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Lethal and sublethal effects of coconut oil on *Tetranychus urticae* (Acari: tetranychidae) and toxicity to *Amblyseius swirskii* (Acari: phytoseiidae)

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Abstract
Tetranychus urticae Koch is a serious mite pest that attacks various agricultural crops worldwide. The present study aimed to assess the lethal effect of coconut oil against *T. urticae* in addition to evaluate the sublethal effects of LC_{15}, LC_{30} of this oil on development and life table parameters of *T. urticae*. Also, the toxicity of coconut oil to the predatory mite *Amblyseius swirskii* Athias-Henriot was assessed in the current study. The obtained results indicated that coconut oil had acaricidal activity against *T. urticae* (LC_{50}=0.843 and LC_{90}=2.522%). The pre-adult development of *T. urticae* was increased by the LC_{15} and LC_{30} of coconut oil compared with the control. However, the oil treatments reduced the longevity of *T. urticae* females to 13.89 and 12.00 days for LC_{15} and LC_{30} treatments, respectively in compared to control (15.59 days). A total of 63.82 eggs/female were produced by control females; while LC_{15} and LC_{30} treatments decreased the total fecundity of *T. urticae* to 45.78 and 31.12 eggs/female, respectively. Here, the values of intrinsic rate of increase (r) in LC_{15} and LC_{30} treatments (0.212 and 0.189 day^{-1}, respectively) were lower than that in control (0.236 day^{-1}). The values of finite rate of increase (λ), net reproductive rate (R_0), and gross reproductive rate (*GRR*) were reduced by coconut oil treatments, being significantly higher for control mites. On the other hand, coconut oil caused lower mortality to the predatory mite *A. swirskii* in compared to the pest (*T. urticae*). In conclusion, the present results suggested the possibility of using coconut oil in integrated pest management (IPM) programs of *T. urticae*.

Keywords: coconut oil, life table parameters, predatory mites, sublethal effects, toxicity, two-spotted spider mite

Introduction
The two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), is a serious mite pest that attacks various agricultural crops worldwide (Cote *et al.* 2002; Laborda *et al.* 2013; Maleknia *et al.* 2016) [1, 2, 3]. Chemical pesticides were the major control system that used against *T. urticae*. Due to the long-time application of chemical pesticides as well as short life cycle and high reproductive rate of *T. urticae*, this pest is capable of rapidly develop resistance to these chemicals (Knowles 1997; Bugeme *et al.* 2015) [4, 5]. The pest resistance to synthetic pesticides led to the re-application of these chemicals which increased costs, concerns about the residues of pesticides, and risks to human health and the environment, along with the pest re-outbreak (Garriga and Caballero 2011) [6]. As a result of these various toxicological and environmental problems, more attention has been paid to the use of natural products originating from plants as alternatives to chemical pesticides. In addition, there is a great desire to use natural pesticides for pest control, especially with edible agricultural crops (Havasi *et al*. 2019) [7] and in the developed countries where people prefer to use the organic products (Duke *et al.* 2010) [8]. In this regard, the natural products of plant origin degrade easily in the environment (Ebadollahi *et al*. 2020) [9] in addition to having minimal negative impacts on environment and human health (Pavela 2017) [10]. Therefore, some previous studies recommended the use of plant oils and plant extracts in the management of pest species (e.g., Chitgar *et al.* 2013; Oliveira *et al*. 2017; Al sendi *et al.* 2018; Havasi *et al.* 2019) [11, 12, 13, 7].
Coconut (*Cocos nucifera* L.) oil is widely used for industrial and food purposes (Marina *et al*. 2009) [14]. The coconut oil has been found to contain different fatty acids including lauric, myristic, linoleic, and palmitic acids (Oliveira *et al*. 2017) [12]. In this context, previous literatures have demonstrated the toxicity of various fatty acids against insect species (Parry and Rose 1983; Sims *et al*. 2014) [15,16]. In addition, Oliveira *et al*. (2017) [12] indicated that coconut oil displayed an acaricidal activity against *Aceria guerreronis* Keifer (Acari: Eriophyidae).
Pesticides toxicity studies mostly assess the acute toxicity on the target pests (Robertson and Worner 1990; Kim *et al.* 2004) [17, 18]. On the other hand, studying the sublethal effects of pesticide on pest life history traits is essential to evaluate the total impacts of the pesticide on pest population. Consequently, the life-table analysis was suggested to be the best way to assess the lethal and sublethal effects of pesticides on target pests (Kim *et al.*

2006; Li *et al.* 2017) [19, 20] and could provide the information required for their effective use in control programs of these pests.

Amblyseius swirskii Athias-Henriot (Acari: Phytoseiidae) is a generalist predatory mite (McMurtry *et al.* 2013) [21] that can feed on various types of diets including pollen, insects, and different mite species (e.g., tetranychid and tarsonemid mites) (Messelink *et al.* 2006; Abou-Awad *et al.* 2014; Nemati *et al.* 2019; Fahim and El-Saiedy 2021) [22, 23, 24, 25]. In greenhouses, this predator is extensively used to control thrips and whitefly (e.g. Calvo *et al.* 2011) [26], and is also a candidate for the biological control of spider mites (Piyani *et al.* 2021) [27]. One of the main gaps in the studies evaluating the activity of plant oils against target pests is the impact of these oils on natural enemies (Pavela and Benelli 2016) [28]. The use of toxic compounds may hinder biological control by displaying toxic effect on natural enemies (such as predatory mites). Consequently, it is not only required to assess the impact of pesticides on the mite pests, but also their toxicity to the natural enemies in order to develop successful management strategies. Based on the previous literatures, there is no information available on the acaricidal activity of coconut oil against *T. urticae* along with its sublethal effects on the life table parameters of this mite pest. Therefore, the present study aimed to assess the lethal effect of coconut oil against *T. urticae* as well as to evaluate the sublethal effects of this oil on development and life table parameters of *T. urticae*. In addition, the toxicity of coconut oil to the predatory mite *A. swirskii* was also assessed.

