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Evaluation of two predatory mites and acaricide to suppress *Tetranychus urticae* (Acari: Tetranychidae) on strawberry

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Abstract

Background: The two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), is a major pest of strawberry. It was necessary to control this mite pest that can reducing the quality and quantity of the fruits. In this regard, the effect of ZORO acaricide, *Neoseiulus californicus* (McGregor) and *Amblyseius swirskii* Athias-Henriot for suppressing the naturally occurring *T. urticae* populations on three strawberry cultivars were investigated.

Results: The two predatory mites and ZORO treatments significantly suppressed the populations of *T. urticae* below the control in all tested cultivars. In most cases of the current study, significantly lower numbers of *T. urticae* were generally observed in ZORO and *N. californicus* treatments compared to *A. swirskii* treatment. In all cultivars, the overall mean of reduction percentages of *T. urticae* populations in *N. californicus* and ZORO treatments were not statistically different, and all were significantly higher than that in *A. swirskii* treatment.

Conclusion: The present results suggested that the release of *N. californicus* and the application of ZORO acaricide could be promising strategies for controlling *T. urticae* on strawberry, although the release of *N. californicus* appears to be more competent tactic than ZORO acaricide.

Keywords: Acaricides, Biological control, Phytoseiid mites, Strawberry, *Tetranychus urticae*

Background

The strawberry (*Fragaria × ananassa* Duchesne) (Family: Rosaceae) is one of the highest consumed fruits over the last two decades worldwide (Albendin et al. 2015). The ripe fresh strawberry fruits are rich in vitamins and minerals (Khunte et al. 2020). In 2017, Egypt occupied the fourth place among the countries of the world in the production of strawberry (FAO 2019). In recent years, the cultivated area of strawberry has been increasing in Egypt (Abd-Elgawad 2019). The two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), is a main pest of several crops and attacks more than 1000 various plant species which includes economically important crops worldwide (van Leeuwen et al. 2010,

2015). However, *T. urticae* is also a major pest-infested strawberry in many countries such as New Zealand (Butcher et al. 1987), Spain (Garcia-Mari and Gonzalez-Zamora 1999), Argentina (Greco et al. 1999), USA (Dara et al. 2018) and Egypt. In strawberry, the high population of *T. urticae* can decrease the floral and foliar development and therefore reducing the quality and quantity of the fruits (Rhodes et al. 2006).

In Egypt, the chemical control is still widely used for the management of *T. urticae* in strawberry crop. The rapid developmental rate of spider mites and their high fecundity allows them to attain destructive population levels very quickly (Sato et al. 2007). In addition, they became resistance to several extensively used acaricides (Gerson and Weintraub 2007). Consequently, the extensive use of pesticides led to the outbreaks of *T. urticae* during the last few decades (Fraulo et al. 2008). Due to the environmental and health hazards resulted

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from the chemical pesticides as well as their side effects on the non-target organisms (e.g., soil microorganisms (Scheepmaker and van de Kasstele 2011) and predators (Bergeron and Schmidt-Jeffris 2020)), its use has been regulated firmly (Horikoshi et al. 2017). Take into account the economic significance of strawberry, it is important to search for efficient alternatives for the controlling of *T. urticae*. In this regard, biological control is one of the most economical and environmentally harmless methods of pest controlling for farmers (Cock et al. 2010). In some agricultural systems, the natural enemies can suppress the spider mite populations below levels of the economic damage (Nyrop et al. 1998). Among many natural enemies, phytoseiids are the most important biocontrol agents of *T. urticae* (McMurtry and Croft 1997). In different countries, phytoseiid mites are successfully used in the management of *T. urticae* in protected environments and in an open fields (e.g., Strong and Croft 1995; Gerson et al. 2003; Zhang 2003; Croft et al. 2004). However, phytoseiids are commonly used to control *T. urticae* in strawberry (Raworth 1990; Easterbrook 1992; Garcia-Mari and Gonzalez-Zamora 1999; Easterbrook et al. 2001; Oliveira et al. 2009).

