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Article

Predatory mites, a green pesticide, and an entomopathogenic compound: A proposed IPM tactic based on pest species diversity indices and population dynamics

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ABSTRACT

This study was aimed to investigate the population dynamics and diversity indices of three invasive species; the two-spotted spider mite (TSSM) *Tetranychus urticae* Koch (Acari: Tetranychidae), the silver leaf whitefly *Bemisia tabaci* Genn. (Hemiptera: Aleyrodidae), and the onion thrips *Thrips tabaci* Lindman (Thysanoptera: Thripidae) on four tested plants; Siberian (Russian) kale *Brassica napus var. pabularia* L., Italian (Tuscan) kale *Brassica oleracea var. palmifolia* L. (Brassicaceae), spearmint *Mentha spicata* L. and Saudi Mint *Mentha longifolia* L. (Lamiaceae); in addition to evaluating a proposed IPM protocol in two experimental sites (Om Saber, Beheira Governorate and Kom Oshim, Fayoum Governorate). The proposed IPM program consisted using predatory mites; *Phytoseiulus persimilis* Athias-Henriot, *Amblyseius swirskii* Athias-Henriot, and *Cydnoseius negevi* (Swirski & Amitai) (Acari: Phytoseiidae), a green pesticide, and an entomopathogenic compound. Samples were collected from tested plants for two seasons to calculate pest population dynamics, and diversity indices, before and after IPM treatments. The resulting data showed statistically significant fluctuation, population dynamics, abundance, distribution, and diversity indices of the three targeted pest species recorded on the four tested plants. The proposed IPM protocol resulted in a significant reduction percentage when *A. swirskii* was used compared to other tactics. It is discussed that abiotic and biotic factors together help in explaining why various pest species build their communities rapidly and increase their parameters that become above the Economic Injury Level (EIL). Such factors are hypothesized to affect the plant-arthropod, predator-herbivore, predator-predator, and tri-trophic interactions. The proposed protocol recommends the consideration of application timing and merging tactics together to get maximum efficiency.

KEY WORDS: Biological Control; Brassicaceae; Lamiaceae; Phytoseiidae; arthropod interactions; weed management.

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INTRODUCTION

Different kinds of relationships exist between plants and various taxa of arthropods in the Agro-ecosystem, regardless of the plant taxa being economic crops or spontaneous plants. Plant-herbivore interaction is one of the possible forms of these relationships. It depends on diversified chemical and

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morphological relations (Frago *et al*. 2022). Another relationship is the predator-herbivore relationship, which is considered to be the second level of trophic interactions occurring in an ecosystem (Alba *et al*. 2012; Gardarin *et al*. 2018). Connecting these interactions together forms a tri-trophic relationship, that consists of Plant-Herbivore-Predator interactions (Verkerk 2004; Kavitha and Reddy 2014), and this one we hypothetically suggest, is the main method of the biological control applications and Integrated Pest Management (IPM) tactics to be used to suppress pest infestations.

IPM is a combination of agricultural, chemical, biological, and ecological procedures, as well as, good knowledge about biodiversity and distribution of living organisms within a habitat (El-Shafie 2019). Most IPM strategy goals are to prevent pests from reaching economically damaging levels without causing a risk to the environment. A successful IPM program may have some components such as monitoring crops for pests, pest identifying accuracy, detecting economic thresholds, implementing integrated pest control tactics, and evaluation. The factors that render crop habitats unsuitable for pests and diseases include limitation of resources, competition, parasitism, and predation (Ehi-Eromosele *et al*. 2013).

The first use of biological control dates back to Chinese in the 3rd–4th centuries A.D. (Shijiang 1983). Until now, a very large number of predatory and/or parasite taxa have been used to control pest infestations that caused massive economic losses (Smagghe and Diaz 2012). Predatory phytoseiid mites have been reported to be effective control means against spider mites (Negm *et al*. 2014; Alatawi *et al*. 2019; El-laithy *et al*. 2021; Barghout *et al*. 2022), eriophyids (Momen *et al*. 2004, 2014; Momen and Abdel-Khalek 2008; Abou-Elella *et al*. 2014; Melo *et al*. 2015; Abdel-Khalek and Momen 2022; Ferreira *et al*. 2022), whiteflies (Nomikou *et al*. 2001, 2002, 2003), thrips (Messelink *et al*. 2006; Arthurs *et al*. 2009; Sanad and Hassan 2019; El-laithy *et al*. 2021; Barghout *et al*. 2022), aphids (Messelink *et al*. 2013) and they were proven to feed on alternative sources such as pollen (van Rijn and Tanigoshi 1999; Abou-Elella *et al*. 2014; Delisle *et al*. 2015b; Zhang 2021), fungi (Zemek and Prenerová 1997; Momen and Abdelkhader 2010) or other factitious food/artificial diet to be mass produced (Janssen and Sabelis 2015; Delisle *et al*. 2015 a, b; Momen *et al*. 2020; Xin and Zhang 2021).

New trends of bio-agents are employed in the form of the entomopathogenic fungal species, e.g., *Beauveria bassiana* (Bals.) Vuill. and *Metarhizium anisopliae* (Metschn.) Sorokīn to control insect and mite pests (Akmal *et al*. 2013; Wraight *et al*. 2016). These fungi can inhabit the plant/crop ecosystem; on leaves (Garrido-Jurado *et al*. 2015), soil (Evans 1982) or endophytically (Greenfield *et al*. 2016). These fungi were highly recommended on IPM protocols due to their wide distribution and diversity of hosts in different localities and conditions (Lacey *et al*. 2015; McGuire and Northfield 2020).

Another new trend of IPM is using eco-friendly or green-pesticides, which consist mainly of natural resources, such as plant essential oils and extracts (Isman 2006; Isman and Machial 2006; Koul *et al*. 2008). Plant essential oils were reported to suppress pest infestations in different climatic zones (Regnault-Roger *et al*. 1993; de Melo *et al*. 2019; Allam *et al*. 2020; Ebadollahi *et al*. 2020).

Some studies have proposed using a mixture of phytoseiids, entomopathogenic, and biopesticides to control different pest infestations (El-Saiedy *et al*. 2008, 2015; Abou-Awad *et al*. 2017; El-Saiedy and Fahim 2021; Barghout *et al*. 2022). On the other hand, the climate change factors are affecting different kinds of agricultural pests and beneficial arthropods (Shrestha 2019; Skendžić *et al*. 2021); these changes have affected the biological aspects, prey preferences, distribution, population dynamics, and threat the IPM applications (Halsch *et al*. 2021: Karthik *et al*. 2021). Thus, this study aimed to investigate the population dynamics and diversity indices of three invasive species; the two-spotted spider mite (TSSM) *Tetranychus urticae* Koch (Acari: Tetranychidae), the silver leaf whitefly *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae), and the onion thrips *Thrips tabaci* Lindman (Thysanoptera: Thripidae) in four tested plants belonging to Brassicaceae and Lamiaceae. In addition to evaluating a proposed IPM protocol consisting of predatory mites, green pesticide, and an entomopathogenic compound in two experimental sites.

MATERIAL AND METHODS

Experimental sites

Two locations were selected to perform the field experiments; Om Saber, Kom Hamada, El Beheira Governorate (30° 29' 50.6'' N, 30° 46' 18.8'' E), and Kom Oshim, Fayoum Governorate (29° 34' 40.9'' N, 30° 55' 38.3'' E) (Fig. 1). The data of population dynamics was recorded for two seasons; March to August 2016, and February to July 2017. The proposed IPM procedures took place from April to August 2017, and from February to June 2018.

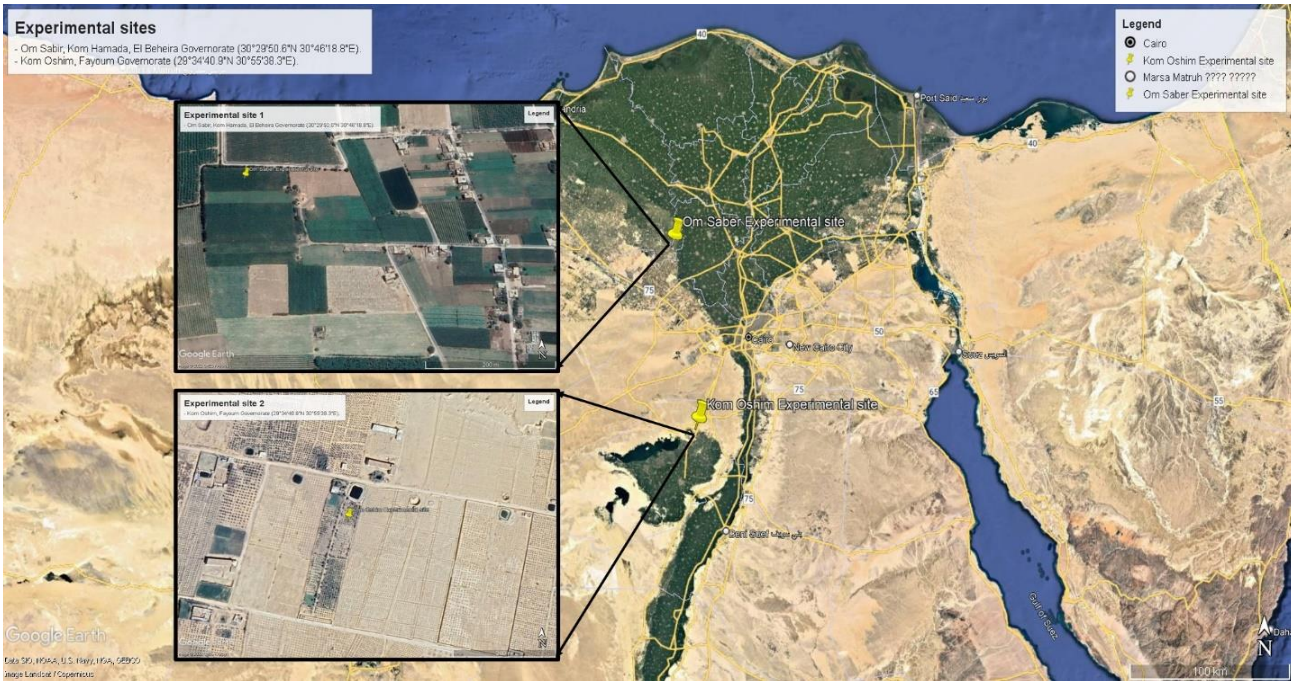

Figure 1. Google Earth map photography of the experimental locations (pointed with pin) – i) Om Sabir, Kom Hamada, El Beheira Governorate (30° 29' 50.6'' N, 30° 46' 18.8'' E), and ii) Kom Oshim, Fayoum Governorate (29° 34' 40.9'' N, 30° 55' 38.3'' E).

