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Effects of Climatic Fluctuations on Potentialities of Phytoseiid Species and A Biopesticide in Solo Applications against Pests of the Pepper (*Capsicum annum* L.)

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ABSTRACT

Climatic conditions and their fluctuations are playing an important role in the potentiality of predatory mite species in the biological control applications. This study was aimed to evaluate the impact of temperature and relative humidity fluctuations on the efficiency of the predatory mites and a biopesticide Egyxide to control *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae), *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), and *Tetranychus urticae* Koch (Acari: Tetranychidae) infestations on Yellow-Delta-Star pepper in winter and summer seasons. *Amblyseius swirskii* Athias-Henriot, *Phytoseiulus persimilis* Athias-Henriot, *Neoseiulus cucumeris* (Oudemans), and *Cydnoseius negevi* (Swirski & Amitai) (Acari: Phytoseiidae) were the predatory mite species used in this study. The study was carried out according to complete randomised block design experiments. The experimental size under high plastic-net tunnel conditions consisted of six sections and three replicated plots. Temperature and relative humidity significantly affected predation potentialities after inundative release. All predatory species showed high reduction responses during winter weeks. Data showed significant correlation between bio-agents and the biopesticide to the temperature changes in winter and relative humidity in summer. *Amblyseius swirskii* and *N. cucumeris* showed high reduction percentages in winter than summer weeks. In addition, *C. negevi* recorded an adaptability and non-significant responses to temperature fluctuations in both experimental seasons. Egyxide has recorded the least reduction against all targeted pests in both seasons. In conclusion, the study would recommend using *A. swirskii*, *N. cucumeris*, and *C. negevi* during winter weeks to guarantee achieving successful biocontrol application. Especially in the dry arid locations such as the Egyptian Agro-ecosystems

Keywords: Classical biological control (CBC), Climate change, Phytoseiidae, Predator-herbivore interactions.

1. Introduction

According to FAOSTAT in 2023, the world's production of pepper, *Capsicum* spp. L. (Solanaceae), reached 52.64 million tonnes in 2021. Additionally, Egypt is on the top ten producers by 564,689.18 tonnes in 2021. Globally, the production of sweet/bell pepper, *Capsicum annuum* L., either in plastic-net houses, greenhouses, or open fields has been reported to be infested by large number of insect and mite pest species (Dekebo 2023). For instance, whitefly, *Bemisia tabaci* (Gennadius) (Aleyrodidae: Hemiptera) (Li *et al.,* 2021); onion thrips, *Thrips tabaci* Lindeman, *T. parvispinus* (Karny), the western flower thrips, *Frankliniella occiddntalis* (Pergande) (Thripidae: Thysanoptera) (Maharijaya *et al.,* 2011; Visschers *et al.,* 2019), the broad mite, *Polyphagotarsonemus latus* (Banks)

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(Tarsonemidae: Acari) (Abou-Awad *et al.,* 2014), and the two spotted spider mite (TSSM), *Tetranychus urticae* Koch (Tetranychidea: Acari) (EL-Kasser *et al.,* 2023).

Recently, predatory mites of the family Phytoseiidae have been successfully employed in the classical biological control applications (CBC) and/or integrated pest management tactics (IPM) against a complex of pest mite and insect species simultaneously. They have been used either as solo application of one predatory species (Zhang *et al.,* 2012; El-Laithy *et al.,* 2021), or several species (Zidan *et al.,* 2022). As well as, in a combined application of several predatory species together (Barghout *et al.,* 2022). Phytoseiids are produced commercially on a wide scale to be used in greenhouses, high plastic-net houses conditions, as well as in open fields in several Agro-ecosystems (Knapp *et al.,* 2018). In this regard, a fundamental question is raised; how phytoseiid potentialities are affected by their outer factors positively and/or negatively?

Above and beyond, climatic conditions are one of the strongest abiotic factors that powerfully impact arthropod activities, diversity, and distribution (Prather *et al.,* 2023). Consequently, based on the updated Köppen-Geiger's world map of climate (Kottek *et al.,* 2006; Rubel and Kottek, 2010), Egypt is located on the hot arid desert area. Massive fluctuations in the Egyptian air temperature and relative humidity, have been detected either on daily or annually records during the last three decades (El-Marsafawy *et al.,* 2019). These variations include the risk of gradual increase in air and/or soil temperature, drought, and water scarcity (Mirhosseini *et al.,* 2017). Generally, several phytoseiid species negatively affected by temperature more than 32°C (Kasap *et al.,* 2023). For example, *Typhlodromus recki* Wainstein (Ersin *et al.,* 2021), *Neoseiulus womersleyi* (Schicha), *N. longispinosus* (Evans) (Sugawara *et al.,* 2017), *T. athiasae* Porath and Swirski (Kasap *et al.,* 2023), *Euseius finlandicus* (Broufas and Koveos, 2001), *T. bagdasarjani* Wainstein and Arutunjan (Ganjisaffar *et al.,* 2011), *Galendromus flumenis* (Chant) (Ganjisaffar and Perring, 2015), and *Amblyseius swirskii* Athias-Henriot (Lee and Gillespie, 2011; Rahimi *et al.,* 2022). Additionally, the soil dwelling mite species, *Lasioseius japonicus* Ehara (Acari: Blattisociidae) (Zhang *et al.,* 2022).