Materials and Methods

Mite colonies

Colony of *T. urticae* was maintained on leaves of *Phaseolus vulgaris* L. The plant leaves were put on water-saturated cotton pads in Petri dishes. Water was added as necessary to keep the cotton pads saturated.

Colony of the predatory mite *A. swirskii* was maintained on leaves of *P. vulgaris* infested with *T. urticae* as prey. The leaves were put on water-saturated cotton pads in Petri dishes. Water was added as necessary to keep the cotton pads saturated. The leaves margins were surrounded by wet cotton strips to prevent mite escaping.

All mite colonies were kept separately in the incubator at 28-30 ℃, 70-75 % RH and 16 L: 8 D photoperiod.

Lethal effect of coconut oil on *T. urticae*

Coconut oil used in the present study was a commercial oil purchased from El Captain Company for extracting natural oils, plants and cosmetics. The toxicity of coconut oil against *T. urticae* females was tested using direct spray method. The tested concentrations of coconut oil were chosen based on preliminary tests. The concentrations of coconut oil were prepared using distilled water; and Triton X-100 was used as an emulsifier. Females of *T. urticae* were transferred onto surfaces of leaf discs of *P. vulgaris* and sprayed with different concentrations of coconut oil using glass atomizer. Each leaf disc was put on a cotton pad placed inside a Petri dish (one leaf disc/dish). Control females of *T. urticae* were sprayed with distilled water. The Petri dishes were kept in an incubator at 28-30 ℃, 70-75 % RH and 16 L: 8 D photoperiod. Mortality of mite females was recorded at forty-eight hours after treatment. Mites that did not move after a gentle touch with a small fine brush were considered as dead. Five concentrations of coconut oil were tested. One Petri dish with one leaf disc was considered a replicate (Twenty-five females/replicate); each tested concentration had five replicates. Control had five replicates too. The experiment was repeated two times.

Sublethal effects of coconut oil on development and population parameters of the progeny from treated females of *T. urticae*

The sublethal effects of coconut oil were evaluated by comparing development and life table parameters of offspring of *T. urticae* females exposed to LC_{15} (0.347%), LC_{30} (0.538%) of coconut oil or distilled water (control). Each experimental unit consisted of a leaf disc of *P. vulgaris* placed on a cotton pad in a Petri dish. Wet cotton strips were surrounded the leaf discs margins to prevent mite escaping.

In this experiment, adult mated females of *T. urticae* were treated with distilled water (control), LC_{15} or LC_{30} of coconut oil as described in the section "Lethal effect of coconut oil on *T. urticae*". The treated females (from each treatment) were carefully transferred to new leaf discs (experimental units) individually and allowed to lay eggs for twenty-four hours. After 24 h, only one egg was kept on each experimental unit, by which the development was observed, while the additional eggs and mites were removed. The experimental units were kept in an incubator at 28-30 ℃, 70-75 % RH and 16 L: 8 D photoperiod. The eggs and subsequent stages of *T. urticae* were observed daily and their developmental duration were recorded until maturity. After reaching adulthood, every newly emerged female was paired with a male. The mated females were daily observed to determine their longevity and oviposition periods as well as recording the daily and total number of eggs laid by each female. However, all adult individuals of *T. urticae* were daily observed until their death. The numbers of *T. urticae* individuals (replications) subjected to the statistical analyses in the case of LC_{15}, LC_{30} of coconut oil and control were 25, 24 and 28, respectively.

Toxicity of coconut oil to the predatory mite *A. swirskii*

In this assay, the effect of LC_{15}, LC_{30}, and LC_{50} (estimated for *T. urticae*) of coconut oil on females' mortality of *A. swirskii* was tested.

Leaf discs of *P. vulgaris* were sprayed separately with the three tested concentrations of coconut oil (LC_{15}, LC_{30}, and LC_{50}; estimated for *T. urticae*), while distilled water was used to spray the control leaf discs using glass

atomizer. Each leaf disc was placed on a wet cotton pad in a Petri-dish (experimental unit). After that, predatory females were transferred to the treated or control discs. In this experiment, *T. urticae* was add to the control and treated leaf discs to serve as a food source for *A. swirskii* females. The experimental units were kept in an incubator at 28-30 °C, 70-75 % RH and 16 L: 8 D photoperiod. For each tested concentration and control, mortality of *A. swirskii* females was recorded at forty-eight hours after treatment. Each tested concentration of coconut oil had six replicates (fifteen females/replicate). Control had six replicates too. The experiment was repeated twice.

Data analysis

The concentrations-mortality response curve was obtained using Ldp-line computer program to estimate the lethal concentrations (LC_{15}, LC_{30}, LC_{50} and LC_{90}) of coconut oil for *T. urticae* females, along with slope ± SE. Mortality data for *A. swirskii* were corrected by Abbott's formula (Abbott 1925) [29].

