg/100 g fresh weight (FW) followed by 109.15 ± 3.79 mg/100 g FW was recorded in cv. Mazurka during the S-F and W-Sp seasons, respectively. While, the lowest Chl. (a + b) content was recorded in cv. Cannon at both seasons without any significant differences. The highest Car. content was recorded in cv. Mazurka during the S-F season, while the lowest one was detected in cv. Cannon during the W-Sp season. The results also showed that during the W-Sp season, the Chl. (a + b) and Car. contents were lower during the W-Sp season than during the S-F season due to the highest infestation of TSSM and the other insect pests.

Regarding the total protein content, it was significantly affected by cultivars, while the effect of the season and the interaction between growing season and cultivar were not significant (Fig. 2A). The cv. Mazurka had the highest total protein content (27.68 ± 0.51 mg g^{-1} FW) as compared to cv. Cannon (21.49 ± 0.96 mg g^{-1} FW). Regarding the total phenol content, it was significantly affected by season, cultivar, and their interaction. The results of the interaction effect between growing season and cultivar, indicated that the highest phenol content was recorded in the S-F season (Fig. 2A).

The growing season had a significant effect on the activity of GST, PPO, and POD due to the different levels of mite's infestation and other insect pests between the two seasons ($P \leq 0.05$), while the growing season had a non-significant effect on CAT activity ($P \geq 0.05$). Our findings revealed that the W-Sp season was more significant in GST, PPO, and POD activities than in the S-F season, as shown in Figure 2B. Regarding the effect of cultivar and the interaction between growing season and cultivar, they significantly affected the activities of all the aforementioned enzymes ($P \leq 0.05$). The cv. Mazurka was highly significant in GST, PPO, POD, and CAT activities than cv. Cannon. The results of the interaction between growing season and cultivar showed that the highest activity of GST, PPO, and POD was found in cv. Mazurka during the W-Sp season (52.83 ± 1.80, 10.10 ± 0.43, and 91.63 ± 2.52, respectively). However, the highest CAT activity was found in cv. Mazurka during the S-F season (20.50 ± 0.40). GST, PPO, POD, and CAT activities were found to be the lowest in cv. Cannon during the S-F season (26.20 ± 1.68, 4.05 ± 0.26, 52.08 ± 1.01 and 12.08 ± 0.74, respectively). In addition, the interaction effect showed no significant differences between the two growing seasons in the activity of GST and CAT in cv. Cannon. Furthermore, the results indicated no significant differences between the two cultivars in the activity of GST and CAT during the S-F season. Based on the activity of GST, PPO, POD, and CAT, the cv. Cannon had the lowest activity compared to cv. Mazurka; consequently, the cv. Cannon was highly susceptible to TSSM infestation than cv. Mazurka.

DISCUSSION

The field study conducted on the effect of cultivars and growing seasons on the abundance and scarcity of the target insect and non-insect pests revealed significant differences in the populations of predators and herbivores between the two studied sweet pepper cultivars. The TSSM was the primary pest observed during the two growing seasons studied. Our survey identified four predator species, including *N. cucumeris*, *P. persimilis*, *S. longicornis*, and *O. laevigatus*, and three insect pests, including *B. tabaci*, *F. occidentalis*, and *M. persicae*, this finding conforms with Calvo *et al*. (2012) and Kim *et al*. (2018). In contrast, Gallardo *et al*. (2005) recorded another phytoseiid genus, *Euseius* as a predator associated with *T. urticae* on sweet pepper.

The abundance of the two-spotted spider mite and the associated pest was season and/or cultivar dependent. During this study, the TSSM was more abundant during W-Sp than S-F seasons. *Bemisia tabaci* abundance was not significantly affected by the growing season, whereas *F. occidentalis* and

M. persicae appeared only in the S-F season. The populations of TSSM, pests, and predators as shown may be higher or lower in the different seasons. This fluctuation can be attributed to a range of environmental factors, such as changes in temperature, humidity levels, or the availability of food sources (Bale *et al*. 2002). For instance, certain seasons may be less favorable for the development and reproduction of the spider mites and the other associated pest, leading to lower abundance during those times (Yigezu *et al*. 2019). Our findings are in agreement with those by El-Laithy *et al*. (2013) who attributed the principal damage on sweet pepper over the two growing seasons (fall and summer plantations) to the two-spotted spider mite and the onion thrips, *Thrips tabaci*. During the fall plantation, the highest density of TSSM was recorded, followed by *T. tabaci*, while during the summer plantations, light infestations with the whitefly *B. tabaci* were recorded. In addition, Ssemwogerere *et al*. (2013) found that the incidence of *F. occidentalis* was significantly influenced by the type/variety of pepper in 2008 but in 2009 they had no discernible influence on the occurrence of thrips. This suggests that specific environmental conditions during summer, fall, winter and spring seasons may be more favorable for the growth and survival of some pests but not for others.