In addition, herbivore species have been reported to be affected by temperature increase, e.g., citrus brown mite, *Eutetranychus orientalis* Banks (Acari: Tetranychidae) (Imani and Shishehbor, 2009), the lychee erinose mite, *Aceria litchii* (Keifer) (Acari: Eriophyidae) (Ataide *et al.,* 2024), and the white fly, *B. tabaci* (Wang and Tsai, 1996).

Relative humidity (RH) in an ecosystem would affect the distribution and abundance of mite species and their activities. Besides, it has been proven to affect survival and demographic parameters of predatory mites, accordingly the success of CBC application (De Vis *et al.,* 2006; Ferrero *et al.,* 2010). For example, some species cannot survive or reaching maturity in dry conditions, e.g., the predatory species, *Amblyseius largoensis* Muma (Gómez-Moya *et al.,* 2018), and the herbivore species, the broad mite, *P. latus* (Abou-Awad *et al.,* 2014).

Therefore, this study was conducted to evaluate the impact of temperature and relative humidity fluctuations on the potentialities of phytoseiid bioagents and biopesticide means. The study can help to determine the appropriate release timing according to the optimum temperature and RH in high plastic-net conditions.

2. Methods

2.1. Experimental location and habitat structure

Our experiments have been conducted in high tunnel plastic-net house at Om Saber, Badr Centre, Kom Hamada, El-Beheira Governorate (30°28'59.4"N 30°46'52.9"E) (Google Maps https://www.google.com/maps/@30.4833034,30.7789384,469m/data) (Fig. 1A).

The experimental plastic-net unit belonged to a private sector farm that commercially produces peppers and beans, *Phaseolus vulgaris* L. (Fabaceae) at large scale under controlled agricultural procedures. Besides, some varieties of strawberries, *Fragaria × ananassa* spp. Duchesne (Family: Rosaceae), were commercially produced under open field conditions.

Yellow Delta Star (YDS) pepper variety, *C. annuum*, has been used in the recent study. The farm administration is protecting their seed sources due to copyrights. The experimental unit area was 145×45 m^2 of flat/horizontal surface. The study area was equally divided using wooden parries to separate the total area into six chamber like sections (section's dimension was 23×45 m^2; 5 treatments and 1 for control) (Fig. 1B). Parries were covered with plastic sheets and organdie mesh to prevent mite and insect species' dispersal. Each section had three plots (replicates) each was 21 × 13 m^2 in area. The

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uncalculated areas were used for passages and boarders to manage sampling, investigation, handling, maintenance, weed removal, and other agricultural procedures. Each plot had five rows, and each row had 40 plants (200 plant/plot) where the distance between each seedling was 0.35 meter. The irrigation and fertilization regime were conducted as custom. Plants were equally receiving all light requirements.