The raw life history data of the individuals of *T. urticae* were analyzed according to the age-stage, two-sex life table theory (Chi and Liu 1985; Chi 1988) [30, 31] using TWOSEX-MS Chart program (Chi 2017) [32]. The age-stage specific survival rate (s_{xj}) (where x=age in days and j=stage), age-specific survival rate (l_x), age-specific fecundity (m_x), age-stage specific fecundity (f_{xj}), age-stage specific life expectancy (e_{xj}), and age-stage specific reproductive value (v_{xj}) as well as all population growth parameters including the intrinsic rate of increase (r), finite rate of increase (λ), net reproductive rate (R_0), gross reproductive rate (GRR), and mean generation time (T) were calculated using TWOSEX-MS Chart program (Chi 2017). The means and standard errors of all calculated biological and population growth parameters of *T. urticae* were estimated using the Bootstrap procedure with 100000 resampling; and the means were compared by the Paired Bootstrap test (Huang and Chi 2013) [33] using the TWOSEX-MS Chart program (Chi 2017).

Results and Discussion

Lethal effect of coconut oil on *T. urticae*

The obtained results indicated that coconut oil had acaricidal activity against *T. urticae* females (Table 1). The calculated values of LC_{50} and LC_{90} of coconut oil were 0.843 and 2.522%, respectively (Table 1). Similarly, Oliveira *et al.* (2017) [12] demonstrated that coconut oil was toxic to the eriophyid mite *A. guerreronis*. Along the same lines, previous studies have reported the toxicity of different plant oils to *T. urticae* (Motazedian *et al.* 2011; Momen *et al.* 2014) [34, 35].

Table 1: Lethal effect of coconut oil against *Tetranychus urticae* females.

*LC (%)		Lower – upper limits	Slope ± SE
LC_{50}	0.843	0.733 – 0.947	2.694 ± 0.255
LC_{90}	2.522	2.163 – 3.102	

*LC: Lethal concentration.

Developmental duration, longevity, and reproduction of *T. urticae*

The developmental duration, longevity, and reproduction of progeny of *T. urticae* females exposed to LC_{15}, LC_{30} of coconut oil or distilled water (control) were given in Table (2). The pre-adult development was significantly increased by the LC_{15} and LC_{30} treatments compared with the control (P<0.05). The pre-adult development continued 10.55, 10.89, and 11.56 days for control, LC_{15}, and LC_{30} treatments, respectively. However, the oil treatments significantly reduced the longevity of *T. urticae* females to 13.89 and 12.00 days for LC_{15} and LC_{30} treatments, respectively in compared to control (15.59 days) (P<0.05). Herein, the significantly minimum and maximum total life span of *T. urticae* were observed for LC_{30} (23.56 days) and control (26.14 days), respectively (P<0.05) (Table 2). In the same way, Al sendi *et al.* (2018) [13] reported that *Atropa belladonna* herbal extract reduced longevity and total life span of *T. urticae*. According to Havasi *et al.* (2019) [7], the treatment with LC_{10} and LC_{20} of pomegranate peels extract decreased longevity along with total life span of *T. urticae*, which is consistent with the present results.

Table 2: Developmental time (days), female longevity (days) and fecundity of offspring from females of *Tetranychus urticae* treated with coconut oil.

Parameters	Control	Coconut oil treatments	
		LC_{15}	LC_{30}
Egg (days)	4.27±0.22a	4.11±0.23b	4.31±0.25a
Larva (days)	2.18±0.11c	2.28±0.14b	2.5±0.13a
Protonymph (days)	1.95±0.10c	2.44±0.15a	2.38±0.12b
Deutonymph (days)	2.14±0.10b	2.06±0.10c	2.38±0.15a
Pre-adult (days)	10.55±0.23c	10.89±0.35b	11.56±0.35a
APOP (days)	1.05±0.05b	1.06±0.06b	1.19±0.10a
TPOP (days)	11.59±0.21c	11.94±0.35b	12.75±0.41a
Oviposition days	12.41±0.28a	11.17±0.54b	8.25±0.34c

Female longevity (days)	15.59±0.29a	13.89±0.52b	12.00±0.47c
Total fecundity (eggs/female)	63.82±1.76a	45.78±1.85b	31.12±1.26c
Total life span (days)	26.14±0.40a	24.78±0.55b	23.56±0.53c

APOP: adult pre-oviposition period; TPOP: total pre-oviposition period.
Means in each row followed by different letters are significantly different (P<0.05; Paired Bootstrap test with 100000 re-sampling).

In LC_{30} treatment, the adult pre-oviposition period (APOP) and total pre-oviposition period (TPOP) of *T. urticae* were significantly elongated in compared to control (all P's<0.05). Similarly, an increase in APOP was also reported by Havasi *et al.* (2019) [7] for *T. urticae* exposed to pomegranate peel extract in compared to control mites. Herein, the minimum oviposition days was observed for LC_{30} treatment (8.25 days), whereas the maximum oviposition days was recorded for control (12.41 days). A total of 63.82 eggs/female were produced by control females, while LC_{15} and LC_{30} treatments statistically decreased the total fecundity of *T. urticae* to 45.78 and 31.12 eggs/female, respectively (P<0.05) (Table 2). Likewise, *Thymus vulgaris* oil reduced longevity and fecundity of *T. urticae* (Chitgar *et al.* 2013) [11]. In agreement with the present results, other studies reported reduction in oviposition period and fecundity of *T. urticae* exposed to *A. belladonna* herbal extract (Al sendi *et al.* 2018) [13] and pomegranate peel extract (Havasi *et al.* 2019) [7]. Besides, previous researches revealed that different plant oils can cause a reduction in fecundity of tetranychid mites (El-Gengaihi *et al.* 1996; Refaat *et al.* 2002; Chitgar *et al.* 2013) [36, 37, 11]. However, decreasing fecundity of phytophagous mites may reduce damage level to host plants (Esmaeily *et al.* 2017) [38].