Neoseiulus californicus (McGregor) (Acari: Phytoseiidae) is a phytoseiid mite that has wide range of diets, e.g., several phytophagous mite species (McMurtry and Croft 1997) and pollen (Pascua et al. 2020). On various crops, *N. californicus* found to be an effective control agents of *T. urticae* in different countries (Barber et al. 2003; Elmoghazy et al. 2011). *Amblyseius swirskii* Athias-Henriot (Acari: Phytoseiidae) is also one of the most effective biocontrol agents and is used in over 50 countries worldwide (Calvo et al. 2015). This predatory mite is a polyphagous phytoseiid that can feed on several kinds of prey, such as thrips, whiteflies (Calvo et al. 2011) and *T. urticae* (Xu and Enkegaard 2010). The aim of the current study was to evaluate the effect of an acaricide (ZORO) and the individual release of two predatory mites (*N. californicus* and *A. swirskii*) for suppressing the naturally occurring *T. urticae* populations on three strawberry cultivars.

Methods

Rearing of mites

The two-spotted spider mite, *T. urticae*, and the two phytoseiid mites (*A. swirskii* and *N. californicus*) were obtained from colonies reared in the Laboratory of Acarology, Pests and Plant Protection Department, National Research Centre, Dokki, Cairo, Egypt.

The colony of *T. urticae* was reared on kidney bean plants, *Phaseolus vulgaris* L. The stock colonies of the two phytoseiid mites, *N. californicus* and *A. swirskii*, were maintained separately on kidney bean leaves placed on wet cotton pads in large trays. The cotton pad was put in

the center of each tray, leaving an empty space provided with water to prevent the phytoseiids from escaping. Infested leaves from *T. urticae* culture were provided to the phytoseiids cultures as food. The trays were kept in an incubator at 28 ± 2 °C, 70 ± 5 % RH. For the mass rearing of these predatory mites, the two phytoseiids were released and reared separately on kidney bean plants infested with *T. urticae* in greenhouses.

Acaricide used

Abamectin (ZORO 3.6% EC) is the acaricide that was used in the present study at the rate of 100 cm³/100 liter of water.

Experimental design

These experiments were conducted to evaluate the effect of ZORO acaricide and the individual release of two predatory mites for suppressing the naturally occurring *T. urticae* populations on three strawberry cultivars. The tested cultivars (029, Fortona, and Wanter star) were cultivated during the 2018/2019 season in strawberry field located at Markaz Badr, Beheira Governorate, Egypt. The experimented area of each strawberry cultivar was consists of four equal plots (control and three treatments plots) with three replicates/plot. The size area of each treatment plot was about 84 m² and the plots were completely separated by plastic sheets. Recommended agricultural process were performed.

All the tested strawberry cultivars were naturally infested with all stages of *T. urticae*. In the present study, four treatments were assessed and included 1) the releases of *N. californicus*, 2) the releases of *A. swirskii*, 3) ZORO acaricide, and 4) the untreated control. On the three cultivars, the two predatory mites were released on November 1, 2018, and December 13, 2018, while for *A. swirskii* an additional release was carried out on January 31, 2019. However, ZORO acaricide had four applications that carried out on November 1, 2018, December 13, 2018, January 31, 2019 and March 7, 2019. Predatory mites were released on bean leaves with an estimated numbers of each phytoseiid. The two predatory mites were released at predator–prey ratio of 1:7.

Mite sampling

Sampling was initiated from the first of November, the date of first treatment (week 0), and continued for 26 weeks after the first treatment. The leaves samples were collected weekly from the three treatments and control of each cultivar till the end of the study. Each week, 10 leaves per replicate (30 leaves/plot) were collected from 10 randomly selected plants and transferred to the laboratory. The numbers of *T. urticae* (all stages) on each leaf were counted under a stereomicroscope.