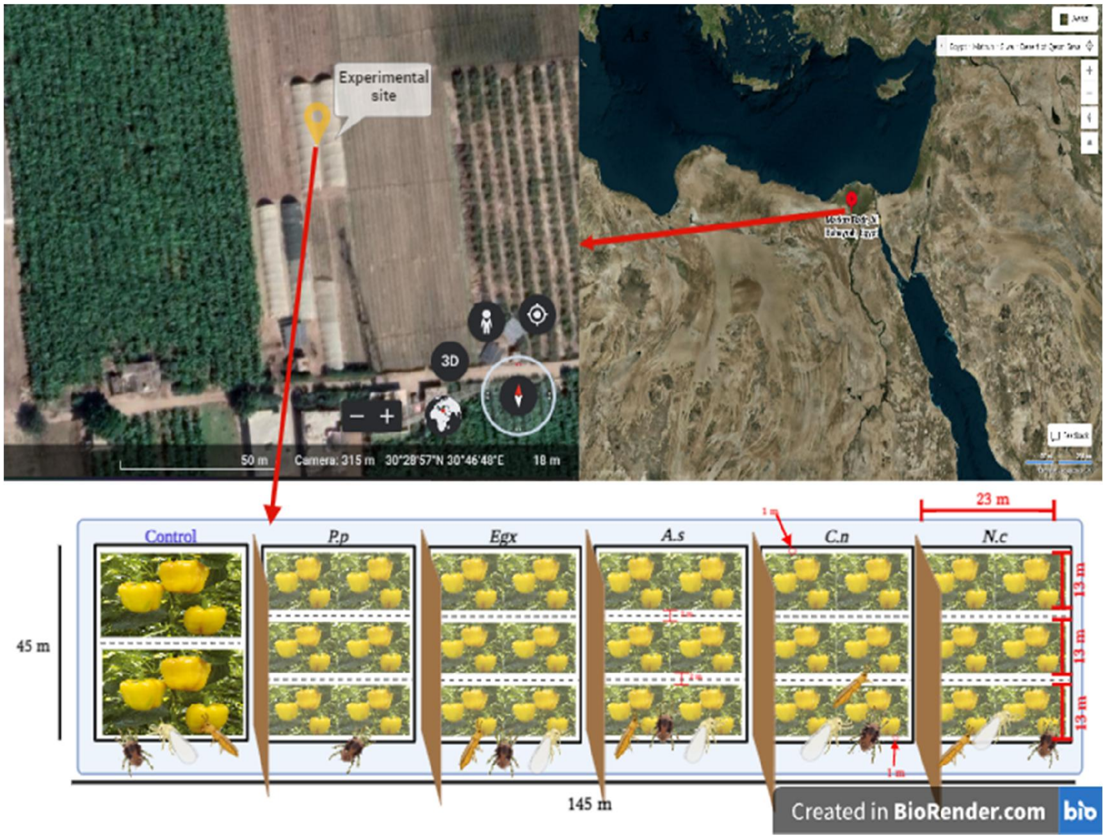

Fig. 1: A) The experimental location at Om Saber, Badr Center, El Beheira Governorate, Egypt. B) The experimental design of land area under high-net-plastic conditions. The total area was 145 × 45 m^2 and each section's area was 23 × 45 m^2. Mapping has been generated using Bing maps https://www.bing.com/maps and Google Earth https://earth.google.com/web. Graphic illustration is created with BioRender https://www.BioRender.com.

2.2. Natural enemies and the biopesticide

Four phytoseiid species were tested *A. swirskii* (*A.s*), *N. cucumeris* (Oudemans) (*N.c*), *Phytoseiulus persimilis* Athias-Henriot (*P.p*), and *Cydnoseius negevi* (Swirski & Amitai) (*C.n*). Predatory mites were commercially available from private companies in Qaha, Al-Qalioubia Governorate and Badr centre, Al-Beheira Governorate. A single mite package contained about 1000 individuals. The releasing ratio was 1:5 (predator: pest), based on sampled pest density in preliminary examinations.

The biopesticide, Egyxide® (*Egx.*) is a commercial water-soluble natural oils mixture. It is recommended for both organic and clean farming systems in different conditions. It contains natural 10% emulsified plant oils and 2% glue. Foliar application was recommended with dosage of 5 mL/Litre. Package of one litre was available at Royal for Agricultural Development, Cairo, Egypt.

2.3. Experimental procedures

Ten leaves (with three replicates) of each plot have been randomly sampled, covering all plant levels. Samples have been checked in the Acarology and Entomology labs, NRC. The reduction after applying biological control treatments has been counted from the sampled leaves (n= 10 leaves × 3 replicates/plots × 6 sections = 180 samples weekly).

The experiments extended over 11 weeks with 7 days interval between each sample/count during two seasons;

1) Winter season started from November 22, 2021 until January 31, 2022.
2) Summer season started from June 20, 2022 until August 22, 2022.

It was hypothesized that climatic conditions significantly affect the potentialities of predatory mites. Therefore, all main meteorological data were recorded using Ventusky (available online https://www.ventusky.com/app), and NASA Worldview (open source https://worldview .earthdata. nasa.gov/).

Preliminary investigations have been conducted to randomly check the population fluctuations of *T. urticae*, *T. tabaci*, and *B. tabaci*, and detect the release of predatory mites timing and amount. Once the pests' population density was built up, and the average number of pests per plant leaves reached the economic threshold level, biological control treatments were applied. Our biological control treatments were inundatively applied on the 1st week of the experiment in both seasons. Predatory mites' releasing ratio has done with a rate of 1:5 predator/prey (based on the preliminary check). Egyxide foliar application's rate was 5L/100L for an area of 4200 m^2.

2.4. Data analysis

Experimental trials have been applied in completely randomized block design (CRPD). Collected data have been performed using one way analysis of variance ANOVA by Duncan's test at probability level $P \leq 0.05$ using SPSS computer program ver. 26. The reduction percentages of pests in treated plots were calculated according to Henderson and Tilton (1955) equation, as follows:

$$(Reduction\ Percentage = \left(1 - \frac{n\ in\ C\ before\ treatment\ x\ n\ in\ T\ after\ treatment}{n\ in\ C\ after\ treatment\ x\ n\ in\ T\ before\ treatment}\right) x\ 100)$$

Where: n = pest population, T = treated, C = control.

Pearson correlation coefficient (r) was calculated to test the effects of climatic factors (mean temperature °C and mean relative humidity %) on the predatory mites and biopesticide using GraphPad Prism ver. 9.5.1.

3. Results

3.1. Impact of climatic factors on the predatory mites and biopesticide activities

The results indicated that during winter experiments the temperature significantly affected the efficiency of all predatory mites to control tested pests. The findings also demonstrated that, temperature had a significant impact on Egyxide effectiveness for controlling *T. urticae* active stages and *T. tabaci* (P=0.04 and 0.001, respectively), but not for controlling *T. urticae* eggs or *B. tabaci* (P=0.0995 and 0.001, respectively) (Table 1).

In the winter season, the release of *A. swirskii* gradually decreased the number of target pests starting from the 2nd to 11th week (Fig. 2A). While the population density of *B. tabaci* was less than one individual/leaf starting from week 9 compared to increased population density in control plot (Fig. 2K). In summer season, a similar gradual reduction in the number of tested pests was observed by *A. swirskii* treatment (Fig. 2B). The population of *B. tabaci* decreased by its release more than that of the other two target preys.

Releasing *P. persimilis* showed high efficacy in controlling both *T. urticae* targeted stages in the winter season (Fig. 2C). Contrary, the populations of *T. urticae* eggs and *T. urticae* active stages did not reach <1 until the last two weeks of the summer experiment (Fig. 2D).