Plant sources

Four plant species belonging to families; Brassicaceae, Siberian (Russian) kale *Brassica napus var. pabularia* L., Italian (Tuscan) kale *Brassica oleracea* var. *palmifolia*, and Lamiaceae, spearmint *Mentha spicata* L. and Saudi Mint *Mentha longifolia* L. Brassicaceae plants were introduced from Egyptian Hydrofarms farm (KM 53 Cairo-Alex Desert Road, inside Al-Azzazy Village, 30° 09' 07.0'' N, 30° 51' 00.2'' E). Lamiaceae plants were introduced from a private farm of herbal and medicinal plants in Fayoum Governorate (Ibshway, 29° 21' 07.4'' N, 30° 44' 17.8'' E).

Plantation

The total area was 145 × 45 m^2 (area approximately = 1.5 Feddans) of flat/horizontal surface. The study area, in both locations, was designed into 6 sections equally; five treatments and one control, each section's dimension was 23 × 45 m^2. Between sections, there were wooden blocks/parries covered with plastic sheets to prevent mite and insect species movements and dispersal. Each section was divided into four plots (two Brassicaceae and two Lamiaceae) 10 × 20 m^2 in area (the uncalculated areas were used for passages and borders to manage sampling, investigation, handling, maintenance, weed removal, and other agricultural procedures) (Fig. 2). Each plot had five rows, each row had 20 plants (100 plant/species) where the distance between each seedling was one meter in case of Brassicaceae plots, and 40 plant/row (200 plants) in case of Lamiaceae plants (2 seedlings/1 meter). In the pre-plantation phase, we added a mixture of organic manure (mixture of cattle and chicken origin) + compost (1:1) in the soil (the package of 50 kg/Feddan was recommended). Thus, we used two packages of each to cover the total area in both locations (100 kg manure + 100 kg compost), mixture mixed together in soil, covered with a sand layer, then irrigated before planting the seedlings. The study locations were irrigated using a dripping irrigation system, and all water requirements were saved for each plot (irrigation was controlled by valves). Due to the flat surface, plants were receiving all light requirements equally.

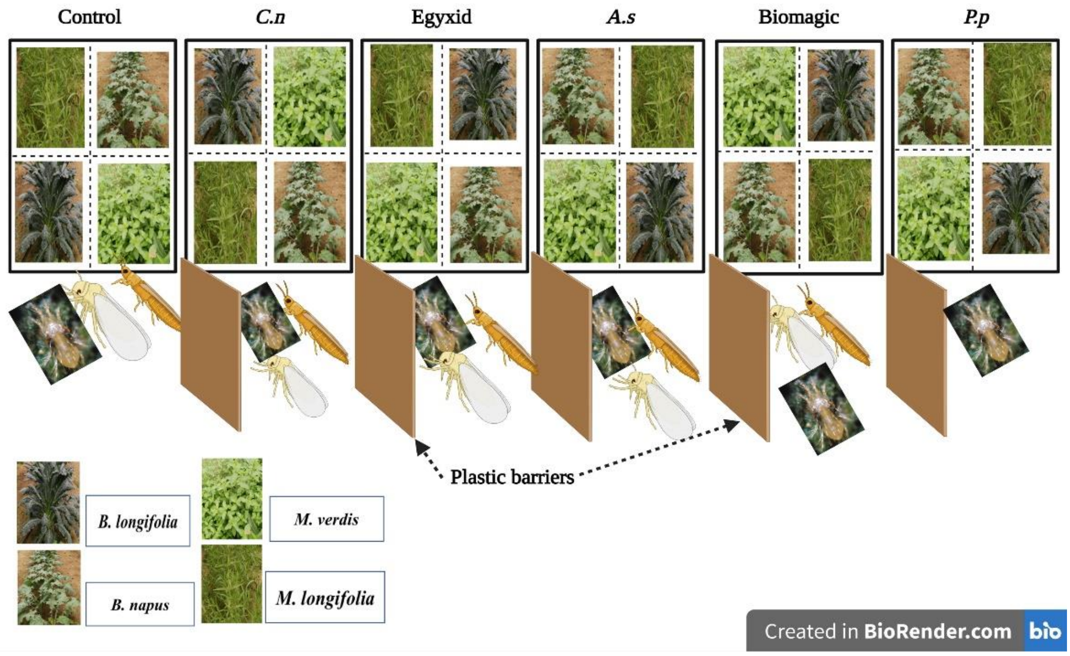

Figure 2. Schematic diagram of the experiment's plantation and IPM methodology, ***C.n***: *Cydnoseius negevi,* ***A.s***: *Amblyseius swirskii, and* ***P.p*** *Phytoseiulus persimilis*. (Photo credits: Dr. Zidan has created this diagram on www.biorender.com).

Sampling

Samples were collected for the pest population dynamics weekly from each site, and investigated in the Acarology lab., NRC. Active stages were counted and recorded. Besides, weeds were checked for arthropod occurrence to figure out the possible interactions. Ten leaves of each plant (1000 leaves of each Brassicaceae and 2000 leaves of each Lamiaceae) were checked for pest dynamics and diversity indices randomly. Another group of leaves was checked randomly to record the pest population before/after each treatment.

Used control strategies

Predatory mite species

Three phytoseiid species, *Phytoseiulus persimilis* Athias-Henriot, *Amblyseius swirskii* Athias-Henriot, and *Cydnoseius negevi* (Swirski & Amitai), were introduced as bio-agents to control pests existing in the experimental locations. Predatory mites were commercially available from private companies in Qaha, Al-Qalioubia Governorate, Badr City, Al Beheira Governorate, and Al-Ayat, Giza Governorate. A single mite package contained about 1000 individuals. The releasing ratio was 1:5 predatorto pest, based on sampled pest density in preliminary investigations.

Plant extracts

Egyxide® is a commercial compound recommended in organic farming systems protocols and clean farming in open and semi-field conditions. Egyxide is a water-soluble natural oils mixture, that is used for mite and insect pests, and also to prevent plant diseases. It contains natural emulsified plant oils 10% and glue 2%. It is recommended as a foliar application with a dosage 5 ml/Litre, and was available at Royal for Agricultural Development, Cairo, Egypt. http://royalagri.com.

Pest pathogens

Bio-Magic® is a biological insecticide based on a selected strain of naturally-occurring entomopathogenic fungus, *M. anisopliae*. It was available in a liquid package containing spores and mycelial fragments (1×10^9 CFU's/ml), was used as foliar spray 6 ml/Litre, and was available at Gaara Establishment for Import and Export, Cairo (www.gaara.com.eg).

Control experimental procedure

Pest infestations were recorded weekly. Ten leaves of each plant (1000 leaves of each Brassicaceae and 2000 leaves of each Lamiaceae) (of both locations) were sampled randomly, to check the pest population density/leaf/plant to detect the Economic Injury Level (EIL) and the Economic Threshold Level (ETL). When population reached the EIL, we started applying the proposed strategy. Predators releasing ratio was 1:5 depending on pest density/plant. *Phytoseiulus persimilis* was introduced for TSSM infestations; while *A. swirskii* and *C. negevi* were planned for controlling the TSSM, whiteflies, and thrips. Pest population before and after treatments was counted and calculated using Henderson and Tilton (1955) module:

$$\text{Reduction percentage} = \left(1 - \frac{n\ in\ Co\ before\ treatment \times n\ in\ T\ after\ treatment}{n\ in\ Co\ after\ treatment \times n\ in\ T\ before\ treatment}\right) \times 100.$$

Where n is the pest population, T treated, Co control.

Statistical analyses

Hypothesis was tested by the Kruskal-Wallis test using SPSS computer program ver. 20.0. The null hypothesis H_0 suggested that distribution of pests would be the same across the host plants and locations during the experimental time. While the alternative hypothesis H_1 was designed as there were significant differences among pest populations in both tested plants and experimental locations. The test was conducted to determine whether H_0 or H_1 is accepted. The test results rejected the H_0 due to significant differences within the three major pest populations recorded; *T. urticae*, *B. tabaci*, and *T. tabaci* (Figs. 29–32). Results between two locations were tested by Student's test (T-test) using SPSS v. 20.0. Differences in the mean number of species before/after treatments were analyzed by one-way analysis of variance ANOVA and were tested with Tukey's test at 95% confidence level using SPSS v. 20.0. Biodiversity indices were measured; Shannon-Wiener index (H'), Simpson's index (dominance D and species richness 1/D), and the similarity index between locations (Jaccard's index) (Magurran 2004) were calculated using the BioDiversity Pro. ver. 2.0 software (McAleece *et al.* 1997) and PAST ver. 4.08 software (Hammer *et al.* 2001).

RESULTS

Population dynamics and diversity indices of three major pest species

Om Saber location

The population dynamics of *T. urticae*, *B. tabaci* and *T. tabaci* were detected for the two seasons, 2016 and 2017. The highest mean population of *T. urticae* was found on *B. napus* var. *pabularia* (63.22 ± 6.10 immatures/10 leaves, and 57.11 ± 5.68 adults/ 10 leaves, $F = 20.762$, $P = 0.000$); while the lowest mean was recorded in case of *M. spicata* (3.34 ± 0.21 immatures/10 leaves and 2.78 ± 0.18 immatures/10 leaves; $F = 19.289$, $P = 0.000$). *Thrips tabaci* was the lowest population recorded in both Lamiaceae plants. Similar results were detected in the second season, 2017, when all pest populations recorded the highest levels of occurrence on *B. napus* var. *pabularia* (*F* = 22.688, *P* = 0.001), and the lowest in *M. spicata* (*F* = 3.117, *P* = 0.001), while *B. tabaci* has the highest population recorded on the Brassicaceae in both seasons (Table 1). Diversity indices reflected the three pest species populations' preferences. The dominance (D) was the highest in the case of *B. oleracea* var. *palmifolia* leaves (D = 0.423 in 2016 and 2017), which also showed the highest species richness (1/D = 2.362 in 2016 and 2017), and the highest Shannon-Winner diversity index (H' = 0.933 in 2016, and 0.935 in 2017) in both seasons (Table 2). Despite the occurrence of pest populations; species distribution varied for each population. While *B. tabaci* recorded the highest density distribution on the four tested plants ($\chi2$ = 734.223, *P* = 0.000) in 2016, *T. tabaci* ($\chi2$ = 3730.706, *P* = 0.000) in 2017, and *T. urticae* had a significant fluctuated distribution among plants in both seasons (2016: $\chi2$ = 5370.34, *P* = 0.000; 2017: $\chi2$ = 805.3225, *P* = 0.000) (Table 3).