Data analysis

A randomized complete block design was used in the present study. For each cultivar, the efficacy of the three treatments on *T. urticae* population was estimated by comparing the numbers of *T. urticae* that recorded in the treated plot with those recorded in the control (untreated) plot in each sampling week. We also calculated the reduction percentages of *T. urticae* in the treated plots of each cultivar according to Henderson and Tilton equation (Henderson and Tilton 1955). For each cultivar, the overall mean of reduction percentages of mite (during the period from the first sample after treatment to the last sample of the study, the weekly values of reduction percentages of mite were averaged over this period to obtain the overall mean of reduction percentages of mite on each treatment) were also calculated at the end of study. All data were subjected to analysis of variance (ANOVA), F test. For comparing the means, Tukey's multiple range test ($P < 0.05$) was applied. All statistical analysis were performed by Statistical Package of Social Science (SPSS), version 20.

Results

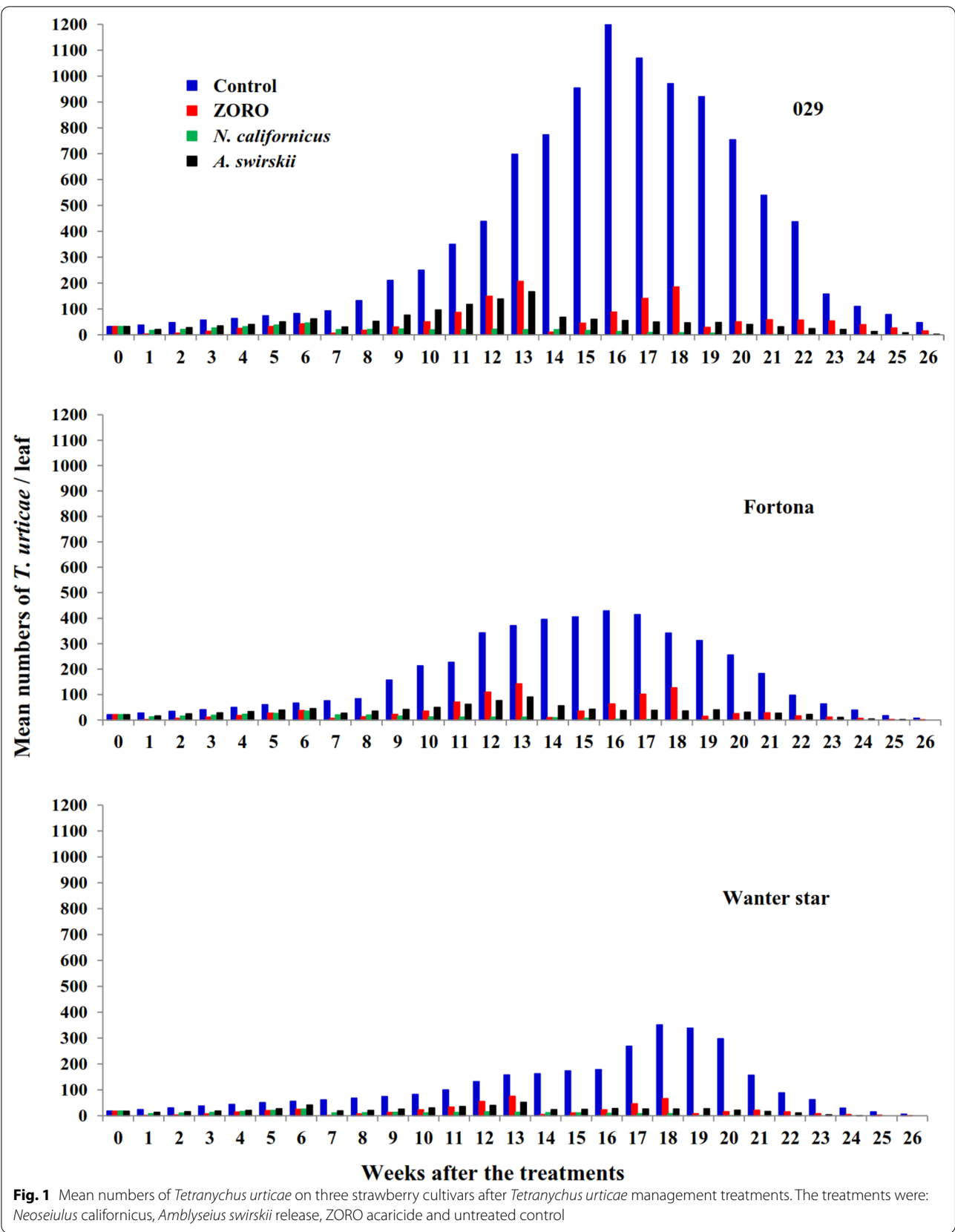
Natural populations of *T. urticae* occurred in all strawberry experimental plots. On November 1, the pre-treatment samples (week 0) revealed that there were no significant differences in *T. urticae* natural populations among the four experimental plots of each cultivar (029: $F = 0.06$; $P > 0.05$, Fortona: $F = 0.01$; $P > 0.05$, Wanter star: $F = 0.11$; $P > 0.05$) (Fig. 1). For all cultivars, the first treatment was made on November 1. On all tested cultivars, the three treatments significantly reduced the numbers of *T. urticae* in treated plots as compared to control plot after one week of treatment (029: $F = 217.28$; $P < 0.01$, Fortona: $F = 140.11$; $P < 0.01$, Wanter star: $F = 69.44$; $P < 0.01$) (Fig. 1). However, the numbers of *T. urticae* in the untreated plots remained significantly higher than those in treated plots on all weeks following the first treatment (all P 's < 0.01). Generally, from week 1 to week 10, the mean numbers of *T. urticae* in ZORO and *N. californicus* plots were significantly less than that in *A. swirskii* plots. By weeks 12 and 13, the mean numbers of *T. urticae* in ZORO treatment became significantly higher than those in *A. swirskii* treatment (all P 's < 0.01). During the two weeks followed the third treatment of ZORO and *A. swirskii*, the numbers of *T. urticae* significantly reduced by ZORO treatment compared to *A. swirskii* treatment (all P 's < 0.01). Again by week 17 and 18, the mean numbers of *T. urticae* in *A. swirskii* plots were statistically less than that in ZORO plots (all P 's < 0.01). One week after fourth ZORO treatment, *T. urticae* numbers in both *N.*