Regarding the population density of four pests after the release of *N. cucumeris*, the data in Fig. 2E shows the reduction in their numbers during the winter season. Although *T. urticae* eggs and *T. urticae* active stages were observed in higher numbers during the first week of winter experiment, their population declined rapidly on week 5 compared to their numbers in control plot (Fig. 2K). Additionally, their population density reached to <1 on weeks 7 and 8, respectively. The population density of *B. tabaci* and *T. tabaci* decreased to <1.0 individual/leaf on weeks 8 and 10, respectively, in contrast to their recorded numbers in the control plot (Fig. 2K).

Table 1: Correlation relationship (r) of temperature (T) and relative humidity (RH%) to the efficiency of applied biological control against pepper pests in winter and summer seasons

Experimental season	Relation to Temperature / Humidity	Pearson	*T. urticae*					
			Eggs					
			A.s	*P.p*	*N.c*	*C.n*	*Egx.*	Control
Winter	T	*r*	0.87	0.69	0.85	0.80	-0.52	-0.84
		Sig.	0.001***	0.018*	0.001***	0.003**	0.099*ns*	0.001**
	RH	*r*	-0.14	-0.11	-0.12	-0.006	0.25	0.13
		Sig.	0.677*ns*	0.754*ns*	0.734*ns*	0.826*ns*	0.460*ns*	0.710*ns*
Summer	T	*r*	-0.54	-0.53	-0.53	-0.48	0.34	0.51
		Sig.	0.084*ns*	0.091*ns*	0.093*ns*	0.133*ns*	0.310*ns*	0.105*ns*
	RH	*r*	-0.78	-0.80	-0.81	-0.82	0.81	0.81
		Sig.	0.005**	0.003**	0.002**	0.002**	0.003**	0.003**
					B. tabaci			
Winter	T	*r*	0.81		0.85	0.80	-0.50	-0.77
		Sig.	0.002**		0.001***	0.003**	0.118 *ns*	0.005**
	RH	*r*	-0.04		-0.14	-0.05	0.15	0.03
		Sig.	0.897*ns*		0.687*ns*	0.882*ns*	0.658*ns*	0.938*ns*
Summer	T	*r*	-0.60		-0.58	-0.51	-0.12	0.06
		Sig.	0.052*ns*		0.059*ns*	0.113*ns*	0.723*ns*	0.870*ns*
	RH	*r*	-0.63		-0.65	-0.81	-0.74	0.56
		Sig.	0.038**		0.029**	0.003***	0.01	0.133

Table 1: Cont.

Experimental season	Relation to Temperature / Humidity	Pearson	*T. urticae*					
			Active stages					
			A.s	*P.p*	*N.c*	*C.n*	*Egx.*	Control
Winter	T	*r*	0.85	0.85	0.84	0.80	-0.62	-0.80
		Sig.	0.001***	0.001***	0.001**	0.003**	0.04*	0.003**
	RH	*r*	-0.13	-0.14	-0.14	-0.04	0.29	0.07
		Sig.	0.712*ns*	0.674*ns*	0.671*ns*	0.915*ns*	0.388*ns*	0.844*ns*
Summer	T	*r*	-0.50	-0.54	-0.51	-0.49	0.29	0.59
		Sig.	0.116*ns*	0.084*ns*	0.112*ns*	0.128*ns*	0.394*ns*	0.057*ns*
	RH	*r*	-0.83	-0.84	-0.82	-0.83	0.84	0.78
		Sig.	0.002**	0.001**	0.002**	0.002**	0.001**	0.005**
					T. tabaci			
Winter	T	*r*	0.80		0.81	0.82	-0.84	-0.80
		Sig.	0.003**		0.002**	0.002**	0.001**	0.003**
	RH	*r*	-0.03		-0.08	-0.13	0.09	0.06
		Sig.	0.925*ns*		0.820*ns*	0.703*ns*	0.802*ns*	0.865*ns*
Summer	T	*r*	-0.50		-0.50	-0.52	0.29	0.49
		Sig.	0.120*ns*		0.116*ns*	0.103*ns*	0.394*ns*	0.129*ns*
	RH	*r*	-0.84		-0.82	-0.81	0.84	0.56
		Sig.	0.001***		0.002***	0.003***	0.001***	0.072*ns*

*, **, *** significancy level, ns not significant at P ≤ 0.05.
Pearson correlation was tested at 95% confidence level, number of XY pairs= 11.