Table 1. Pest species populations on four medicinal plant species (mean/10 leaves ± SE) in Om Saber location (2016 and 2017)

Plant species	*T. urticae*		*T. tabaci*	*B. tabaci*	*F*-test
	Nymphs	Adults			
2016					
	25[z]	25	22	22	df = 3, 89
B. napus	63.22 ± 6.10[b]	57.11 ± 5.68[c]	17.89 ± 3.49[d]	143.86 ± 20.02[a]	20.762*
B. oleracea	45.75 ± 2.78[b]	38.79 ± 2.88[c]	19.62 ± 3.96[d]	111.30 ± 15.38[a]	21.839*
M. spicata	3.43 ± 0.2[a]	2.78 ± 0.18[b]	0.66 ± 0.13[c]	3.77 ± 0.51[a]	3.289*
M. longifolia	4.81 ± 0.40[a]	4.29 ± 0.33[a]	1.00 ± 0.21[c]	2.71 ± 0.38[b]	9.423*
2017					
	25	25	21	21	df = 3, 89
B. napus	62.50 ± 4.78[b]	50.96 ± 4.93[b]	22.36 ± 3.71[c]	149.86 ± 21.42[a]	22.688*
B. oleracea	44.81± 2.54[b]	39.54 ± 2.52[b]	22.14 ± 4.10[c]	116.52 ± 17.25[a]	20.904*
M. spicata	4.68 ± 0.21[a]	4.28 ± 0.18[a]	0.91 ± 0.13[b]	4.41 ± 0.24[a]	3.117*
M. longifolia	6.60 ± 0.40[a]	6.10 ± 0.33[a]	1.39 ± 0.24[c]	3.69 ± 0.55[b]	5.991*

Means within rows, followed by the same letter are not significantly different (Tukey, P ≤ 0.05), (*) significant at P ≤ 0.05.

[z] Number of samples during the experimental duration.

Kom Oshim location

The population dynamics of *T. urticae*, *B. tabaci* and *T. tabaci* reflected significant differentiations among tested plants. The highest mean population recorded in Brassicaceae was in *B. napus* var. *pabularia* (*F* = 80.963, *P* = 0.000), while *T. urticae* recorded 35.17 ± 2.91 adults/10 leaves, and *B. tabaci* 67.54 ± 7.60 individuals/10 leaves in 2016. While *T. tabaci* highest mean population was recorded in *B. aleracea* var. *plamifolia* (11.04 ± 2.62 individuals/10 leaves) (Table 4). The second season showed a similarity in population density dynamics, and the recorded results were statistically significant on a probability level of 95% (*B. napus* var. *pabularia*, *F* = 50.413; *B. aleracea* var. *plamifolia*, *F* = 43.405; *M. spicata*, *F* = 5.410; *M. longifolia*, *F*= 7.462) (Table 4). Diversity indices did not change too much between two seasons, however the sampled individuals significantly differed. Although they showed a real indication of pest species abundance, richness and preference due to their significant values of dominance (D), species richness (1/D), diversity (H'), similarities (J') and evenness (e^H/S) (Table 5). Besides, the species distribution of each species has statistically significant differences, where *B. tabaci* (2016 $\chi2$= 257.95; 2017 $\chi2$ = 299.50, *P* = 0.000) and *T. tabaci* (2016 $\chi2$ = 1968.09; 2017 $\chi2$ = 1971.23, *P* = 0.000) were the most distributed species on the four tested plants in two experimental seasons, and *T. urticae* recorded a moderate distribution on Brassicaceae and *M. spicata*, and heavy occurrence on *M. longifolia* in 2016 ($\chi2$ = 1575.60, *P* =

0.000), and heavy distribution on Lamiaceae plants only in the second season ($\chi 2$ = 219.82, P = 0.000) (Table 6).

Table 2. Diversity indices of pest species infesting Brassicaceae and Lamiaceae in Om Saber experimental site (2016 and 2017).

	2016				2017			
	B. napus	***B. oleracea***	***M. spicata***	***M. longifolia***	***B. napus***	***B. oleracea***	***M. spicata***	***M. longifolia***
Individuals	6547	4974	251	306	6458	5019	335	423
Simpson (D)	0.448	0.423	0.488	0.586	0.436	0.423	0.525	0.600
Simpson (1/D)	2.233	2.362	2.050	1.706	2.296	2.367	1.911	1.671
Shannon-Wienner (H')	0.873	0.933	0.833	0.730	0.904	0.935	0.788	0.711
Evenness (e^H/S)	0.798	0.847	0.767	0.692	0.823	0.849	0.733	0.679
Brillouin	0.869	0.930	0.790	0.677	0.901	0.930	0.760	0.683
Menhinick	0.037	0.043	0.189	0.171	0.037	0.042	0.164	0.146
Margalef	0.228	0.235	0.362	0.349	0.228	0.235	0.344	0.331
Jaccard's index (J')	0.794	0.849	0.758	0.665	0.823	0.851	0.717	0.648
Fisher alpha	0.300	0.34	0.479	0.461	0.301	0.309	0.454	0.436
Berger-Parker	0.483	0.484	0.615	0.737	0.487	0.487	0.667	0.748

Diversity indices were tested at $P \leq 0.05$.

Table 3. Pest Species distribution in Om Saber location (2016 and 2017).

Pest species	***B. napus***	***B. oleracea***	***M. spicata***	***M. longifolia***	**Variance**	χ^2	***P***
	2016						
	Species distribution						
T. tabaci	++	+	+++	+++	2005760	4372.649	0.000
T. urticae	+++	+++	+	++	2557160	5370.342	0.000
B. tabaci	+++	+++	+++	+++	52963.15	734.223	0.000
	2017				**Variance**	χ^2	***P***
	Species distribution						
T. tabaci	+++	+++	+++	+++	1705812	3730.706	0.000
T. urticae	+++	+++	++	++	66332.41	805.3225	0.000
B. tabaci	++	++	+++	+++	2533514	5274.391	0.000

Distribution variance and χ^2 were tested at $P \leq 0.05$.

The proposed IPM tactic for resulted pests

Using the predatory phytoseiid species was efficient to reduce the *T. urticae*, *B. tabaci*, and *T. tabaci* populations on *B. napus* var. *pabularia*, *B. oleracea* var. *palmifolia*, *M. spicata* and *M. longifolia*. Releasing *P. persimilis* and *A. swirskii* effectively reduced the mean number of *T. urticae* in both Brassicaceae and Lamiaceae tested plants compared with the control. *Amblyseius swirskii* was effective not only towards TSSM infestations but also to reduce *T. tabaci* and *B. tabaci*. While *C. negevi* was less effective compared with the two other phytoseiids, the average reduction percentage of releasing *C. negevi* against *T. urticae*, *T. tabaci*, and *B. tabaci* on the four tested plant species was 50% in Om Saber and 55% in Kom Oshim (Tables 7–10).

Weather data was recorded during the experiment duration period; the average temperature was 28 °C in Om Saber and Kom Oshim, and the relative humidity was 54% in Om Saber and 52% in Kom Oshim. The least reduction percentage was recorded in Bio-Magic and Egyxide applications. These two means were replicated (spray application) three times every three weeks due to their low performance. The least reduction percentage recorded in the case of using Bio-Magic was 34% in Om Saber, and 40% in Kom Oshim, and in the case of Egyxide it was recorded at 40% in Om Saber and

45% in Kom Oshim (Table 11).

Table 4. Pest species populations on four medicinal plant species (mean/10 leaves ± SE) in Kom Oshim experimental site (2016 and 2017).

Plant species	*T. urticae* (18)[z]		*T. tabaci*		*B. tabaci*		*F*-test
	Nymphs	Adults	N	Mean ± SE	N	Mean ± SE	
	2016						
B. napus	37.90 ± 2.52[b]	35.17 ± 2.91[c]	16	8.16 ± 1.90[d]	18	67.54 ± 7.60[a]	80.963*
B. oleracea	35.12 ± 2.59[b]	30.82 ± 2.51[c]	16	11.04 ± 2.62[d]	18	48.94 ± 6.42[a]	82.651*
M. spicata	5.75 ± 0.31[a]	2.32 ± 0.26[b]	10	1.05 ± 0.17[c]	14	1.92 ± 0.25[bc]	6.021*
M. longifolia	9.92 ± 0.76[a]	3.24 ± 0.23[b]	10	1.23 ± 0.15[c]	14	1.27 ± 0.25[c]	9.736*
	2017						
B. napus	40.26 ± 3.14 b	36.38 ± 2.77 c	16	15.16 ± 1.90 d	18	62.54 ± 7.60 a	50.413*
B. oleracea	38.14 ± 3.23 b	35.39 ± 2.50 c	16	13.04 ± 2.62 d	18	52.94 ± 6.42 a	43.405*
M. spicata	8.24 ± 0.36 a	5.31 ± 0.26 c	10	4.33 ± 0.17 d	14	7.98 ± 0.25 b	5.410*
M. longifolia	11.14 ± 0.86 a	6.53 ± 0.23 b	10	3.44 ± 0.15 c	14	6.44 ± 0.25 b	7.462*

Means within rows, followed by the same letter are not significantly different (Tukey, $P \leq 0.05$). (*) significant at $P \leq 0.05$.
[z] Number of samples during the experimental duration.

Table 5. Diversity indices of pest species infesting Brassicaceae and Lamiaceae in Kom Oshim (2016 and 2017).

	2016				2017			
	B. napus	*B. oleracea*	*M. spicata*	*M. longifolia*	*B. napus*	*B. oleracea*	*M. spicata*	*M. longifolia*
Individuals	2593	2243	181	265	3503	3147	1560	1516
Simpson (D)	0.455	0.440	0.656	0.793	0.499	0.515	0.949	0.955
Simpson (1/D)	2.196	2.274	1.524	1.261	2.005	1.942	1.054	1.047
Shannon-Wienner (H')	0.856	0.904	0.627	0.429	0.805	0.807	0.138	0.124
Evenness (e^H/S)	0.784	0.8232	0.624	0.512	0.745	0.747	0.383	0.378
Brillouin	0.780	0.823	0.571	0.39	0.798	0.802	0.13	0.115
Menhinick	0.850	0.895	0.558	0.372	0.051	0.053	0.076	0.077
Margalef	0.059	0.063	0.222	0.184	0.245	0.248	0.272	0.273
Jaccard's index (J')	0.254	0.259	0.385	0.358	0.733	0.735	0.126	0.113
Fisher alpha	0.335	0.341	0.51	0.473	0.323	0.327	0.358	0.359
Berger-Parker	0.507	0.529	0.794	0.884	0.622	0.659	0.974	0.977

Diversity indices were tested at $P \leq 0.05$.

Table 6. Pest species distribution in Kom Oshim location (2016 and 2017).

Pest species	*B. napus*	*B. oleracea*	*M. spicata*	*M. longifolia*	Variance	χ^2	*P*
	2016						
	Species distribution						
T. urticae	++	++	++	+++	378705	1575.60	0.000
B. tabaci	+++	+++	+++	+++	7091.29	257.95	0.000
T. tabaci	+++	+++	+++	+++	340108.5	1968.09	0.000
	2017				**Variance**	χ^2	***P***
	Species distribution						
T. urticae	++	++	+++	+++	132967.08	219.82	0.000
B. tabaci	+++	+++	+++	+++	9860.65	299.50	0.000
T. tabaci	+++	+++	+++	+++	341292.63	1971.23	0.000

Distribution variance and χ^2 were tested at $P \leq 0.05$.

Table 7. Mean number (± SE) of Brassicaceae pests after proposed application, Om Saber experimental site in 2017.