Our findings revealed that the TSSM and predator populations reached two peaks during the two growing seasons studied. The first peak was in the S-F season (July), and the second peak was in the W-Sp season (March and April). Regarding the associated insect pests, they reached three peaks, the first two in the S-F season (October and November) and the third at the end of the W-Sp season (May). This result agrees with Romeih *et al*. (2013) who reported the highest numbers of adult, immature, and egg of *T. urticae* averaged 26.4, 49.14 and 37.14 individuals per leaf, respectively, in March with a peak in spring. Similarly, Patel *et al*. (2020) found that *Amblyseius alstoniae* was positively correlated with the abundance of TSSM. In addition to Wang *et al*. (2010) who recorded the peak of *Tetranychus urticae* red form on sweet pepper in spring, while in autumn, no mite was recorded.

In addition, Maklad *et al*. (2014) found that the population of *A. gossypii*, *B. tabaci*, and *T. urticae* on pepper were the most severe during May-June compared to January-March for the two growing seasons studied. In addition, they found that the density of *B. tabaci* was the most severe, followed by *A. gossypii*, while the *T. urticae* density was less severe. In contrast, Çobanoğlu and Kumral (2016) and Mustafa and Al Mallah (2021) found that *T. urticae* reached a peak in the middle of August. Consequently, the season alone and interaction with the presence of the predators were the limiting factors of TSSM abundance.

The results herein showed distinct differences between the two cultivars regarding pest and predator densities. The cv. Cannon had the highest populations of TSSM, *B. tabaci* and *M. persicae* and the lowest populations of *P. persimilis* and *O. laevigatus* than the cv. Mazurka. Meanwhile, cultivars did not significantly affect the density of *N. cucumeris* and *S. longicornis.* It is obvious that the different cultivars of the same plant species can vary in their susceptibility to pest species and/or predators. They emit various secondary metabolites that attract predators of the herbivorous pests. These chemicals serve as a source of nourishment and protection for the predators, which in turn increases their ability to effectively control the population of herbivores (Arimura *et al*. 2009; Pappas *et al*. 2017). Hence, it is important to choose cultivars that balance pest resistance with predator support. This can help reduce the need for pesticides and promote the growth and survival of natural predators. Previous studies on pepper cultivars showed that the cultivar's resistance to some mite species, such as *Polyphagotarsonemus latus* (Banks) (Acari: Tarsonemidae), was correlated with the contents of chlorophyll, soluble sugar, polyphenol, and tannin (Li *et al*. 2015). Similarly, the photosynthetic pigments showed a negative relationship with aphids, whiteflies, spider mites, leafhoppers, thrips, and the associated predator infestation during the two early summer seasons (Helmi and Rashwan 2015; Bakr 2020). Likewise, *B. tabaci* resistance in pepper cultivars was strongly related to protective enzyme activity and total phenolic content (Kong *et al*. 2014). These findings are in line with our results which showed that cv. Mazurka was less susceptible to TSSM and the other insects due to the high leaf content of chlorophyll, phenol, and activity of antioxidant enzymes (GST, PPO, POD, and CAT).

However, there is a paucity of data regarding the influence of growing season and cultivar, together with herbivores density, on the resistance of sweet pepper. Previous research demonstrated that plants react differently to damage caused by various herbivorous insects. The aphid *Macrosiphum euphorbiae* Thomas feeding could induce the POD but not PPO activity, whereas the corn earworm *Helicoverpa zea* (Boddie) feeding induces the PPO but not POD activity of tomato *Lycopersicon esculentum* (Mill.) (Stout *et al*. 1997). TSSM increased POD but not CAT activity (Hildebrand *et al*. 1986). The feeding of *Tetranychus evansi* did not cause any significant changes in the GST activity of tomato but induced its total protein content (Ximénez-Embún *et al*. 2016). In contrast, the TSSM infestation induces phenols but not the protein content of tomato (Mustafa and Al Mallah 2021). In addition, TSSM could induce total protein content but not total phenolics of sweet pepper (El-Saiedy *et al*. 2013).

Increasing the population of TSSM and other insects is affected by different plant cultivars, and these differences may be related to nutritional value, chemical contents, and/or morphology of the host plant (Afifi *et al*. 2010). The more resistant cultivar exhibited a more considerable increase in secondary metabolites upon infestation, which could explain its more robust defense (Zhang *et al*. 2020). Plant secondary metabolites, such as phenols, proteins, and photosynthetic pigments, have various defensive chemicals that can cause a decrease in the population growth rate of herbivores (Gotoh and Gomi 2000).