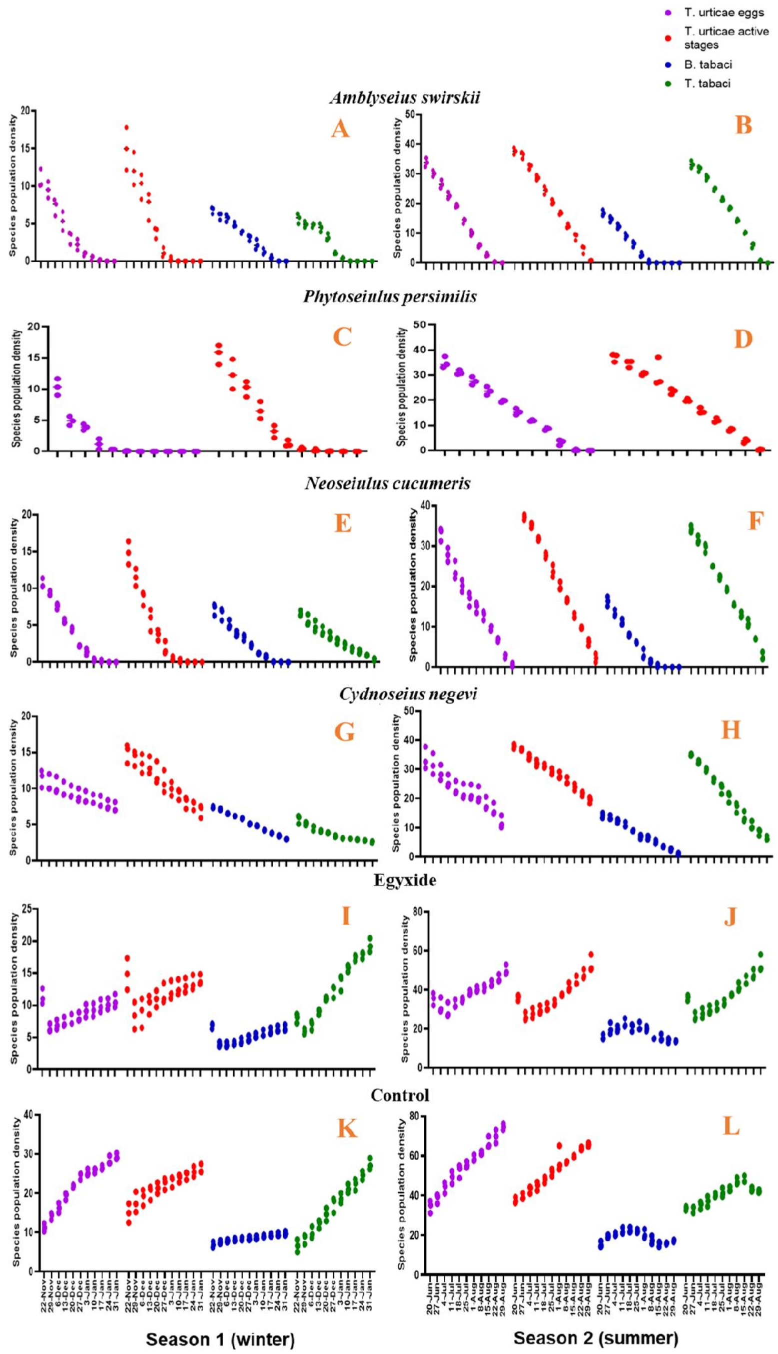

Fig. 2: Pest populations of the *T. urticae*, *T. tabaci*, and *B. tabaci* when predatory mites *A. swirskii* (**A, B**), *P. persimilis* (**C, D**), *N. cucumeris* (**E, F**), *C. negevi* (**G, H**), and the biopesticide, Egyxide (**I, J**) have been applied in two experimental seasons comparing to the control (**K, L**). Data at significance level of 95% using GraphPad Prism.

The release of *N. cucumeris* in summer season successfully decreased the number of three pests (Fig. 2F). Throughout the experiment, only *B. tabaci* was found in fewer numbers than the other two pests. However, a gradual reduction in the population density of three pests was observed.

Results also show that the release of *C. negevi* reduced the population density of three pests during winter experiment (Fig. 2G). However, on the last week of winter experiment, the number of pests did not reach <1 individual/leaf. Whereas in summer experiment, the number of observed egg-individual pest/leaf in the plot where *C. negevi* was released on the eleventh week decreased to 11.83, 19.50, 1.18, and 6.39 for *T. urticae* eggs, *T. urticae* active stages, *B. tabaci*, and *T. tabaci*, respectively (Fig. 2H).

It can be observed that the population density of the three pests varied in plot treated with Egyxide during the winter months (Fig. 2I). The numbers of three pests were seen to decline until the fourth week following treatment, at which point they all began to rise once more until the end of season. In Egyxide treated plot, *B. tabaci* was one of three pests that was found in high population in contrast to predatory mite treatments. Following Egyxide treatment, the population density of *T. urticae* eggs slightly decreased in weeks 2, 3, and 4, then increased until the final week of the summer experiment (Fig. 2J), in contrast to what was seen in the control (Fig. 2L).

A similar trend was observed for *T. urticae* active stages and *T. tabaci* where their numbers started to increase in week 3 post-treatment till the end of the season. While it was noticed that Egyxide slightly reduced the population density of *B. tabaci*.

Figure 3 illustrates the predatory potentialities at different thermal ranges for *A. swirskii* (Fig. 3A, B), *P. Persimilis* (Fig. 3C, D), *N. cucumeris* (Fig. 3E, F), *C. negevi* (Fig. 3G, H), and Egyxide (Fig. 3I, J) comparing to control (Fig. 3K, L). When the average range of temperature was 10° – 25°C in winter and 28° - 32°C in summer at $P \leq 0.05$. Populations of *T. urticae* eggs and active stages, *T. tabaci*, and *B. tabci* have been significantly reduced at T_{opt} = 15°C in winter. While at the highest T_{opt} in summer (=32°C) the least population of herbivores recorded in the case of *A. swirskii* (Fig. 4B), *N. cucumeris* (Fig. 3F), and *C. negevi* (Fig. 3H) comparing to the control (Fig. 3L) at $P \leq 0.05$.

Simultaneously, RH did not significantly influence the effectiveness of any treatments during the winter experiment. Temperature during the summer experiment had no effect on the effectiveness of any applied treatments to the three tested pests: *T. urticae*, *B. tabaci*, and *T. tabaci*. Conversely, RH had a major impact on how effective they were against the target pests (Table 1).