		T. urticae nymphs	*T. urticae* adults	*T. tabaci*	*B. tabaci*
Brassica napus* var. *pabularia	**N**	21	21	19	16
	Phytoseiulus persimilis	4.90 ± 1.51[c]	7.18 ± 2.05[c]	19.85 ± 3.62[a]	112.91 ± 17.00[a]
	Amblyseius swirskii	11.65 ± 1.94[bc]	14.34 ± 1.48[bc]	0.82 ± 0.21[c]	3.32 ± 0.81[c]
	Cydnoseius negevi	19.37 ± 1.41[b]	21.35 ± 0.80[b]	19.56 ± 3.60[a]	5.20 ± 0.60[c]
	Bio-Magic	20.27 ± 1.30[b]	23.11 ± 1.53[b]	5.96 ± 0.79[b]	19.85 ± 3.50[b]
	Egyxide	20.34 ± 1.33[b]	23.73 ± 1.33[b]	9.60 ± 1.81a[b]	16.58 ± 2.25[b]
	Control	71.31 ± 5.66[a]	65.00 ± 5.12[a]	19.70 ± 3.61[a]	113.68 ± 16.81[a]
	***F*-test**	77.310*	65.615*	9.587*	28.665*
Brassica oleracea* var. *palmifolia	**N**	21	21	19	21
	Phytoseiulus persimilis	7.48 ± 2.33[c]	7.94 ± 2.10[d]	24.08 ± 4.04[a]	114.64 ± 15.70[a]
	Amblyseius swirskii	8.09 ± 2.36[c]	16.66 ± 1.14[c]	0.96 ± 0.25[c]	2.38 ± 0.65[c]
	Cydnoseius negevi	8.93 ± 2.11[c]	19.70 ± 1.22[c]	22.91 ± 3.71[a]	4.80 ±0.75[c]
	Bio-Magic	26.28 ± 1.84[b]	22.00 ± 0.91[b]	5.96 ± 0.79[b]	27.86 ± 5.00[b]
	Egyxide	20.42 ± 1.50[b]	22.92 ± 1.17[b]	9.60 ± 1.81[b]	38.27 ± 8.11[b]
	Control	50.19 ± 2.07[a]	43.55 ± 2.06[a]	23.65 ± 4.00[a]	114.74 ± 15.72[a]
	***F*-test**	64.816*	61.471*	12.631*	27.281*

N = the number of application weeks/samples.
Within each column, means followed by similar letters are not significantly different (Tukey HSD), (*) significant at P ≤ 0.05.

Table 8. Mean number (± SE) of Lamiaceae pests after proposed application, Om Saber experimental site in 2017.

		T. urticae nymphs	*T. urticae* adults	*T. tabaci*	*B. tabaci*
Mentha spicata	**N**	21	21	21	21
	Phytoseiulus persimilis	0.29 ± 0.13[c]	0.40 ± 0.14[d]	1.10 ± 0.11[a]	5.48 ± 0.40[a]
	Amblyseius swirskii	0.46 ± 0.16[c]	0.68 ± 0.14[cd]	0.04 ± 0.02[c]	0.95 ± 0.31[c]
	Cydnoseius negevi	0.52 ± 0.15[c]	1.52 ± 0.05[b]	1.05 ± 0.10[a]	0.87 ± 0.22[c]
	Bio-Magic	1.43 ± 0.20[b]	0.97 ± 0.06[c]	0.52 ± 0.10[b]	2.53 ± 0.27[b]
	Egyxide	1.29 ± 0.19[b]	0.95 ± 0.07[c]	0.70 ± 0.12[b]	3.23 ± 0.37[b]
	Control	3.74 ± 0.20[a]	3.06 ± 0.14[a]	1.08 ± 0.11[a]	5.27 ± 0.34[a]
	***F*-test**	56.907*	77.717*	17.946*	38.640*
Mentha longifolia	**N**	14	14	14	14
	Phytoseiulus persimilis	0.32 ± 0.15[c]	0.41 ± 0.16[d]	1.63 ± 0.19[a]	4.75 ± 0.43[a]
	Amblyseius swirskii	0.58 ± 0.17[c]	1.20 ± 0.15[c]	0.01 ± 0.01[c]	0.62 ± 0.21[c]
	Cydnoseius negevi	0.91 ± 0.18[c]	2.06 ± 0.07[b]	1.60 ± 0.18[a]	1.14 ± 0.21[c]
	Bio-Magic	2.10 ± 0.15[b]	2.44 ± 0.20[b]	0.01 ± 0.00[b]	1.66 ± 0.15[b]
	Egyxide	2.27 ± 0.16[b]	1.97 ± 0.12[b]	0.60 ± 0.15[c]	1.96 ± 0.24[b]
	Control	5.33 ± 0.38[a]	4.70 ± 0.33[a]	1.62 ± 0.18[a]	3.88 ± 0.25[a]
	***F*-test**	72.997*	59.199*	30.995*	37.860*

N = the number of application weeks.
The means followed by similar letters in the column are not significantly different (Tukey HSD), (*) significant at $P \leq 0.05$.

A Kruskal-Wallis test was carried out to determine which hypothesis to accept; either the null hypothesis (H_0) (which suggested that there were no significant differences between seasons 2017 and 2018), or the alternative hypothesis (H_1) (which suggested that there were significant differences), at confidence level = 95%. Kruskal-Wallis result was to reject the alternative hypothesis H_1 and accept the null hypothesis H_0. Results obtained in 2018 of the two experiment locations were not significantly different when compared with those gathered in 2017 using Student's test and ANOVA.

Bio-Magic and Egyxide have the least reduction percentage results while *A. swirskii* was the most effective for controlling targeted pests, followed by *C. negevi* which successfully suppressed *B. tabaci* and *T. urticae* populations. The specialist *P. persimilis* showed a successful application toward TSSM populations in both experimental locations in the two seasons (Table 11).

Table 9. Mean number (± SE) of Brassicaceae pests after proposed application in Kom Oshim experimental site in 2017.

		***T. urticae* nymph**	***T. urticae* adult**	***Thrips tabaci***	***Bemisia tabaci***
Brassica napus* var. *pabularia	**N**	18	18	13	10
	Phytoseiulus persimilis	6.86 ± 2.30^{c}	7.72 ± 1.78^{d}	10.67 ± 2.17^{a}	125.13 ± 13.17^{a}
	Amblyseius swirskii	8.93 ± 1.02^{c}	8.95 ± 0.87^{d}	0.55 ± 0.14^{b}	20.70 ± 5.75^{b}
	Cydnoseius negevi	11.26 ± 0.97^{c}	13.08 ± 0.47^{cd}	10.43 ± 2.10^{a}	21.38 ± 5.90^{b}
	Bio-Magic	26.60 ± 2.61^{b}	19.78 ± 1.75^{b}	3.85 ± 0.71^{ab}	35.11 ± 3.70^{b}
	Egyxide	24.50 ± 2.48^{b}	24.68 ± 2.32^{bc}	4.23 ± .080^{b}	39.49 ± 3.88^{b}
	Control	37.89 ± 2.52^{a}	35.17 ± 2.91^{a}	9.88 ± 2.05^{a}	122.44 ± 13.16^{a}
	F-test	31.980*	29.448*	5.250*	32.522*
Brassica oleracea* var. *palmifolia	**N**	18	18	13	10
	Phytoseiulus persimilis	7.92 ± 2.01^{c}	6.82 ± 1.15^{c}	13.78 ± 2.84^{a}	85.90 ± 11.28^{a}
	Amblyseius swirskii	10.84 ± 0.86^{b}	18.31 ± 2.04^{bc}	0.68 ± 0.20^{c}	11.76 ± 3.51^{c}
	Cydnoseius negevi	18.10 ± 1.97^{b}	26.06 ± 1.75^{b}	13.62 ± 2.84^{a}	12.60 ± 2.43^{c}
	Bio-Magic	18.05 ± 1.86^{b}	22.27 ± 2.00^{b}	5.81 ± 1.15^{b}	32.90 ± 4.67^{b}
	Egyxide	20.89 ± 2.72^{b}	27.93 ± 2.26^{b}	5.57 ± 1.21^{b}	33.01 ± 5.86^{b}
	Control	84.96 ± 12.70^{a}	57.62 ± 6.90^{a}	13.40 ± 2.85^{a}	84.44 ± 11.20^{a}
	F-test	24.144*	24.773*	4.623*	19.545*

N = the number of application weeks.
The means followed by similar letters in the column are not significantly different (Tukey HSD), (*) significant at $P \leq 0.05$.

Table 10. Mean number (± SE) of Lamiaceae pests after proposed application in Kom Oshim experimental site in 2017.

		***T. urticae* nymphs**	***T. urticae* adult**	***T. tabaci***	***B. tabaci***
Mentha spicata	**N**	18	18	13	10
	Phytoseiulus persimilis	1.01 ± 0.32^{c}	1.43 ± 0.30^{d}	1.71 ± 0.20^{a}	4.17 ± 0.31^{a}
	Amblyseius swirskii	1.13 ± 0.24^{b}	2.15 ± 0.24^{d}	0.25 ± 0.12^{b}	0.54 ± 0.20^{d}
	Cydnoseius negevi	0.96 ± 0.20^{b}	2.32 ± 0.30^{c}	1.30 ± 0.14^{a}	0.57 ± 0.15^{d}
	Bio-Magic	1.23 ± 0.13^{b}	3.55 ± 0.10^{b}	0.60 ± 0.10^{b}	1.78 ± 0.10^{c}
	Egyxide	1.06 ± 0.16^{b}	3.13 ± 0.12^{bc}	0.63 ± 0.07^{b}	1.80 ± 0.07^{c}
	Control	3.77 ± 0.22^{a}	5.75 ± 0.34^{a}	1.27 ± 0.14^{a}	2.42 ± 0.11^{b}
	***F*-test**	36.327*	40.602*	13.811*	63.012*
Mentha longifolia	**N**	18	18	13	10
	Phytoseiulus persimilis	0.64 ± 0.30^{d}	0.98 ± 0.27^{d}	1.75 ± 0.11^{a}	3.69 ± 0.25^{a}
	Amblyseius swirskii	0.77 ± 0.25^{c}	1.42 ± 0.24^{c}	0.32 ± 0.12^{c}	0.11 ± 0.03^{b}
	Cydnoseius negevi	1.63 ± 0.10^{bc}	2.31 ± 0.10^{bc}	1.41 ± 0.11^{a}	0.11 ± 0.02^{b}
	Bio-Magic	3.47 ± 0.31^{b}	2.46 ± 0.30^{b}	0.75 ± 0.10^{b}	0.22 ± 0.07^{b}
	Egyxide	3.15 ± 0.30^{bc}	2.15 ± 0.29^{bc}	0.81 ± 0.08^{b}	0.22 ± 0.06^{b}
	Control	5.03 ± 0.20^{a}	3.43 ± 0.20^{a}	1.43 ± 0.11^{a}	3.92 ± 0.21^{a}
	***F*-test**	25.858*	19.857*	21.880*	37.201*

Within each column, means followed by similar letters are not significantly different (Tukey HSD), (*) significant at $P \leq 0.05$

Table 11. Reduction percentages of control applications. An evaluation between 2017 and 2018 results using the Student's test and ANOVA.