californicus and ZORO treatments were significantly lower than that in *A. swirskii* treatment (all P 's < 0.01). In the last month of the study, *N. californicus* treatment led to the highest decreases in *T. urticae* numbers, followed by *A. swirskii* and ZORO treatments (Fig. 1).

The reduction percentages of *T. urticae* populations after the treatments of the two phytoseiids and ZORO acaricide on three strawberry cultivars were presented in Fig. 2. For 029, Fortona and Wanter star cultivars, the first samples after predatory mites releasing (week 1) showed that the reduction percentages of *T. urticae* were reached to 56.16, 58.19 and 67.55% in *N. californicus* and 44.37, 42.41 and 44.76% in *A. swirskii* treatments, respectively. In general, this values were declined in both phytoseiid treatments for the following weeks then increased by week 7 (one week after the second release). In *A. swirskii* plots, the reduction percentages of *T. urticae* were fluctuated for the following weeks then increased by week 14 (one week after the third release). On the other hand, the reduction percentages of *T. urticae* in *N. californicus* treatment were gradually increased from week 7 until attained their peaks (100% reduction) by week 23, 20 and 21, on the aforementioned cultivars, respectively (Fig. 2).

One week after the first ZORO application, the reduction percentages of *T. urticae* were 91.26, 94.47, and 93.92% for 029, Fortona and Wanter star cultivars, respectively (Fig. 2). These values gradually decreased during the following weeks then greatly increased by week 7 (1 week after second application) to record 92.84, 91.76 and 97.39% on the aforementioned cultivars, respectively. Once again, these values gradually decreased until week 13 (date of the third application) then increased for only a week followed by a gradual decrease until week 18 (date of the fourth application). In all cultivars, the reduction percentages of *T. urticae* in ZORO plots were increased by week 19 followed by a gradual decrease in the next three weeks of study (Fig. 2).