The age-stage, two-sex life table of *T. urticae*

Age-stage specific survival rates (s_{xj}) of offspring from *T. urticae* females treated with LC_{15} and LC_{30} of coconut oil were presented in Figure (1). Presently, the s_{xj} displaying the probability that a newly laid egg of *T. urticae* will survive to age x and stage j. An overlapping in these curves was observed as a result of the developmental rates variations among *T. urticae* individuals. The highest probability that the newly oviposited eggs of *T. urticae* survived to adult stage was 0.72, 0.67, and 0.79 for females and 0.28, 0.33, and 0.21 for males in the case of LC_{15}, LC_{30} of coconut oil, and control, respectively (Figure 1).

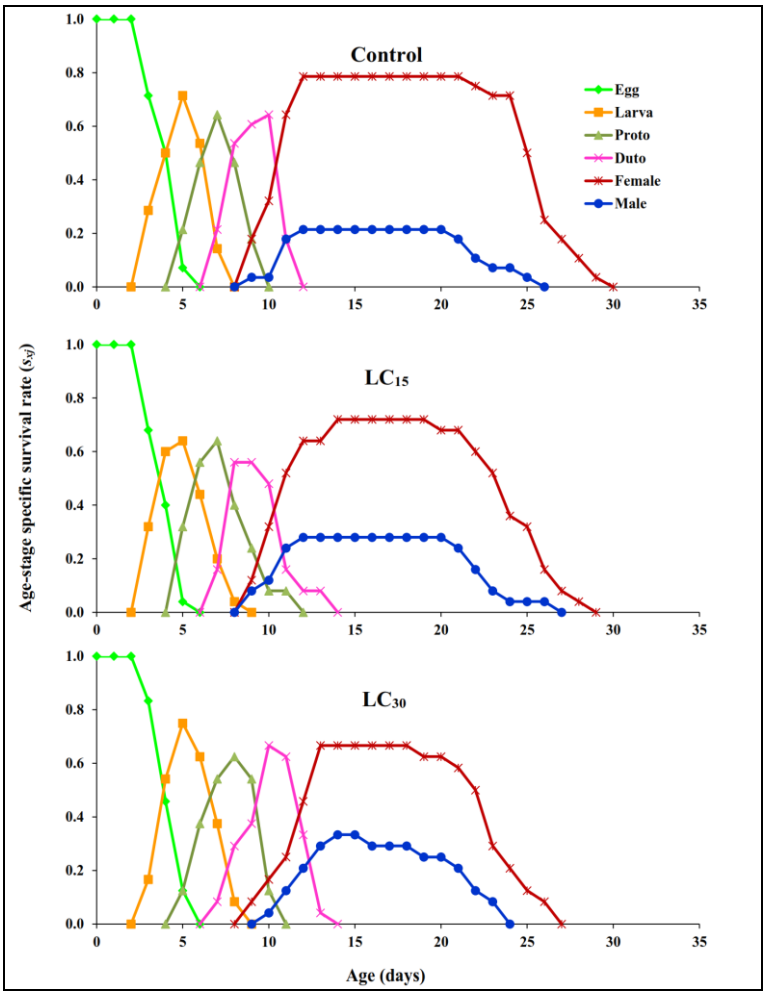

Fig 1: Age-stage specific survival rates (s_{xj}) of offspring from females of *Tetranychus urticae* treated with LC_{15} and LC_{30} of coconut oil.

The age-specific survival rate (l_x), age-specific fecundity (m_x), and age-stage-specific fecundity (f_{xj}) of offspring of *T. urticae* females treated with coconut oil as well as control mites were showed in Figure (2). The f_{xj} of *T. urticae* presented the number of eggs laid by *T. urticae* individuals of age *x* and stage *j*/day. Here, the maximum value of f_{xj} was 6.82 eggs/day for the control mites. However, this value was found to be 5.56 and 4.25 eggs/day for the mites in LC_{15} and LC_{30} treatments, respectively (Figure 2).