	Om Saber			Kom Oshim		
	2017	**2018**	***T*-test**	**2017**	**2018**	***T*-test**
Phytoseiulus persimilis	88%	85%	1.50^{ns}	90%	88%	1.042^{ns}
Amblyseius swirskii	75%	73%	1.000^{ns}	80%	80%	-
Cydnoseius negevi	50%	51%	0.561^{ns}	55%	57%	1.035^{ns}
Bio-Magic	34%	35%	0.675^{ns}	40%	40%	-
Egyxide	40%	42%	1.860^{ns}	45%	44%	0.809^{ns}
ANOVA	40.667*	41.025*		46.145*	45.004*	

T-test df= 18; $P \leq 0.05$

DISCUSSION

Four principles of integrated pest management in an agro-ecosystem are prevention, monitoring, avoidance, and suppression (EPA 2021). According to these tactics, the current study was designed. The prevention phase occurred by managing weeds which were found in each location, employing mechanical removal. However, diverse weed species were recorded in both locations; e.g., the slender amaranth *Amaranthus viridis* L. (Amaranthaceae), the Cheese weed *Malva parviflora* L. (Malvaceae), the burning nettle *Urtica urens* L. (Urticaceae), and the common cocklebur *Xanthium strumarium* L. (Asteraceae). These shared weeds were used as shelter for the recorded pests, besides, other secondary lepidopterans, aphids, and other phytophagous tydied, tarsonemid, and tenuipalpid mite species. Some studies have considered weeds to be of not much harm as prospected and that they might perform another ecological role in an ecosystem; being shelter/banker plants for predatory species (Parolin *et al*. 2012, 2013, 2014), and/or trap plants for herbivore species as applied in commercial applications in Europe (Shelton and Badenes-Pérez 2006) which was vital for the entire process.

Monitoring, as a second tactic, was taking place alongside during the experiment. Detecting climatic factors was very essential for most of the phytophagous species such as spider mites (Praslička and Huszár 2004; White and Liburd 2005; Zou *et al*. 2018), whiteflies (Jha and Kumar 2017; Khan 2019; Gamarra *et al*. 2020; Chandi *et al*. 2021), thrips (McDonald *et al*. 1998; Bergant *et al*. 2005; Cao *et al*. 2018; Garrick and Liburd 2018), also for predacious mites (Tixier 2018; Urbaneja-Bernat and Jaques 2022), as in the current study. As well, for predatory insect (Schuldiner-Harpaz and Coll 2013), or spider (Blamires and Sellers 2019; Napiórkowska *et al*. 2021) species, and even for the stored product and public health pests (Beckett 2011; Mahakittikun *et al*. 2011) life table parameters, population dynamics, and behaviours were affected due to climate changes.

The present study recorded the mean numbers of *T. urticae*, *T. tabaci*, and *B. tabaci* populations, which were significantly varied, increased, and changed (Tables 1, 4). However, *T. urticae* population growth was not significantly changed in the two experimental seasons, where the fluctuation of pest distribution was affected (*T. urticae* immatures $T = 0.719$, $P = 0.474$; *T. urticae* adults $T = 1 .011$, $P = 0.314$). While *T. tabaci*, and *B. tabaci* populations growth were highly significantly increased (*T. tabaci* $T = 3.999$, $P = 0.000$; *B. tabaci* $T = 6.086$, $P = 0.000$) (See Supplement).

Abou-Elella *et al*. (2021) concluded that organic fertilization could affect the life table parameters of the TSSM positively. That helps in explaining why these pest species build their populations rapidly and increase their fluctuations that become higher than the EIL, which need to be controlled. Climatic factors, also, affect the tri-trophic interactions, by changing the chemical responses of herbivore-plant and predator-prey interactions (Laws 2017), which reflects on the ecosystem and any possible IPM program applied.

However, climatic factors were not the only reason causing pest populations to increase; variations could occur due to different abiotic (e.g., plant nutritional contents, soil fertilization plant, and climatic factors), and biotic factors (e.g., plant morphological characters, herbivore physiological characters, plant-herbivore relation, and herbivore-herbivore relation) (Laws 2017; Skendžić *et al*. 2021; Zidan 2021).

Together, these factors are sustainable for the agro-ecosystem balance and suppression of harmful pests. As faunal and floral diversities, which have substantial roles in pest and disease management in the agro-ecosystems (Westerman *et al*. 2003; Hajjar *et al*. 2008). Another example to understand the increase in pest fluctuations and abundance is the presence of primary and secondary pests on the weed species in both sites; monitoring helped in indicating the most abundant and dominant pest species for control applications (secondary pest species have been statistically neglected due to not causing significant damages). Mathematical modulation of diversity indices have been used to measure the community species diversity, and diversity differences in populations within the ecosystem (Magurran 2004).

Avoidance, as the third protocol, was carried for maintaining the predatory species, keeping the pest populations under the EIL/ETL, and to reduce/prevent the need for chemical application. Some arthropods (e.g., *T. urticae*) could build resistant generations toward chemical compounds (Tirello *et al*. 2012), as a specialist predator *P. persimilis* was very efficient towards *T. urticae* (reduction percentage average = 90% in the whole study), and useless for other pests, due to its diet specialty (McMurtry and Croft 1997; McMurtry *et al*. 2013).

To keep other pest species under the EIL, therefore, we used the predatory species, *A. swirskii* and *C. negevi* which were the best candidates, as indigenous species in the Mediterranean basin, and with a wide range of feeding preferences (e.g., whiteflies, thrips, eriophyid and tetranychid pests) in both open fields and greenhouses (Nomikou *et al*. 2001; Arthurs *et al*. 2009; Stansly and Castillo 2009; Calvo *et al*. 2015; Doğramaci *et al*. 2011; Onzo *et al*. 2012; Xiao *et al*. 2012; Negm *et al*. 2014; Alatawi *et al*. 2019; Sanad and Hassan 2019; El-laithy *et al*. 2021; Barghout *et al*. 2022).

Interactions such as competition, intraguild predation (IGP), extraguild predation, and cannibalism would affect the plant-prey-predator relationships in the IPM procedure, thus using multiple predatory species with different dietary preferences and predatory behaviour is better than using individual ones (Momen 2010; Momen and El-Borolossy 2010; Walzer and Schausberger 2012; Momen *et al*. 2013; Guo *et al*. 2016; Knapp *et al*. 2018; Döker *et al*. 2021; Momen and Abdel-Khalek 2009 a, b, 2021).

The reduction percentages of Bio-Magic and Egyxide compounds in both locations were negative (especially in July and August) (See Supplement). This indicated that using these methods in that time was not useful, despite, their active ingredients being of natural origin (*M. anisopliue* fungi and plant essential oils). It is stated that 28 °C and a photoperiod of 16 hours were the most suitable conditions for *M. anisopliue* (Alves *et al*. 1984). The UV-A and UV-B of solar waves radiation extremely reduce *M. anisopliue* capability to form conidia which cause targeted pest mortality (Francisco *et al*. 2008). Besides, storage, transportation, and field application are also limitation factors (Parra 2014; Sinha *et al*. 2016).

The suppression, the final tactic in the present study, represented by *A. swirskii* and *C. negevi* results in reducing whitefly and thrips populations in both Brassicaceae and Lamiaceae plantations. Also, the role of *P. persimilis* as a specialist for *T. urticae*, and hypothetically, therefore, getting a large loss if this specialist is used as a “solo” or single tool. However, *A. swirskii* has gained successful results when applied either on its own (Table 11) or in a combination with other bio-agent predatory species and/or biopesticides (El-Saiedy *et al*. 2008; Abou-Awad *et al*. 2017; Knapp *et al*. 2018; El-Saiedy and Fahim 2021; Barghout *et al*. 2022). Although, the combined use of phytoseiid species was successful in the agro-ecosystem, release timing, capacity, weather conditions such as temperature, humidity, daylight UV waves, and wind speed should also be taken in consideration (Knapp *et al*. 2018).

CONCLUSION

Abiotic and biotic factors together could explain why invasive species build their communities rapidly and above the EIL. Such factors are hypothesized to affect the plant-arthropod, predator-herbivore, predator-predator, and tri-trophic interactions. Therefore, diversity indices have the accuracy to evaluate pest species distribution within the experimental agro-ecosystem, and to detect at which point IPM application should start. The proposed IPM tactic has achieved its target, to suppress pest infestations. Yet, several axes have to be covered in detailed forthcoming studies: the impact of application timing, the impact of combination/merging bio-agents, and to evaluate the impact of abiotic factors on such combinations.

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REFERENCES

Abdel-Khalek, A.A. & Momen, F.M. (2022) Biology and life table parameters of *Proprioseiopsis lindquisti* on three eriophyid mites (Acari: Phytoseiidae: Eriophyidae). *Persian Journal of Acarology*, 11(1): 59–69. DOI: 10.22073/pja.v11i1.68574

Abou-Awad, B.A., Afia, S.I. & El-Saiedy, E.M.A. (2017) Efficiency of two preadatory phytoseiid mites, biopesticide and fungal pathogen for controlling *Tetranychus urticae* Koch (Acari: Tetranychidae) on watermelon and muskmelon at Behera Governorate Egypt. *Bioscience Research*, 14(4): 1042–1049.

Abou-Elella, G.M., Hassan, M.F., Elsaeidy, E.M.A.K., Nawar, M.S. & Zidan, I.M. (2021) How organic medicinal plants affect life table parameters of *Tetranychus urticae* (Acari: Tetranychidae)? *Persian Journal of Acarology*, 10(1): 69–83. DOI: 10.22073/pja.v10i1.59623

Abou-Elella, G.M., Hassan, M.F., Nawar, M.S. & Zidan, I.M. (2014) Survival, development and reproduction of *Euseius finlandicus* (Oudemans) (Acari: Phytoseiidae) fed on various kinds of food substances. *Archives of Phytopathology and Plant Protection*, 47(7): 857–868. DOI: 10.1080/03235408.2013.823715

Akmal, M., Freed, S., Malik, M.N. & Gul, H.T. (2013) Efficacy of *Beauveria bassiana* (Deuteromycotina: Hypomycetes) against different aphid species under laboratory conditions. *Pakistan Journal of Zoology*, 45: 71–78.

Alatawi, F.J., Mushtaq, H.M.S., Mirza, J.H. & Kamran, M. (2019) Predation efficiency and preference of lab-reared and field-collected populations of predatory mite *Cydnoseius negevi* (Acari: Phytoseiidae) on two mite pest species *Oligonychus afrasiaticus* and *Tetranychus urticae* (Acari: Tetranychidae). *International Journal of Pest Management*, 65(4): 363–369. DOI: 10.1080/09670874.2018.1529340.

Alba, J.M., Bleeker, P.M., Glas, J.J., Schimmel, B.C.J., van Wijk, M., Sabelis, M.W., Schuurink, R.C. & Kant, M.R. (2012) The impact of induced plant volatiles on plant-arthropod interactions.