In each cultivars, the statistical analysis indicated that the overall mean of reduction percentages of *T. urticae* were varied significantly among treatments (all P 's < 0.05). The highest value of the overall mean of reduction percentages of *T. urticae* populations was recorded in *N. californicus*, while the lowest was recorded in *A. swirskii* treatments; without significant difference in these values between *N. californicus* and ZORO treatments in each cultivars (Fig. 3). In each treatment, although the highest value of the overall mean of reduction percentages of *T. urticae* was recorded on Wanter star cultivar as compared to the other cultivars, these values were not statistically different among the tested cultivars (all P 's > 0.05) (Fig. 3).



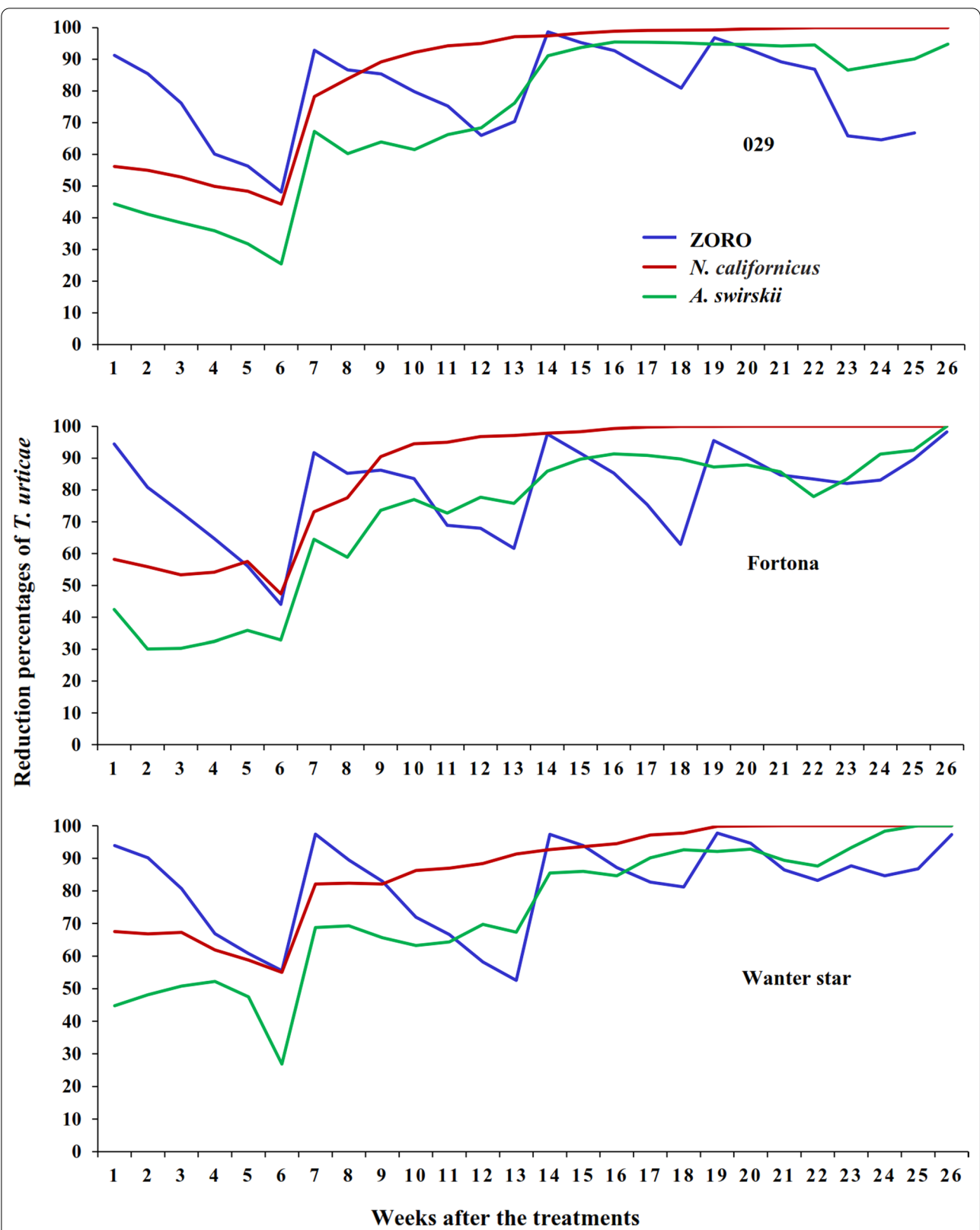


Fig. 2 Reduction percentages of *Tetranychus urticae* populations on three strawberry cultivars after *Tetranychus urticae* management treatments. The treatments were: *Neoseiulus californicus*, *Amblyseius swirskii* release and ZORO acaricide



Discussion

The predatory phytoseiid mites are an effective tool for *T. urticae* management in strawberry crop as indicated by previous studies (Easterbrook et al. 2001; Fitzgerald and Easterbrook 2003; Tuovinen and Lindqvist 2014). In the present study, the two phytoseiids and ZORO treatments suppressed the populations of *T. urticae* below the control in all cultivars (Fig. 1). Although *A. swirskii* preyed and developed on *T. urticae* (Xiao et al. 2012; Farazmand and Amirs-Maafi 2020), our study showed that *N. californicus* suppressed *T. urticae* populations quickly and better than *A. swirskii*; perhaps due to the degrees of phytoseiid specialization with regard to their food. *Neoseiulus californicus* is known to prefer the tetranychid spider mites that producing heavy webbing as prey (e.g., *T. urticae*) (McMurtry and Croft 1997), while *A. swirskii* is a generalist phytoseiid that found to prefer other types of prey such as thrips when compared with *T. urticae* (Xu and Enkegaard 2010). Our results were also in agreement with the study of van Houten et al. (2007) who confirmed that *A. swirskii* can decelerate the populations of *T. urticae* but cannot control *T. urticae* hot spots because it does not enter the colonies with dense webbing. Elmoghazy et al. (2011) found that *N. californicus* reduced the populations of *T. urticae* by 87.22%, while *A. swirskii* reduced the populations of *T. urticae* by 57.49% on faba bean which is corroborating with our findings.