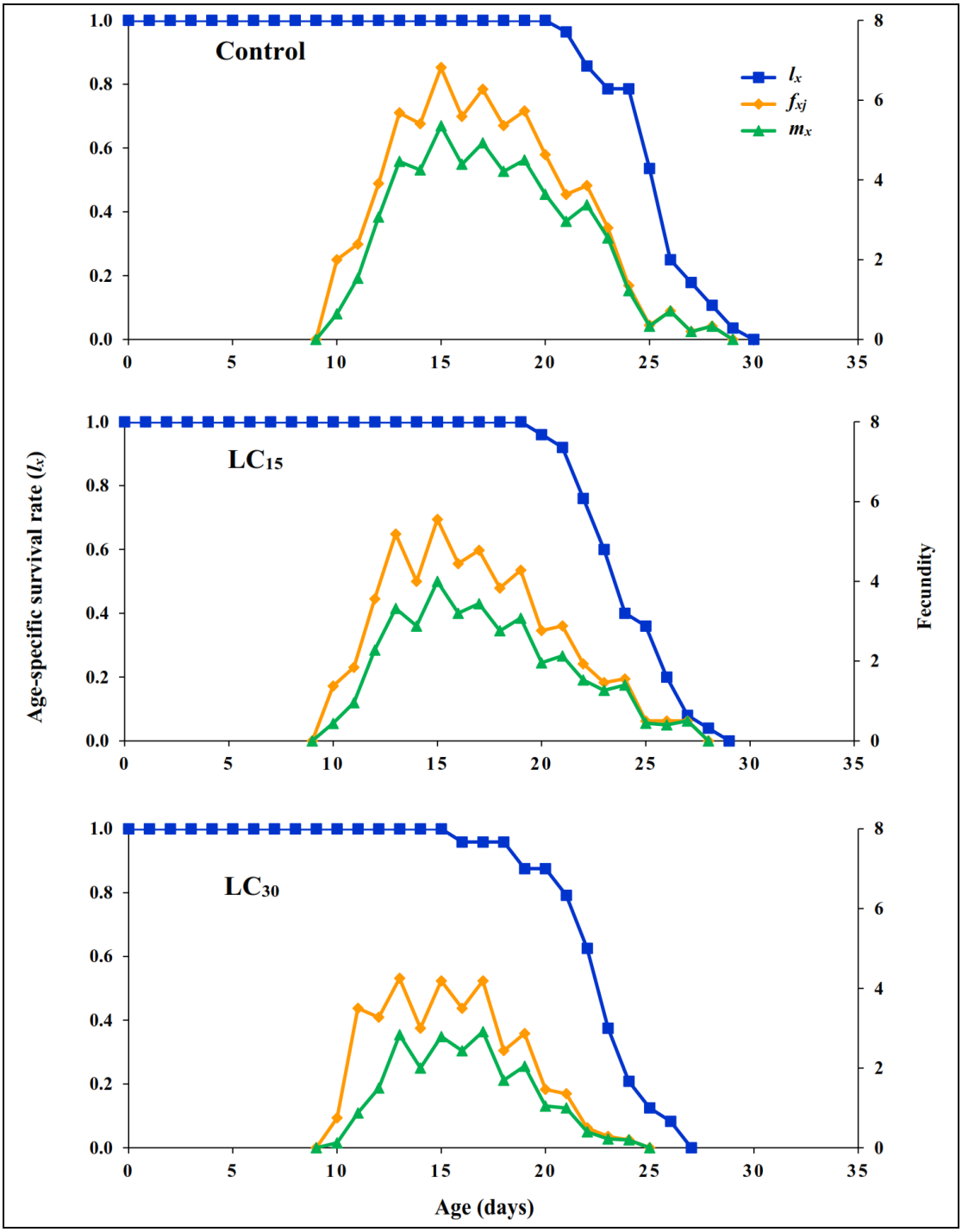

Fig 2: Age-specific survival rate (l_x), age-stage specific fecundity (f_{xj}), and age-specific fecundity (m_x) of offspring from females of *Tetranychus urticae* treated with LC_{15} and LC_{30} of coconut oil.

Age-stage specific life expectancy (e_{xj}) and age-stage specific reproductive value (v_{xj}) of progeny produced by *T. urticae* females treated with coconut oil were showed in Figures (3) and (4), respectively. The e_{xj} of *T. urticae* exhibited the expected length of time that *T. urticae* individuals of age *x* and stage *j* will survive. As seen from Figure (3), the maximum values of e_{xj} of *T. urticae* females were 15.78, 14.56, and 17.14 days for LC_{15}, LC_{30} of coconut oil and control, respectively. In addition, these values in the case of *T. urticae* males were 14.14, 11.38, and 14.17 days, respectively (Figure 3).

The v_{xj} of *T. urticae* displayed the contribution of *T. urticae* individuals of age *x* and stage *j* to the future population. The v_{xj} peaks of *T. urticae* occurred at the age of 13, 11 and 13 days for LC_{15}, LC_{30} of coconut oil and control, respectively (Figure 4). The aforementioned days showed the age at which *T. urticae* females exhibited the highest contribution to future population.