In: Smagghe, G. & Diaz, I. (Eds.), *Arthropod-plant interactions. Progress in biological control*. Vol. 14. Springer, Dordrecht, pp. 15–73. DOI: 10.1007/978-94-007-3873-7_2

Allam, S.F., Mahmoud, M.A-E., Hassan, M.F. & Mabrouk, A.H. (2020) Field application of six commercial essential oils against Date Palm mite, *Phyllotetranychus aegypticus* (Acari: Tenuipalpidae) in Egypt. *Persian Journal of Acarology*, 9(4): 377–389. DOI: 10.22073/pja.v9i4.61821

Alves, S.B., Risco, S.H. & Almeida, L.C. (1984) Influence of photoperiod and temperature on the development and sporulation of *Metarhizium anisopliae* (Metsch.). *Journal of Applied Entomology*, 97(1–5): 127–129. DOI: 10.1111/j.1439-0418.1984.tb03726.x

Arthurs, S., Mckenzie, C.L., Chen, J., Doğramaci, M., Brennan, M., Houben, K. & Osborne, L. (2009) Evaluation of *Neoseiulus cucumeris* and *Amblyseius swirskii* (Acari: Phytoseiidae) as biological control agents of chilli thrips, *Scirtothrips dorsalis* (Thysanoptera: Thripidae) on pepper. *Biological Control*, 49(1): 91–96. DOI: 10.1016/j.biocontrol.2009.01.002

Barghout, M., Ibrahim, S. & El-Saiedy, E. (2022) Efficacy of phytoseiid mites and pesticides to control *Bemisia tabaci*, *Thrips tabaci* and *Tetranychus urticae* on *Capsicum annuum*. *Persian Journal of Acarology*, 11(3): 497–513. DOI: 10.22073/pja.v11i3.74508

Beckett, S.J. (2011) Insect and mite control by manipulating temperature and moisture before and during chemical-free storage. *Journal of Stored Products Research*, 47(4): 284–292. DOI: 10.1016/j.jspr.2011.08.002

Bergant, K., Stanislav, T., Znidarcic, D., Črepinšek, Z. & Kajfež-Bogataj, L. (2005) Impact of climate change on developmental dynamics of *Thrips tabaci* (Thysanoptera: Thripidae): Can it be quantified? *Environmental Entomology*, 34(4): 755–766. DOI: 10.1603/0046-225X-34.4.755

Blamires, S.J. & Sellers, W.I. (2019) Modelling temperature and humidity effects on web performance: implications for predicting orb-web spider (*Argiope* spp.) foraging under Australian climate change scenarios. *Conservation Physiology*, 7(1): coz083. DOI: 10.1093/conphys/coz083

Calvo, F.J., Knapp, M., van Houten, Y.M., Hoogerbrugge, H. & Belda, J.E. (2015) *Amblyseius swirskii*: What made this predatory mite such a successful biocontrol agent? *Experimental & Applied Acarology*, 65(4): 419–433. DOI: 10.1007/s10493-014-9873-0

Cao, Y., Li, C., Yang, W.-J., Meng, Y.-L., Wang, L.-J., Shang, B.-Z. & Gao, Y.-L. (2018) Effects of temperature on the development and reproduction of *Thrips hawaiiensis* (Thysanoptera: Thripidae). *Journal of Economic Entomology*, 111(2): 755–760. DOI: 10.1093/jee/tox359

Chandi, R.S., Kataria, S.K. & Fand, B.B. (2021) Effect of temperature on biological parameters of cotton whitefly, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae). *International Journal of Tropical Insect Science*, 41: 1823–1833. DOI: 10.1007/s42690-020-00397-0

Delisle, J.F., Brodeur, J. & Shipp, L. (2015a) Evaluation of various types of supplemental food for two species of predatory mites, *Amblyseius swirskii* and *Neoseiulus cucumeris* (Acari: Phytoseiidae). *Experimental & Applied Acarology*, 65(4): 483–494. DOI: 10.1007/s10493-014-9862-3

Delisle, J.F., Shipp, L. & Brodeur, J. (2015b) Apple pollen as a supplemental food source for the control of western flower thrips by two predatory mites, *Amblyseius swirskii* and *Neoseiulus cucumeris* (Acari: Phytoseiidae), on potted chrysanthemum. *Experimental & Applied Acarology*, 65(4): 495–509. DOI: 10.1007/s10493-014-9863-2 de Melo, T.M.P., Silva, E.M. da, Silva, A.G. da, Vieira, G.H. da C. & Lopes, B.G. (2019) *Syzygium aromaticum* essential oil to the control of *Tenuipalpus heveae. Journal of Agricultural Science*, 11(8): 1916–9752. DOI: 10.5539/jas.v11n8p295

Doğramaci, M., Arthurs, S.P., Chen, J., McKenzie, C., Irrizary, F. & Osborne, L. (2011) Management of chilli thrips *Scirtothrips dorsalis* (Thysanoptera: Thripidae) on peppers by *Amblyseius swirskii* (Acari: Phytoseiidae) and *Orius insidiosus* (Hemiptera: Anthocoridae). *Biological Control*, 59(3): 340–347. DOI: 10.1016/j.biocontrol.2011.09.008

Döker, İ., Revynthi, A.M., Kazak, C. & Carrillo, D. (2021) Interactions among exotic and native phytoseiids (Acari: Phytoseiidae) affect biocontrol of two-spotted spider mite on papaya. *Biological Control*, 163: 104758. DOI: 10.1016/j.biocontrol.2021.104758

Ebadollahi, A., Ziaee, M. & Palla, F. (2020) Essential oils extracted from different species of the Lamiaceae plants family as prospective bioagents against several detrimental pests. *Molecules*, 25: 1556. DOI: 10.3390/molecules25071556

Ehi-Eromosele, C.O., Nwinyi, O.C. & Ajani, O.O. (2013) Integrated pest management. *In*: Soloneski, S. & Larramendy, M. (Eds.), *Weed and pest control - conventional and new challenges*. *IntechOpen*, pp. 105–115. DOI: 10.5772/54476

El-laithy, A.Y.M., El-Saiedy, E.M.A. & Hussein, H.E. (2021) Efficacy of the predatory mite *Cydnoseius negevi* (Swirskii & Amitai) (Acari: Phytoseiidae) as a shared predator for sucking pests on sweet pepper in a net house in Egypt. *Systematic and Applied Acarology*, 26(10): 1856–1866. DOI: 10.11158/saa.26.10.3

El-Saiedy, ES.M., Abou-Elella, G.M. & Alotaibi, S.A. (2008) Efficiency of three predatory phytoseiid mites and biocide chemical for controlling *Tetranychus urticae* Koch on egg plant at Beheira governorate. *Research Journal of Agriculture and Biological Sciences*, 4: 238–244.

El-Saiedy, ES.M. & Fahim, S.F. (2021) Evaluation of two predatory mites and acaricide to suppress *Tetranychus urticae* (Acari: Tetranychidae) on strawberry. *Bulletin of the National Research Centre*, 45: 97. DOI: 10.1186/s42269-021-00558-2

El-Saiedy, ES.M., Hassan, M.F., El-Bahrawy, A.F., El-Kady, G.A. & Kemel, M.S. (2015) Efficacy of two phytoseiid predators and a biopesticide against *Tetranychus curcubitacearum* (Sayed) (Acari: Tetranychidae) on eggplant at Ismailia Governorate, Egypt. *Egyptian Journal of Biological Pest Control*, 25: 71–74.

El-Shafie, H.A. (2019) Integrated insect pest management. *IntechOpen*, DOI: 10.5772/intechopen.81827

EPA (United States Environmental Protection Agency) (2021) Integrated Pest Management (IPM) principles. Available from: https://www.epa.gov/integrated-pest-management-principles (Accessed on 13 November 2021)

Evans, H.C. (1982) Entomogenous fungi in tropical forest ecosystems: an appraisal. *Ecological Entomology*, 7: 47–60. DOI: 10.1111/j.1365-2311.1982.tb00643.x

Ferreira, C.T., Noronha, A.C., Souza Neto, E.P., De Oliveira, R.P., Lins, P.M.P. & Batista, T.F.V. (2022) Functional and numerical responses of the predatory mite *Amblyseius aerialis* (Acari: Phytoseiidae) to *Aceria guerreronis* (Acari: Eriophyidae). *Acarologia*, 62(1): 27–35. DOI: 10.24349/w600-25ar

Frago, E., Gols, R., Schweiger, R., Müller, C., Dicke, M. & Godfray, H.C.J. (2022) Herbivore-induced plant volatiles, not natural enemies, mediate a positive indirect interaction between insect herbivores. *Oecologia*, DOI: 10.1007/s00442-021-05097-1

Francisco, E.A., Rangel, D. & La Scala Jr, N. (2008) Exposure of *Metarhizium anisopliae* conidia to UV-B radiation reduces its virulence. *Journal of Anhui Agricultural University*, 35: 246–249.

Gamarra, H., Sporleder, M., Carhuapoma, P., Kroschel, J. & Kreuze, J. (2020) A temperature-dependent phenology model for the greenhouse whitefly *Trialeurodes vaporariorum* (Hemiptera: Aleyrodidae). *Virus Research*, 289: 198107. DOI: 10.1016/j.virusres.2020.198107

Gardarin, A., Plantegenest, M., Bischoff, A. & Valantin-Morison, M. (2018) Understanding plant–arthropod interactions in multitrophic communities to improve conservation biological control: useful traits and metrics. *Journal of Pest Science*, 91(3): 943–955. DOI: 10.1007/s10340-018-0958-0

Garrick, T.A. & Liburd, O.E. (2018) Impact of climate change on a key agricultural pest: Thrips. *In*: Information Resources Management Association (Ed.), *Climate change and environmental concerns: Breakthroughs in Research and Practice*. IGI Global, pp. 65–87. DOI: 10.4018/978-1-5225-5487-5.ch004

Garrido-Jurado, I., Fernandez-Bravo, M., Campos, C. & Quesada-Moraga, E. (2015) Diversity of entomopathogenic Hypocreales in soil and phylloplanes of five Mediterranean cropping systems. *Journal of Invertebrate Pathology*, 130: 97–106. DOI: 10.1016/j.jip.2015.06.001

Greenfield, M., Gomez-Jimenez, M.I., Ortiz, V., Vega, F.E., Kramer, M. & Parsa, S. (2016) *Beauveria bassiana* and *Metarhizium anisopliae* endophytically colonize cassava roots following soil drench inoculation. *Biological Control*, 95: 40–48. DOI: 10.1016/j.biocontrol.2016.01.002

Guo, Y., Lv, J., Jiang, X., Wang, B., Gao, Y., Wang, E. & Xu, X. (2016) Intraguild predation between *Amblyseius swirskii* and two native Chinese predatory mite species and their development on intraguild prey. *Scientific Reports*, 6: 22992. DOI: 10.1038/srep22992

Hajjar, R., Jarvis, D.I. & Gemmill-Herren, B. (2008) The utility of crop genetic diversity in maintaining ecosystem services. *Agriculture, Ecosystems & Environment*, 123: 261–270. DOI: 10.1016/j.agee.2007.08.003

Halsch, C.A., Shapiro, A.M., Fordyce, J.A., Nice, C.C., Thorne, J.H., Waetjen, D.P. & Forister, M.L. (2021) Insects and recent climate change. *Proceedings of the National Academy of Sciences of the United States of America*, 118(2): e2002543117. DOI: 10.1073/pnas.2002543117

Hammer, Ø., Harper, D.A., & Ryan, P.D. (2001) PAST: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica*, 4(1): 19A. Available from: https://paleo.carleton.ca/past.pdf

Henderson, C.E. & Tilton, E.W. (1995) Tests with acaricides against the brown wheat mites. *Journal of Economic Entomology*, 84(2): 157–161. DOI: 10.1093/jee/48.2.157

Isman, M.B. (2006) Botanical insecticides, deterrents, and repellents in modern agriculture and increasingly regulated world. *Annual Review of Entomology*, 51: 45–66. DOI: 10.1146/annurev.ento.51.110104.151146

Isman, M.B. & Machial, C.M. (2006) Pesticides based on plant essential oils: from traditional practice to commercialization. *In*: Rai, M. & Carpinella, M.C. (Eds.), *Naturally occurring bioactive compounds*. Elsevier, pp. 29–44.