3.2. Reduction percentages of control applications used for pepper pests in two experimental seasons

The percentage of reduction caused by each predatory mite species on *T. urticae* eggs varied in winter and summer experiment. During 11 weeks of the winter season the release of *P. persimilis*, followed by the release of *A. swirskii* and *N. cucumeris*, resulted in the highest reduction percentages, while *C. negevi* showed less activity. In the summer experiment, the release of *A. swirskii*, *P. persimilis*, and *N. cucumeris* caused the highest reduction percentage ≥70%. Overall, Egyxide was the least effective treatment on *T. urticae* eggs in both seasons. However, there were no significant differences between the two seasons in the reduction percentages caused by *C. negevi* (Table 2).

Significant differences have been recorded in the reduction percentages of *T. urticae* active stages during the winter and summer seasons as a result of each treatment except for *C. negevi* (t= -0.34, df= 29, P= 0.735) (Table 2).

There were no significant differences in the reduction percentages resulted in the case of *B. tabaci* by *N. cucumeris*, *A. swirskii* and *C. negevi*. The three predatory mites achieved similar reduction results in both seasons. While Egyxide was the least efficient particularly during summer weeks (t= 15.13, df= 29, P= 0.000) (Table 2).

Predatory mites showed high reduction percentages of *T. tabaci* in winter weeks. Additionally, the reduction results were significantly reduced during summer weeks which have high fluctuations of temperature degrees and relative humidity. Consequently, resulted P values of *N. cucumeris*, *A. swirskii* and *C. negevi* = 0.000 at confidence level of 95%. Whereas Egyxide showed no notable changes in the reduction of the pest population during both winter and summer seasons (Table 2).

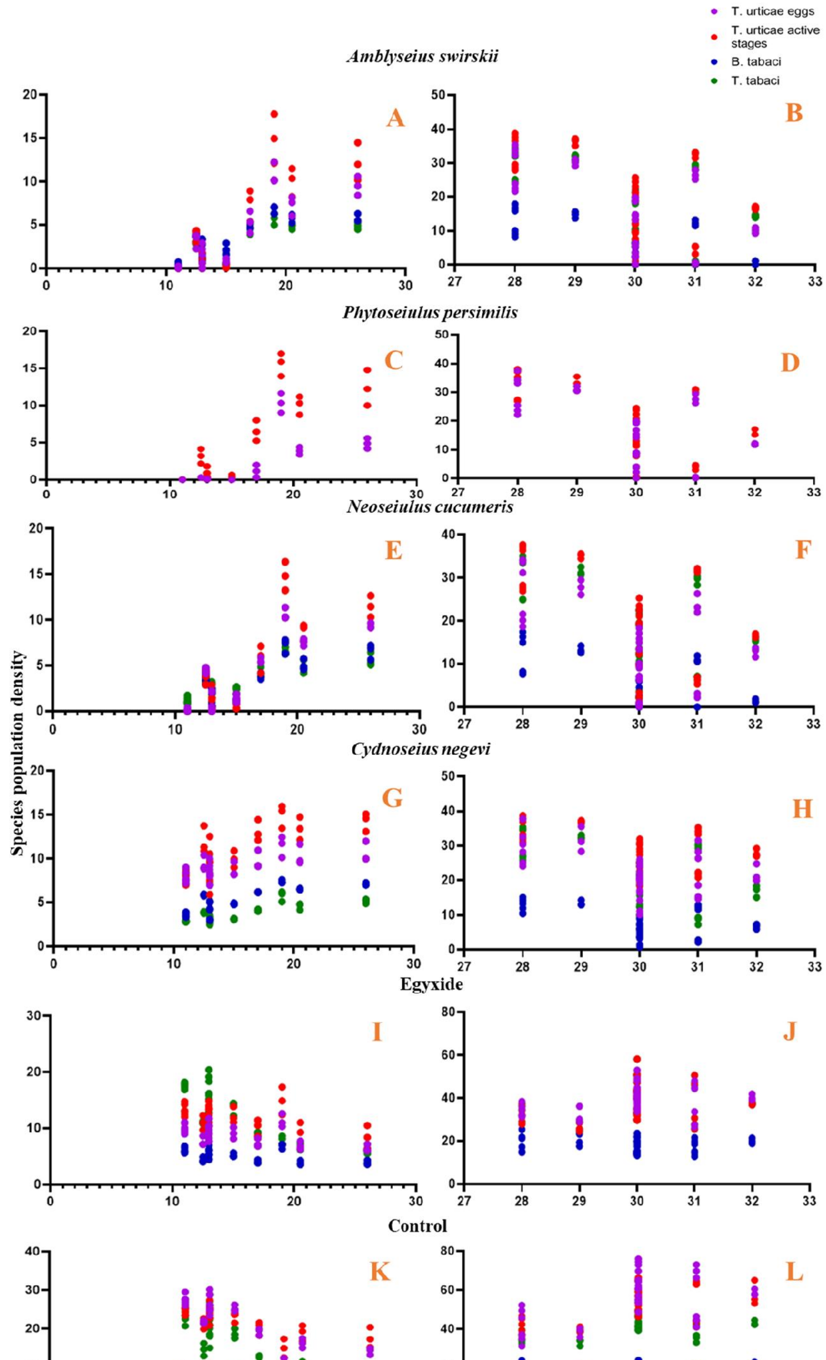

Fig. 3: The potentialities of predatory mites *A. swirskii* (**A, B**), *P. persimilis* (**C, D**), *N. cucumeris* (**E, F**), *C. negevi* (**G, H**), and the biopesticide, Egyxide (**I, J**) at different Temp. ranges of 10° - 25°C (winter) and 28° - 32°C (summer) comparing to the control (**K, L**). Data at significance level of 95% using GraphPad Prism.