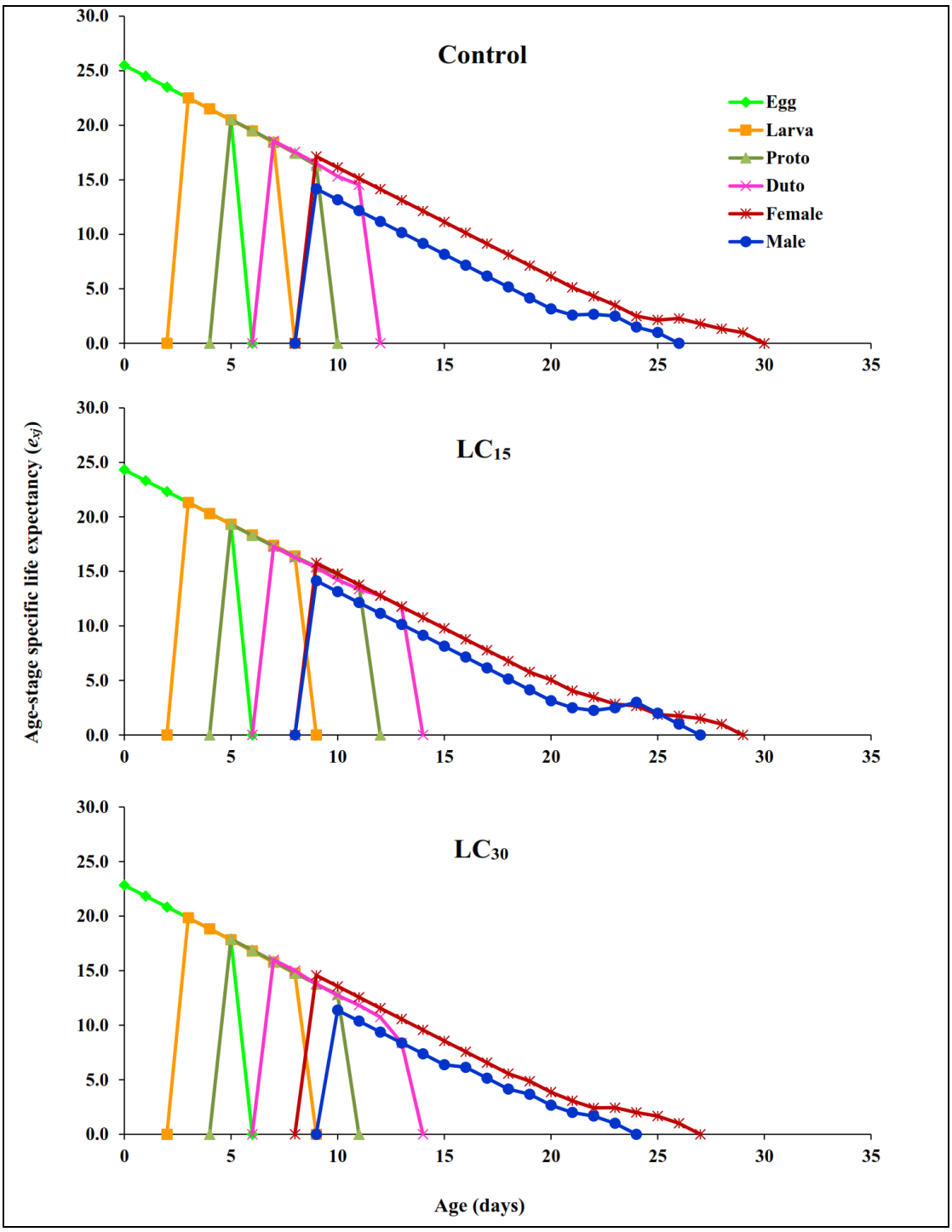

Fig 3: Age-stage specific life expectancy (e_{xj}) of offspring from females of *Tetranychus urticae* treated with LC_{15} and LC_{30} of coconut oil.

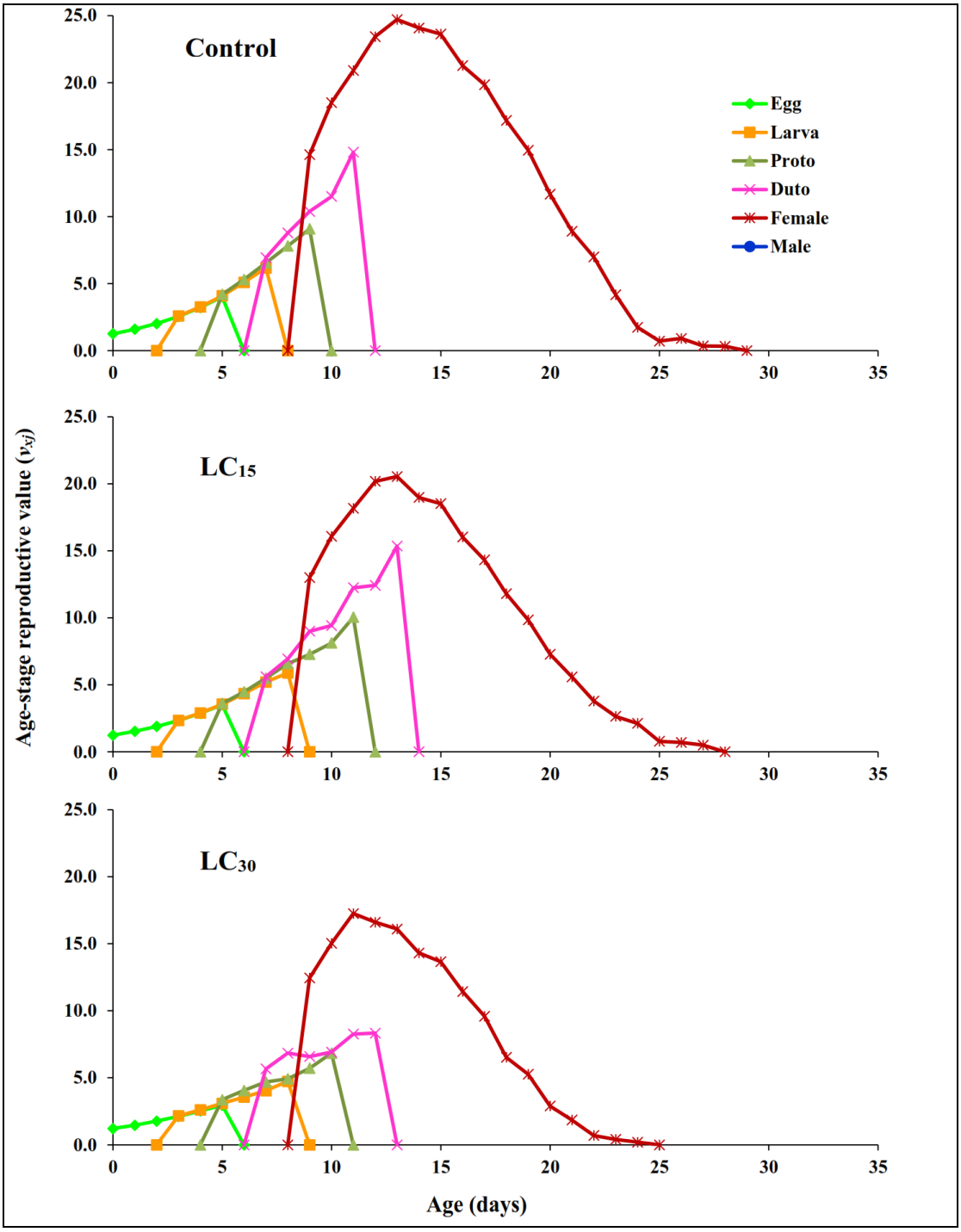

Fig 4: Age-stage specific reproductive value (v_{xj}) of offspring from females of *Tetranychus urticae* treated with LC_{15} and LC_{30} of coconut oil.