Janssen, A. & Sabelis, M.W. (2015) Alternative food and biological control by generalist predatory mites: the case of *Amblyseius swirskii*. *Experimental & Applied Acarology*, 65(4): 413–418. DOI: 10.1007/s10493-015-9901-8

Jha, S.K. & Kumar, M. (2017) Effect of weather parameters on incidence of whitefly, *Bemisia tabaci* (Gennadius) on tomato. *Journal of Entomology and Zoology Studies*, 5(6): 304–306.

Karthik, S., Reddy, M.S. & Yashaswini, G. (2021) Climate change and its potential impacts on insect-plant interactions [Online First]. *IntechOpen*, DOI: 10.5772/intechopen.98203

Kavitha, K. & Reddy, K.D. (2014) Tritrophy - A new dimension in IPM-A review. *Journal of Progressive Agriculture*, 5(2): 99–111. DOI: 10.5958/0976-0741.2014.00907.6

Khan, M.M.H. (2019) Effect of temperature and relative humidity on the population dynamics of brinjal and tomato infesting whitefly, *Bemisia tabaci*. *Jahangirnagar University Journal of Biological Sciences*, 8(1): 83–86. DOI: 10.3329/jujbs.v8i1.42471

Knapp, M., van Houten, Y., van Baal, E. & Groot, T. (2018) Use of predatory mites in commercial biocontrol: current status and future prospects. *Acarologia*, 58: 72–82. DOI: 10.24349/acarologia/20184275

Koul, O., Walia, S. & Dhaliwal, G.S. (2008) Essential oils as green pesticides: Potential and constraints. *Biopesticides International*, 4(1): 63–84.

Laws, A.N. (2017) Climate change effects on predator–prey interactions. *Current Opinion in Insect Science*, 23: 28–34. DOI: 10.1016/j.cois.2017.06.010

Lacey, L.A., Grzywacz, D., Shapiro-Ilan, D.I., Frutos, R., Brownbridge, M. & Goettel, M.S. (2015) Insect pathogens as biological control agents: Back to the future. *Journal of Invertebrate Pathology*, 132: 1–41. DOI: 10.1016/j.jip.2015.07.009

Magurran, A. (2004) *Measuring biological diversity*. Blackwell Publishing, Oxford, UK, 256 pp.

Mahakittikun, V., Boitano, J., Ninsanit, P., Wangapai, T. & Ralukruedej, K. (2011) Effects of high and low temperatures on development time and mortality of house dust mite eggs. *Experimental & Applied Acarology*, 55(4): 339–347. DOI: 10.1007/s10493-011-9480-2

McAleece, N., Gage, J.D.G., Lambshead, P.J.D. & Paterson, G.L.J. (1997) *Biodiversity professional statistics analysis software*. Scottish Association for Marine Science and the Natural History Museum London, 2 pp. Available from: http://www.sams.ac.uk/biodiversity-pro.

McDonald, J.R., Bale, J.S. & Walters, K.F.A. (1998) Effect of temperature on development of the Western Flower Thrips, *Frankliniella occidentalis* (Thysanoptera: Thripidae). *European Journal of Entomology*, 95: 301–306.

McGuire, A.V. & Northfield, T.D. (2020) Tropical occurrence and agricultural importance of *Beauveria bassiana* and *Metarhizium anisopliae*. *Frontiers in Sustainable Food Systems*, 4: 6. DOI: 10.3389/fsufs.2020.00006

McMurtry, J.A. & Croft, B.A. (1997) Life-styles of phytoseiid mites and their roles in biological control. *Annual Review of Entomology*, 42: 291–321. DOI: 10.1146/annurev.ento.42.1.291

McMurtry, J.A., de Moraes, G.J. & Sourassou, N.F. (2013) Revision of the lifestyles of phytoseiid mites (Acari: Phytoseiidae) and implications for biological control strategies. *Systematic & Applied Acarology*, 18(4): 297–320. DOI: 10.11158/saa.18.4.1

Melo, J.W.S., Lima, D.B., Staudacher, H., Silva, F.R., Gondim Jr, M.G.C. & Sabelis, M.W. (2015) Evidence of *Amblyseius largoensis* and *Euseius alatus* as biological control agent of *Aceria guerreronis*. *Experimental & Applied Acarology*, 67: 411–421. DOI: 10.1007/s10493-015-9963-7

Messelink, G.J., Bloemhard, C.M.J., Sabelis, M.W. & Janssen, A. (2013) Biological control of aphids in the presence of thrips and their enemies. *BioControl*, 58: 45–55. DOI: 10.1007/s10526-012-9462-2

Messelink, G.J., Van Steenpaal, S.E.F. & Ramakers, P.M.J. (2006) Evaluation of phytoseiid predators for control of western flower thrips on greenhouse cucumber. *BioControl*, 51(6): 753–768. DOI: 10.1007/s10526-006-9013-9

Momen, F.M. (2010) Intra- and interspecific predation by *Neoseiulus barkeri* and *Typhlodromus negevi* (Acari: Phytoseiidae) on different life stages: Predation rates and effects on reproduction and juvenile development. *Acarina*, 18(1): 81–88.

Momen, F.M. & Abdelkhader, M.M. (2010) Fungi as food source for the generalist predator *Neoseiulus barkeri* (Hughes) (Acari: Phytoseiidae). *Acta Phytopathologica et Entomologica Hungarica*, 45(2): 401–409. DOI: 10.1556/aphyt.45.2010.2.18

Momen, F.M. & Abdel-Khalek, A.A. (2008) Effect of the tomato rust mite *Aculops lycopersici* (Acari: Eriophyidae) on the development and reproduction of three predatory phytoseiid mites. *International Journal of Tropical Insect Science*, 28(1): 53–57. DOI: 10.1017/S174275840894259 4

Momen, F.M. & Abdel-Khalek, A.A. (2009a) Cannibalism and intraguild predation in the phytoseiid mites *Typhlodromips swirskii*, *Euseius scutalis* and *Typhlodromus athiasae* (Acari: Phytoseiidae). *Acarina*, 17(2): 223–229.

Momen, F.M. & Abdel-Khalek, A.A. (2009b) Juvenile survival and development of *Typhlodromips swirskii*, *Euseius scutalis* and *Typhlodromus athiasae* (Acari: Phytoseiidae) feeding on con- and heterospecific immatures. *Acta Phytopathologica et Entomologica Hungarica*, 44(1): 167–176. DOI: 10.1556/aphyt.44.2009.1.18

Momen, F.M. & Abdel-Khalek, A.A. (2021) Intraguild predation in three generalist predatory mites of the family Phytoseiidae (Acari: Phytoseiidae). *Egyptian Journal of Biological Pest Control*, 31: 8. DOI: 10.1186/s41938-020-00355-5

Momen, F.M. & El-Borolossy, M. (2010) Juvenile survival and development in three phytoseiid species (Acari: Phytoseiidae) feeding on con- and heterospecific immatures. *Acta Phytopathologica et Entomologica Hungarica*, 45(2): 349–357. DOI: 10.1556/aphyt.45.2010.2. 12

Momen, F.M., Hassan, M.F. & Lamlom, M. (2020) Evaluation of two factitious preys for rearing *Neoseiulus barkeri* (Acari: Phytoseiidae). *International Journal of Acarology*, 46(6): 387–393. DOI: 10.1080/01647954.2020.1804998

Momen, F.M., Hussein, H. & Reda, A. (2013) Intra-guild vs extra-guild prey: Effect on development, predation and preference of *Typhlodromus negevi* Swirski and Amitai and *Typhlodromips swirskii* (Athias-Henriot) (Acari: Phytoseiidae). *Acta Phytopathologica et Entomologica Hungarica*, 48(1): 95–106. DOI: 10.1556/aphyt.48.2013.1.9

Momen, F.M., Metwally, A.M., Nasr, A.K., Abdallah, A.A. & Saleh, K.M. (2014) Life history of *Proprioseiopsis badri* feeding on four eriophyid mite species (Acari: Phytoseiidae and Eriophyidae). *Phytoparasitica*, 42(1): 23–30. DOI: 10.1007/s12600-013-0333-x

Momen, F.M., Rasmy, A.H., Zaher, M.A., Nawar, M.S. & Abou-Elella, G.M. (2004) Dietary effect on the development, reproduction and sex-ratio of the predatory mite *Amblyseius denmarkeri* Zaher & El-Borolossy (Acari: Phytoseiidae). *International Journal of Tropical Insect Science*, 24(2): 192–195. DOI: 10.1079/IJT200414

Napiórkowska, T., Templin, J., Grodzicki, P. & Kobak, J. (2021) Thermal preferences of two spider species: an orb-web weaver and a synanthropic funnel-web weaver. *The European Zoological Journal*, 88(1): 824–836. DOI: 10.1080/24750263.2021.1950223

Negm, M.W., Alatawi, F.J. & Aldryhim, Y.N. (2014) Biology, predation, and life table of *Cydnoseius negevi* and *Neoseiulus barkeri* (Acari: Phytoseiidae) on the Old World Date Mite, *Oligonychus afrasiaticus* (Acari: Tetranychidae). *Journal of Insect Science*, 14(1): 177. DOI: 10.1093/jisesa/ieu039

Nomikou, M., Janssen, A., Schraag, R. & Sabelis, M.W. (2001) Phytoseiid predators as potential biological control agents for *Bemisia tabaci*. *Experimental and Applied Acarology*, 25: 270–290. DOI: 10.1023/A:1017976725685

Nomikou, M., Janssen, A., Schraag, R. & Sabelis, M.W. (2002) Phytoseiid predators suppress populations of *Bemisia tabaci* on cucumber plants with alternative food. *Experimental and Applied Acarology*, 27: 57–68. DOI: 10.1023/A:1021559421344

Nomikou, M., Janssen, A. & Sabelis, M.W. (2003) Phytoseiid predator of whitefly feeds on plant tissue. *Experimental and Applied Acarology*, 31: 27–36. DOI: 10.1023/B:APPA.0000005150.33813.04

Onzo, A., Houedokoho, A.F. & Hanna, R. (2012) Potential of the predatory mite, *Amblyseius swirskii* to suppress the broad mite, *Polyphagotarsonemus latus* on the Gboma eggplant, *Solanum macrocarpon*. *Journal of Insect Science*, 12: 7–12. DOI: 10.1673/031.012.0701

Parolin, P., Bresch, C., Desneux, N., Brun, R., Bout, A., Boll, R. & Poncet, C. (2012) Secondary plants used in biological control: A review. *International Journal of Pest Management*, 58(2): 91–100. DOI: 10.1080/09670874.2012.659229

Parolin, P., Bresch, C., Poncet, C. & Desneux, N. (2014) Introducing the term 'Biocontrol Plants' for integrated pest management. *Scientia Agricola*, 71(1): 77–80. DOI: 10.1590/S0103-90162014000100011

Parolin, P., Bresch, C., Ruiz, G., Desneux, N. & Poncet, C. (2013) Testing banker plants for biological control of mites on roses. *Phytoparasitica*, 41: 249–262. DOI: 10.1007/s12600-012-0285-6

Parra, J.R.P. (2014) Biological control in Brazil: an overview. *Scientia Agricola*, 71(5): 420–429. DOI: 10.1590/0103-9016-2014-0167

Praslička, J. & Huszár, J. (2004) Influence of temperature and host plants on the development and fecundity of the spider mite *Tetranychus urticae* (Acarina: Tetranychidae). *Plant Protection Science*, 40(4): 141–144.