Phenolic compounds were found to be highly over-accumulated in leaves of pepper, tomato, and cucumber following herbivory infestation (Kielkiewicz 2004; Tehri *et al*. 2014; Golan *et al*. 2017). Similarly, we noticed that the less infested sweet pepper plants were accompanied by an increase in their phenol content. Phenolic compounds are important components of secondary metabolites that function as antifeedants, digestibility reducers, or direct toxins for herbivores (Johnson and Felton 2001). Previous studies indicated that increasing the concentrations of foliar phenolic contents resulted in a reduction in *T. urticae* fecundity and/or a delay in the mite developmental times (Ali *et al*. 2015). Therefore, selecting sweet pepper cultivars with high concentrations of phenolic compounds could reduce the population growth rate of *T. urticae.*

However, cv. Mazurka was highly significant in GST, PPO, POD, and CAT activities than cv. Cannon. Our findings also showed that the W-Sp season was highly significant in GST, PPO, and POD activities due to highly infestation than the S-F season, except in CAT activity which was not changed. These results are in accordance with Steinite and Ievinsh (2002) who indicated that POD, PPO, and CAT activity in strawberry leaves depended on the cultivar. They found that the more resistant cultivar to *T. urticae* infestation had higher activity of POD and PPO and lower CAT activity. In addition, Bakr (2020) recorded a remarkable increase in POD and PPO activities, phenolic content, and a significant decrease in CAT activity upon TSSM infestation in the bean. Based on the activity of GST, PPO, POD, and CAT, the cv. Cannon had the lowest activity as compared to cv. Mazurka. Therefore, cv. Mazurka was highly resistant to TSSM infestation than the cv. Cannon.

These results demonstrated how the cultivar as well as the growing season, might affect the population fluctuations of the pests along with the host plant resistance. By exploring the ecological aspects of the two-spotted spider mite and its associated predators in a newly invaded agro-ecosystem, this study provides critical elements for establishing bases for the IPM and paves the way for controlling TSSM worldwide.

CONCLUSION

The use of resistant plant cultivars in conjugation with other control tactics generates more effective and long-lasting results in the management of many pests, especially TSSM, as farmers avoid chemicals due to residual risks in the fruit yields for export purposes.

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حساسیت فلفل شیرین (*Capsicum annuum* L.) به آلودگی به *Tetranychus urticae* (Acari: Tetranychidae) و حشرات آفت مختلف در شرایط گلخانه‌ای در اسماعیلیه، مصر

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چکیده

فلفل شیرین، محصول صادراتی مهم در مصر، به تازگی توسط کنهٔ تارتن دولکه‌ای (TSSM) به موازات سایر حشرات آفت که پتانسیل کاهش عملکرد آن را دارند مورد حمله قرار گرفته است. این مطالعه با هدف تعیین حساسیت دو رقم فلفل دلمه‌ای (رقم‌های مازورکا و کانن) به آلودگی به کنهٔ تارتن دولکه‌ای انجام شد. افزون بر این، هدف بررسی چگونگی تأثیر رقم و همچنین فصل رشد بر نوسانات جمعیت آفات همراه با مقاومت گیاه میزبان بود. همچنین فعالیت آنتی اکسیدانی آنزیمی و غیر آنزیمی برای تمایز بین دو رقم پس از آلودگی طبیعی تعیین شد. کنهٔ تارتن دولکه‌ای به عنوان آفت اولیه که در طول دو فصل رشد مورد بررسی به هر دو رقم حمله کرد، شناسایی شد. افزون بر کنهٔ تارتن دولکه‌ای، سه حشرهٔ آفت (*Bemisia tabaci*، *Frankliniella occidentalis* و *Myzus persicae*) و چهار شکارگر (*Neoseiulus cucumeris*، *Phytoseiulus persimilis*، *Scolothrips longicornis* و *Orius laevigatus*) در این بررسی شناسایی شدند. رقم کانن دارای بیشترین تراکم کنهٔ تارتن دولکه‌ای، *B. tabaci* و *M. persicae* نسبت به رقم مازورکا بود که بیشترین تراکم *P. persimilis* و *O. laevigatus* را نشان داد. همچنین یافته‌های این پژوهش نشان داد که فعالیت‌های آنزیم‌های آنتی‌اکسیدانی در فصل زمستان–بهار نسبت به فصل تابستان–پاییز بسیار معنی‌دار بود. رقم مازورکا به دلیل محتوای کلروفیل و فنل زیاد و فعالیت آنزیم آنتی اکسیدانی در برگ‌های آن، مقاومت بیشتری در برابر کنهٔ تارتن دولکه‌ای و سایر حشرات آفت داشت. تراکم جمعیت کنهٔ تارتن دولکه‌ای و آفات مرتبط بر اساس فصل و/یا رقم تغییر می‌کند.

واژگان کلیدی: آنزیم‌های آنتی اکسیدان، *Myzus persicae*، رقم مقاوم، متابولیت‌های ثانویه، کنهٔ تارتن دولکه‌ای.

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