Population growth parameters of *T. urticae*

Studying the sublethal impacts of toxicants on life table parameters of target pests gives the most complete picture of the responses of pests populations to these toxicants (Esmaeily *et al.* 2017; Saber *et al.* 2018; Leviticus *et al.* 2020) [38, 39, 40]. Table (3) showed the life table parameters of progeny produced by *T. urticae* females treated with LC_{15} and LC_{30} of coconut oil in compared to control. The obtained results showed that all population growth parameters of *T. urticae* were significantly influenced by two tested concentrations of coconut oil (all *P*'s<0.05). The intrinsic rate of increase (*r*) is the best parameter that describes the influence of pesticides on pests' populations (Stark and Banks 2003) [41]. Presently, *r* values at LC_{15} and LC_{30} treatments (0.212 and 0.189 day^{-1}, respectively) were statistically lower than that in control (0.236 day^{-1}); indicating the negative impact of coconut oil on this parameter. In this context, it was found that various toxicants are able to reduce *r* value of pest population (Martinez-Villar *et al.* 2005; Chitgar *et al.* 2013; Li *et al.* 2017; Saber *et al.* 2018; Leviticus *et al.* 2020) [42, 11, 20, 39, 40], which was in line with the present findings. The mite population with a low *r*-value would develop much more slowly than that with a high *r*-value (Chitgar *et al.* 2013) [11]. In addition, the finite rate of increase (λ) ranged from 1.208 to 1.266 day^{-1} for *T. urticae* individuals in LC_{30} treatment and those

in control, respectively (Table 3). The values of R_0 and *GRR* were reduced by coconut oil treatments, being significantly higher for control mites (Table 3). Similar to the present results, a reduction in λ and R_0 parameters of *T. urticae* has been reported due to the treatment with azadirachtin (Martinez-Villar *et al.* 2005) [42] and *T. vulgaris* oil (Chitgar *et al.* 2013) [11]. Also, in Havasi *et al.* (2019) [7] study, pomegranate extract treatment showed an adverse impacts on *GRR* and R_0 parameters of *T. urticae*. The mean generation time (*T*) ranged from 16.069 to 16.618 day for *T. urticae* individuals in LC_{30} treatment and those in control, respectively (Table 3).

Table 3: Life table parameters (Mean±SE) of offspring from females of *Tetranychus urticae* treated with coconut oil.

Life table parameters	Control	Coconut oil treatments	
		LC_{15}	LC_{30}
Intrinsic rate of increase (*r*) (day^{-1})	0.236±0.008a	0.212±0.009b	0.189±0.013c
Finite rate of increase (λ) (day^{-1})	1.266±0.010a	1.236±0.012b	1.208±0.015c
Net reproductive rate (R_0) (offspring)	50.143±5.255a	32.960±4.325b	20.750±3.381c
Mean generation time (*T*) (day)	16.618±0.287a	16.477±0.292b	16.069±0.406c
Gross reproductive rate (*GRR*) (offspring)	52.690±5.267a	35.990±4.601b	22.09±3.349c

Means in each row followed by different letters are significantly different ($P<0.05$; Paired Bootstrap test with 100000 re-sampling).

Toxicity of coconut oil to the predatory mite *A. swirskii*

As clearly showed in Figure (5), the three tested concentrations (LC_{15}, LC_{30}, and LC_{50}; estimated for *T. urticae*) of coconut oil caused lower mortality to the predatory mite *A. swirskii* in compared to the pest (*T. urticae*). These results were in agreement with Oliveira *et al*. (2017) [12] who demonstrated that coconut oil was very toxic against the coconut mite *A. guerreronis* in addition to displaying significant selectivity to the predatory phytoseiid mite *Neoseiulus baraki* (Athias-Henriot). Also, Freitas *et al*. (2018) [43] found that the predatory phytoseiid mite *Typhlodromus ornatus* Denmark & Muma was more tolerant to coconut oil in compared with its mite prey *A. guerreronis*. In the same way, *Neoseiulus californicus* McGregor (Acari: Phytoseiidae) was found to be more tolerant to various plant oils than its prey *T. urticae* (Han *et al.* 2010; Ribeiro *et al.* 2016) [44,45]. Also, *A. swirskii* displayed a low sensitivity to sweet basil oil (Momen and Amer 2003) [46]. The variations in the morphological and physiological features, foraging behavior, and metabolism may be the reasons for the tolerance of predatory mites to plant oils as compared to pests (Cloyd *et al*. 2006; Lima *et al*. 2012; Momen *et al.* 2014) [47, 48, 35].