Regnault-Roger, C., Hamraoui, A., Holeman, M., Theron, E. & Pinel, R. (1993) Insecticidal effect of essential oils from Mediterranean plants upon *Acanthoscelides obtectus* Say (Coleoptera, Bruchidae), a pest of kidney bean (*Phaseolus vulgaris* L.). *Journal of Chemical Ecology*, 19: 1233–1244. DOI: 10.1007/BF00987383

Sanad, A.S. & Hassan, G.M. (2019) Controlling the western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) by releasing the predatory phytoseiid mites and pesticides on pepper in a greenhouse. *Egyptian Journal of Biological Pest Control*, 29(1): 95. DOI: 10.1186/s41938-019-0186-9

Schuldiner-Harpaz, T. & Coll, M. (2013) Effects of global warming on predatory bugs supported by data across geographic and seasonal climatic gradients. *PLoS ONE*, 8(6): e66622. DOI: 10.1371/journal.pone.0066622

Shelton, A. & Badenes-Pérez, F. (2006) Concepts and applications of trap cropping in pest management. *Annual Review of Entomology*, 51(1): 285–308. DOI: 10.1146/annurev.ento.51.11 0104.150959

Shijiang, P. (1983) Biological Control – One of the fine traditions of ancient Chinese agricultural techniques. *Scientia Agricultura Sinica*, 1: 92–98.

Shrestha, S. (2019) Effects of climate change in agricultural insect pest. *Acta Scientific Agriculture*, 3(12): 74–80. DOI: 10.31080/ASAG.2019.03.0727

Sinha, K.K., Choudhary, A.K. & Kumari, P. (2016) Entomopathogenic fungi. *In*: Omkar (Ed.), Ecofriendly pest management for food security. Academic Press, Elsevier, pp. 475–505. DOI: 10.1016/B978-0-12-803265-7.00015-4

Skendžić, S., Zovko, M., Živković, I.P., Lešić, V. & Lemić, D. (2021) The impact of climate change on agricultural insect pests. *Insects*, 12: 440. DOI: 10.3390/insects12050440

Stansly, P.A. & Castillo, J. (2009) Control of broad mite *Polyphagotarsomeus latus* and the whitefly *Bemisia tabaci* in open field pepper and eggplant with predaceous mites. *In*: Castañe, C. & Perdikis, D. (Eds.), Proceedings of the working group "Integrated Control in Protected Crops, Mediterranean Climate". *IOBC WPRS Bulletin*, 49: 145–152.

Tirello, P., Pozzebon, A., Cassanelli, S., Van Leeuwen, T. & Duso, C. (2012) Resistance to acaricides in Italian strains of *Tetranychus urticae*: toxicological and enzymatic assays. *Experimental and Applied Acarology*, 57: 53–64. DOI: 10.1007/s10493-012-9536-y

Tixier, M.-S. (2018) Predatory mites (Acari: Phytoseiidae) in Agro-ecosystems and conservation biological control: A review and explorative approach for forecasting plant-predatory mite interactions and mite dispersal. *Frontiers in Ecology and Evolution*, 6: 192. DOI: 10.3389/fevo.2018.00192

Urbaneja-Bernat, P. & Jaques, J.A. (2022) Can pollen provision mitigate competition interactions between three phytoseiid predators of *Tetranychus urticae* under future climate change conditions? *Biological Control*, 165: 104789. DOI: 10.1016/j.biocontrol.2021.104789

Van Rijn, P.C. & Tanigoshi, L.K. (1999) Pollen as food for the predatory mites *Iphiseius degenerans and Neoseiulus cucumeris* (Acari: Phytoseiidae): Dietary range and life history. *Experimental & Applied Acarology*, 23: 785–802. DOI: 10.1023/A:1006227704122

Verkerk, R. H. (2004) Manipulation of tritrophic interactions for IPM. *In*: Koul, O., Dhaliwal, G.S. & Cuperus, G.W. (Eds.), *Integrated pest management: potential, constraints, and challenges*. CABI Publishing, UK, pp. 55–72.

Walzer, A. & Schausberger, P. (2012) Integration of multiple intraguild predator cues for oviposition decisions by a predatory mite. *Animal Behaviour*, 84(6): 1411–1417. DOI: 10.1016/j.anbehav.2012.09.006

Westerman, P.S., Wes, J.S., Kropff, M.J. & van der Werf, W. (2003) Annual losses of weed seeds due to predation in organic cereal fields. *Journal of Applied Ecology*, 40: 824–836. DOI: 10.1046/j.1365-2664.2003.00850.x

White, J. & Liburd, O. (2005) Effects of soil moisture and temperature on reproduction and development of two spotted spider mite (Acari: Tetranychidae) in strawberries. *Journal of Economic Entomology*, 98(1): 1548. DOI: 10.1603/0022-0493-98.1.154

Wraight, S.P., Ugine, T.A., Ramos, M.E. & Sanderson, J.P. (2016) Efficacy of spray applications of entomopathogenic fungi against western flower thrips infesting greenhouse impatiens under variable moisture conditions. *Biological Control*, 97: 31–47. DOI: 10.1016/j.biocontrol.2016.02.016

Xiao, Y., Avery, P., Chen, J., Mckenzie, C. & Osborne, L. (2012) Ornamental pepper as banker plants for establishment of *Amblyseius swirskii* (Acari: Phytoseiidae) for biological control of multiple pests in greenhouse vegetable production. *Biolgical Control*, 63: 279–286. DOI: 10.1016/j.biocontrol.2012.09.007

Xin, T.-R. & Zhang, Z.-Q. (2021) Suitability of pollen as an alternative food source for different developmental stages of *Amblyseius herbicolus* (Chant) (Acari: Phytoseiidae) to facilitate predation on whitefly eggs. *Acarologia*, 61(4): 790–801. DOI: 10.24349/bIV1-2heN

Zemek, R. & Prenerová, E. (1997) Powdery mildew (Ascomycotina: Erysiphales) - an alternative food for the predatory mite *Typhlodromus pyri* Scheuten (Acari: Phytoseiidae). *Experimental and Applied Acarology*, 21: 405–414. DOI: 10.1023/A:1018427812075

Zidan, I.M. (2021) *Biodiversity and natural control of mites associated with medicinal plants in organic farming systems*. Ph. D. dissertation, Faculty of Agriculture, Cairo University, 304 pp.

Zou, Z., Xi, J., Liu, G., Song, S., Xin, T. & Xia, B. (2018) Effect of temperature on development and reproduction of the carmine spider mite, *Tetranychus cinnabarinus* (Acari: Tetranychidae), fed on cassava leaves. *Experimental and Applied Acarology*, 74(4): 383–394. DOI: 10.1007/s10493-018-0241-3

کنه‌های شکارگر، یک آفت‌کش سبز و یک ترکیب انتموپاتوژن: یک تاکتیک پیشنهادی IPM بر اساس شاخص‌های تنوع گونه‌های آفات و پویایی جمعیت

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چکیده

این مطالعه با هدف بررسی پویایی جمعیت و شاخص های تنوع سه گونه مهاجم انجام شد؛ کنهٔ تارتن دو لکه‌ای *Tetranychus urticae* Koch (Acari: Tetranychidae)، سفیدبالک *Bemisia tabaci* Genn. (Hemiptera: Aleyrodidae) و تریپس پیاز *Thrips tabaci* Lindman (Thysanoptera: Thripidae) روی چهار گیاه آزمایش شده کلم‌پیچ سیبری (روسی) *Brassica napus* var. *pabularia* L.، کلم‌پیچ ایتالیایی (توسکانی) *Brassica oleracea* var. *palmifolia* L. (Brassicaceae)، نعناع خوراکی *Mentha spicata* L. و نعناع سعودی *Mentha longifolia* L. (Lamiaceae)؛ افزون بر ارزیابی یک شیوه‌نامه پیشنهادی IPM در دو سایت آزمایشی (اُم صابر، استان بحیرا و کوم اوشیم، استان فیوم). برنامه پیشنهادی IPM شامل استفاده از کنه‌های شکارگر بود. گونه‌های *Phytoseiulus persimilis* Athias-Henriot، *Amblyseius swirskii* Athias-Henriot و *Cydnoseius negevi* (Swirski & Amitai) (Acari: Phytoseiidae)، یک آفت‌کش سبز و یک ترکیب انتموپاتوژن. نمونه‌هایی از گیاهان آزمایش شده برای دو فصل برای محاسبه پویایی جمعیت آفات و شاخص‌های تنوع، پیش و پس از تیمارهای IPM جمع‌آوری شد. داده‌های به‌دست‌آمده نشان‌دهنده نوسان، پویایی جمعیت، فراوانی، پراکنش و شاخص‌های تنوع از سه گونه آفت هدف ثبت‌شده در چهار گیاه مورد آزمایش بود. در حالی که شیوه‌نامه پیشنهادی IPM منجر به کاهش درصد زیادی در استفاده از *A. swirskii* در مقایسه با سایر روش‌ها شده است. بحث شد که عوامل غیرزیستی و زیستی با هم کمک می‌کنند در توضیح اینکه چرا گونه‌های آفات مختلف، جوامع خود را به سرعت ایجاد می‌کنند و آماره‌های خود را به بالاتر از سطح زیان اقتصادی (EIL) افزایش می‌دهند. چنین عواملی روی برهم‌کنش‌های گیاه–بندپا، شکارگر–گیاهخوار، شکارگر–شکارگر و سه سطحی تأثیر می‌گذارند. چنین شیوه‌نامه‌ای در نظر گرفتن زمان‌بندی کاربرد را توصیه می‌کند و روش‌های تلفیقی را با هم برای به دست آوردن بیشترین کارایی پیشنهاد می کند.

واژگان کلیدی: مهار زیستی؛ Brassicaceae؛ Lamiaceae؛ Phytoseiidae؛ برهم‌کنش‌های بندپایان؛ مدیریت گیاهان.

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