In general, it was observed that *T. urticae* populations that naturally occurred on the tested cultivars were dissimilar among these different cultivars (Fig. 1). This

variability in tetranychid mite populations on different plant cultivars may be related to the differentiations in cultivar nutritional value (van de Vrie et al. 1972). However, Fahim et al. (2020) reported variations among the strawberry cultivars in their suitability for the reproduction and development of *T. urticae*, which may explain the variations in *T. urticae* populations on the different tested cultivars in our study.

The pest management programs must be aimed to control the agricultural pests, with considerable success in the terms of environmental safety and long-term economic control. Although a number of studies concluded that *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae) found to be able to successfully control *T. urticae* on strawberry in several countries (Cross 1984; Decou 1994; Cross et al. 1996), other studies have displayed additional advantages of *N. californicus* over *P. persimilis*. The reproduction of *P. persimilis* is depending on the existing of *Tetranychus* mites as prey. Consequently, this phytoseiid has a tendency to disperse after the number of its prey on a crop is greatly reduced as a result of predation (Cakmak et al. 2005) which only offers short-term pest management (Walzer and Schausberger 1999). On the contrary, *N. californicus* be able to adapt to variations in its prey populations, which provide a stable pest control over time (Castagnoli et al. 1999; Greco et al. 2005). In spite of that *N. californicus* prefer tetranychid mites as prey, it can survive on other food sources (e.g., thrips and pollen) if spider mite populations were decreased (Gerson et al. 2003; Pascua et al. 2020).

Moreover, *N. californicus* can survive at low RH (Baker et al. 1993) and can develop on *T. urticae* at 15–35 °C (Gotoh et al. 2004). However, the potential of *N. californicus* as a biocontrol agent that can provide a long-term control of *T. urticae* on strawberry was mentioned by previous studies (Rhodes et al. 2006; Fraulo et al. 2008).