Table 2: Reduction percentages (average ± SE) of natural enemies and the biopesticide in two experimental seasons

	Sig.	*A.s*	*P.p*	*N.c*	*C.n*	*Egx.*
***T. urticae* eggs**	**Winter**	82.42 ± 4.20	92.60 ± 2.50	81.12 ± 4.27	58.67 ± 2.95	62.50 ± 0.79
	Summer	71.70 ± 4.84	70.67 ± 4.80	70.86 ± 4.21	56.60 ± 3.65	33.33 ± 1.10
	t	7.791*	7.217*	7.802*	1.703 *ns*	30.607*
	Sig.	0.000	0.000	0.000	0.099	0.000
***T. urticae* active stages**	**Winter**	78.67 ± 5.38	78.33 ± 5.57	80.41 ± 4.78	43.16 ± 4.20	39.45 ± 2.21
	Summer	60.47 ± 5.35	61.12 ± 5.34	60.26 ± 5.12	44.02 ± 3.68	27.33 ± 1.64
	t	8.33*	6.73*	10.69*	-0.34 *ns*	3.54*
	Sig.	0.000	0.000	0.000	0.735	0.001
B. tabaci	**Winter**	75.51 ± 4.10		80.17 ± 3.88	58.43 ± 3.06	56.24 ± 2.92
	Summer	79.79 ± 4.57		80.26 ± 4.13	61.41 ± 3.71	7.76 ± 1.94
	t	-2.35*		-0.07 *ns*	-1.52 *ns*	15.13*
	Sig.	0.026		0.947	0.140	0.000
T. tabaci	**Winter**	86.98 ± 3.04		85.14 ± 2.55	82.54 ± 2.14	54.56 ± 1.73
	Summer	58.46 ± 5.90		55.29 ± 5.08	53.08 ± 4.92	4.94 ± 1.53
	t	8.25*		10.59*	9.69*	20.50*
	Sig.	0.000		0.000	0.000	0.000

t-test: * significant, *ns* not significant, *df*= 29 at $P \leq 0.05$

4. Discussion

In the current study, tested phytoseiid species had positive proportional linear interaction (*r*) (at $P \leq 0.05$) with critical optimum temperature (T_{opt}) = 15℃ in winter season, while there was non-significant correlation with critical temperatures of 28 - 32℃ during summer weeks. Moreover, highly reduction capacity of almost predatory species in the two experimental seasons recorded.

Temperature has been proven to positively affect the longevity and fecundity around medium to slightly-medium levels (from 20° to 25° C). The gradual increasing of thermal constant (K) and/or critical temperature, e.g., the min, max, and optimum temperatures T_{min}, T_{max}, and T_{opt} for more than 33°C declines the predatory potentialities (Sugawara *et al.,* 2017; Yazdanpanah *et al.,* 2022; Zhang *et al.,* 2022; Rahimi *et al.,* 2022; Kasap *et al.,* 2023).

Concerning that *A. swirskii* has the ability to adapt with temperature and relative humidity changes during different climatic seasons (Abou-Haidar *et al.,* 2021; Barghout *et al.,* 2022; Zidan *et al.,* 2022). This can be explained by its origin, the Mediterranean basin, which makes it successfully adapted to high temperatures and relative humidities (Ferrero *et al.,* 2010). Similarly, *N. cucumeris* showed high reduction rates of pepper herbivores (Zhang *et al.,* 2012; Barghout *et al.,* 2022).

The effectiveness of *N. cucumeris* and *A. swirskii* foraging behaviour, e.g., predation and attack rates, revealed their high ability to acclimate with the outer conditions (Fathipour *et al* 2017; Dalir *et al.,* 2021; Yazdanpanah *et al.,* 2022; Yazdanpanah and Fathipour, 2023; Yalçın *et al.,* 2023). Which reflects their highly performance in the CBC applications globally.

Nevertheless, in case of *C. negevi*, there was no significant impact recorded on its reduction when applied for *T. urticae* eggs, *T. urticae* active stages, and *B. tabaci*. It achieved a higher reduction in winter (83 %) than summer (53%). Except in the case of *T. tabaci* it has significantly recorded a huge difference between both winter and summer reductions. Which reflects a significant correlation to temperature ups and downs. Increasing temperatures induce a proportional increase in the herbivore population (Lemoine *et al.,* 2013). Additionally, several species of thrips have showed anti-predation, avoidance, and aggressiveness behaviours toward predatory mites (Vangansbeke *et al.,* 2023; Beretta *et al.,* 2024).