In all cultivars, the overall mean of reduction percentages of *T. urticae* populations in *N. californicus* treatments were ranged between 85.69 and 86.64%. (Fig. 3). This proposed that *N. californicus* may be a promising biocontrol agent for successful management of *T. urticae* on strawberry. In the same context, the study of Rhodes and Liburd (2006) on strawberry revealed that *N. californicus* has a potential to successfully suppress spider mites under the economic thresholds. Our present results are in accordance with previous studies that have demonstrated that *N. californicus* found to be an efficient suppressor of *T. urticae* in strawberry crop (Greco et al. 2005; Rhodes et al. 2006; Ahn et al. 2010). On the other hand, Cakmak et al. (2009) found that *N. californicus* did not decrease *Tetranychus cinnabarinus* Boisduval population. In our study, *N. californicus* reduced *T. urticae* populations below the control after its releases at a predator–prey ratio of 1:7, whereas in Cakmak et al. (2009) study, *N. californicus* was released at a predator–prey ratio of 1:20; perhaps this is the reason why *N. californicus* did not reduce *T. cinnabarinus* numbers. In this context, phytoseiid–spider mite ratios < 1:10 are considered promising in other cropping systems (e.g., Hamlen and Poole 1982; Strong and Croft 1995; Opit et al. 2004).

Compared with *N. californicus* and ZORO treatments, *A. swirskii* recorded the lowest overall mean of reduction percentages of *T. urticae* populations on the tested cultivars (Fig. 3). This suggests that both *N. californicus* and ZORO may be better in decreasing or controlling *T. urticae* than *A. swirskii* on strawberry. Presently, ZORO acaricide was very effective and successfully knocked down *T. urticae* populations for two weeks after each application. By time, *T. urticae* populations started to increase, and therefore additional ZORO treatments were required to keep *T. urticae* numbers low. We suggested that using ZORO acaricide in combination with an efficient phytoseiid, like *N. californicus*, for the control of *T. urticae* possibly will be an efficient management strategy on strawberry, although further investigation would be required to prove this possibility.

Based on our results, *N. californicus* generally decreased the populations of *T. urticae* to an extent similar to ZORO acaricide in all cultivars. In the same way, Cakmak et al. (2009) indicated that *P. persimilis* suppressed *T. cinnabarinus* populations to a level equal to chemical control. In this regard, spider mite is considered a serious pest on the plants treated with

commercial chemicals due to its ability to develop a resistance against several widely used acaricides (Kim et al. 2006). Additionally, the extensive use of chemical pesticide can lead to negative impact on the environment and its elements (Kumral et al. 2010). This is contrary to the use of biocontrol agents which might allow permanent reduction of the spider mite populations below damaging levels (Abdallah et al. 2012).

In many agricultural systems, biological control found to be an economically and environmentally good alternative to pesticides (van Lenteren and Bueno 2003). Although ZORO acaricide is effective, the costs of its successive applications in the present study are higher than that of *N. californicus*; since the acaricide may be less profitable. In strawberry, a one-time treatment of *N. californicus* costs one-third the costs of chemical applications (Fraulo et al. 2008). Besides, the predatory mites can provide a control for the entire season at a costs approximately equal to one abamectin spray (Waite 2002). However, it is essential to take into consideration the costs of control agents and their effectiveness on the environment when selecting a strategy to control *T. urticae*. Consequently, the release of *N. californicus* appear to be more competent tactic than ZORO acaricide to provide an efficient management of *T. urticae* on strawberry.

Conclusion

In conclusion, both ZORO acaricide and *N. californicus* are very effective for *T. urticae* control as compared to *A. swirskii*. However, the present results suggested that the release of *N. californicus* appears to be more competent strategy for controlling *T. urticae* than the chemical control on strawberry.

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Authors' contributions

The two authors conducted the research experiments (EME conducted most of the research field experiments and SFF participated in conducting the research experiments). SFF carried out the statistical analysis and constructed the figures. SFF wrote the manuscript and revised it. The two authors read and approved the final manuscript.

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Consent for publication

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Competing interests

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