It was concluded that *C. negevi* can adapt to different arid localities in addition to building up its community within an ecosystem for long-term inoculative biological control applications (El-laithy *et al.,* 2021; Barghout *et al.,* 2022; Zidan *et al.,* 2022). The present study demonstrated that climatic conditions could reduce the efficacy of the biopesticide, which was mainly observed in Egyxide during the summer season. In previous studies, it was applied for a long term to suppress the populations of *T. urticae*, *T. tabaci*, and *B. tabaci* on pepper (Barghout *et al.,* 2022) and/or on Brassicaceae and Lamiaceae medicinal plants during summer season in arid localities (Zidan *et al.,* 2022). Egyxide is consisted of a mixture of natural essential oils and plant extracts, due to these contents, a degradation might be occurred, especially in high temperatures (summer). Therefore, resulted in ineffective reductions compared to the natural increase of herbivore community (Zidan *et al.,* 2022).

Phytoseiulus persimilis resulted in an effective performance against *T. urticae* infestations in both experimental seasons. It has been reported that most affordable conditions for *P. persimilis* are dry summers (medium temperatures with high humidity) and mild winters which is similar to its origin, the Mediterranean basin (Galazzi and Nicoli 1996; Riddick and Wu 2010; Rojas *et al.,* 2013). Additionally, the recorded T_{opt} of *P. persimilis* was 27 ℃ and the increase in temperature above 30℃ can derive to stop feeding (Rojas *et al.,* 2013; Adly 2023). Although, specialized phytoseiids have very specific feeding preferences (McMurtry *et al.,* 2013). Hence, the biological control applications are mostly targeting multiple invasive herbivore species. It is hypothetically assumed that specialized phytoseiid species are not significantly preferable in some biological control applications (McMurtry 1992; Pekár *et al.,* 2015).

In the present work, the relative humidity appeared to have negative/inverse correlation relationships in the case of applied predatory mites. This theoretically indicates that temperature has dominancy affecting predatory species' potentialities and/or the biopesticide against *T. urticae* eggs and active stages during winter and summer seasons.

Except Egyxide, which has recorded a positive correlation in both seasons. This obviously explains why it does not have the competence to supress pest populations comparing with other bio-agents (Barghout *et al.,* 2022; Zidan *et al.,* 2022). This inverse correlation has been found in the relation between climatic conditions and the incidence of *P. persemilis* and *T. urticae* in humid/tropical regions on different varieties of French bean, *P. vulgaris* (Sathua and Singh, 2023).

Contrary, highly significant differentiations have been recorded in the reductions' results in the case of *A. swirskii* against the three herbivore species. However, *A. swirskii* is sensitive to low relative humidity, which can extend the life cycle duration and the total pre-oviposition period. While high relative humidity and water availability can increase the net reproductive rate and intrinsic rate of natural increase (San *et al.,* 2021). Additionally, it has been proven that high relative humidity (>85%) reduces the releasing potentialities and searching capacities of *A. swirskii*, as well as the low rates than 25% in biological control applications (Solano-Rojas *et al.,* 2022). Together temperature and precipitation have also been found to affect its population and/or seasonal fluctuations (Devi and Challa, 2019; Kamczyc *et al.,* 2022; Solano-Rojas *et al*., 2022).

Above and beyond, predatory potentialities may depend on the plant secondary metabolites, herbivore's richness (Zidan *et al.,* 2022) and the adaptation ability of these species to weather fluctuations. Since community structure and distribution of herbivores additionally affect their performance at different climatic conditions, understanding how climatic changes affect employing two generalist predators is a must. Therefore, it is strongly recommended to further assess the phytoseiids' potentialities and responses in combined biological control applications under such circumstances.

5. Conclusions

This study revealed that the generalist species, *A. swirskii*, *N. cucumeris*, and *C. negevi* have successful reduction performances in both summer and winter seasons. Moreover, these species were superior to Egyxide as a bio-control mean. Due to the different correlations between climatic factors and predatory performances, these factors have to be considered while using different pest control programs. Therefore, the study recommends using the predatory species *A. swirskii*, *N. cucummeris*, and *C. negevi* in winter seasons, especially in the dry arid locations, to successfully building up their populations and to achieve their target in reducing herbivore infestations.

List of abbreviations

Critical optimum temperature = T_{opt}	Critical minimum temperature = T_{min}
Critical maximum temperature = T_{max}	Two-spotted spider mite= **TSSM**
Classical biological control= **CBC**	Citrus Brown Mite = **CBM**
Integrated Pest Management = **IPM**	Constant temperature = **K**
Relative Humidity **RH**	Yellow Delta Star = **YDS**
Amblyseius swirskii = ***A.s***	*Phytoseiulus persimilis* = ***P.p***
Neoseiulus cucumeris = ***N.c***	*Cydnoseius negevi* = ***C.n***
Egyxide = ***Egx***.	

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and/or analysed during the current study are available upon reasonable request.

Competing interests

Authors declare there is no conflict of interest.

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Authors' contributions

I.M.Z., M.E.B., S.S.I., H.A. Conceptualise and design the framework. **M.E.B., S.S.I., E.M.E.** Methodology; **E.M.E.** pre- plantation and plantation phase, predatory mites supplying. **M.E.B**. investigating mite pest populations during pre- and post-applications, **S.S.I.** investigating insect pest populations in pre- and post-applications. **H.A., I.M.Z., S.S.I.** data preparation, statistical analysis and visualisation. **S.S.I., I.M.Z., M.E.B.** writing drafts and final manuscript. All authors have read, revised, and approved the final manuscript.

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