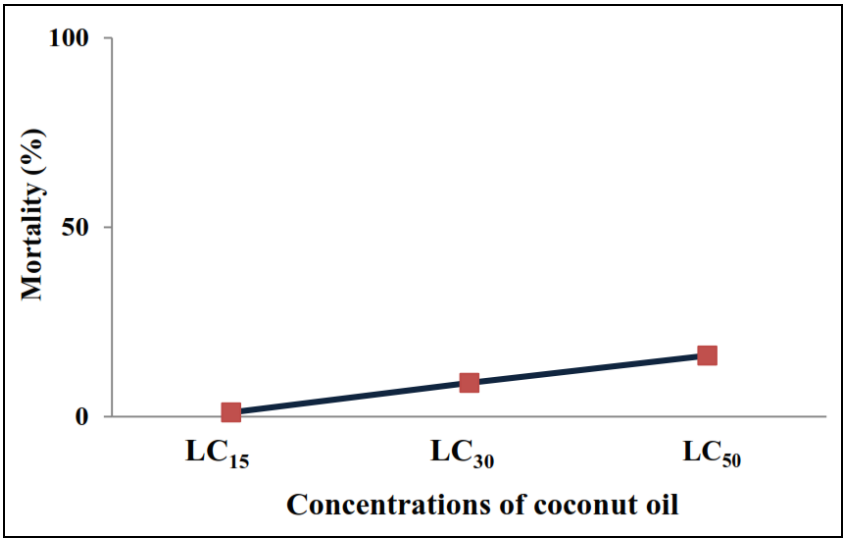

Fig 5: Toxicity effect of three concentrations (LC_{15}, LC_{30}, and LC_{50}; estimated for *T. urticae*) of coconut oil to females of the predatory mite *Amblyseius swirskii*.

Conclusion

The results of the present study provide valuable information about the possibility of utilizing coconut oil in the management of *T. urticae*. The treatment with coconut oil caused marked decrease in adult longevity, reproduction, and most of population growth parameters (*r*, λ, R_0, and *GRR*) of *T. urticae.* Therefore, this oil may have the ability to decrease *T. urticae* population. In addition, coconut oil appeared to be compatible with the phytoseiid mite *A. swirskii* as indicated by its relatively low toxicity to this predator. Overall, the present results suggested the possibility of using coconut oil in IPM programs of *T. urticae*. However, the current results stimulate further studies in the future that aiming to evaluate the efficiency of this oil on *T. urticae* under greenhouse and field conditions.

References

1. Cote KW, Lewis EE, Schultz PB. Compatibility of acaricide residues with *Phytoseiulus persimilis* and their effects on *Tetranychus urticae*. HortScience,2002:37:906-909.
2. Laborda R, Manzano I, Gamon M, Gavidia I, Pérez-Bermodez P, Boluda R. Effects of *Rosmarinus officinalis* and *Salvia officinalis* essential oils on *Tetranychus urticae* Koch (Acari: Tetranychidae). Industrial Crops and Products,2013:48:106-110.
3. Maleknia B, Fathipour Y, Soufbaf M. How greenhouse cucumber cultivars affect population growth and two-sex life table parameters of *Tetranychus urticae* (Acari: Tetranychidae). International Journal of Acarology,2016:42:70-78.
4. Knowles CO. Mechanisms of resistance to acaricides. In: Sjut, Volkert (Ed.), Molecular mechanisms of resistance to agrochemicals. Springer, Berlin, 1997, 57-77.
5. Bugeme DM, Knapp M, Ekesi S, Chabi-Olaye A, Boga HI, Maniania NK. Efficacy of *Metarhizium anisopliae* in controlling the two-spotted spider mite *Tetranychus urticae* on common bean in screenhouse and field experiments. Insect science,2015:22:121-128.
6. Garriga M, Caballero J. Insights into the structure of urea-like compounds as inhibitors of the juvenile hormone epoxide hydrolase (JHEH) of the tobacco hornworm *Manduca sexta*: analysis of the binding modes and structure–activity relationships of the inhibitors by docking and CoMFA calculations. Chemosphere,2011:82:1604-1613.
7. Havasi M, Kheradmand K, Parsa M, Riahi E. Acaricidal activity of *Punica granatum* L. peels extract against *Tetranychus urticae* Koch (Acari: Tetranychidae), Archives of Phytopathology and Plant Protection,2019:52:1215-1228.
8. Duke SO, Cantrell CL, Meepagala KM, Wedge DE, Tabanca N, Schrader KK. Natural toxins for use in pest management. Toxins (Basel),2010:2:1943-1962.
9. Ebadollahi A, Ziaee M, Palla F. Essential oils extracted from different species of the Lamiaceae plants family as prospective bioagents against several detrimental pests. Molecules,2020:25:1556.
10. Pavela R. Extract from the roots of *Saponaria officinalis* as a potential acaricide against *Tetranychus urticae*. Journal of Pest Science,2017:90:683-692.
11. Chitgar MG, Khosravi R, JalaliSendi J, Ghadamyari M. Sublethal effects of *Thymus vulgaris* essential oil on life-table parameters of two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), Archives of Phytopathology and Plant Protection,2013:46:781-788.
12. Oliveira NN, Galvao AS, Amaral EA, Santos AW, Sena-Filho JG, Oliveira EE *et al*. Toxicity of vegetable oils to the coconut mite *Aceria guerreronis* and selectivity against the predator *Neoseiulus baraki*. Experimental and Applied Acarology,2017:72:23-34.
13. Al sendi A, Havasi M, Bozhgani NSS. Sublethal effects of *Atropa belladonna* herbal extract on biological performance of the two-spotted spider mite *Tetranychus urticae* Koch (Acari: Tetranychidae). Journal of Agricultural Science,2018:10:230-241.
14. Marina AM, CheMan YB, Amin I. Virgin coconut oil: emerging functional food oil. Trends in Food Science and Technology,2009:20:481-487.
15. Parry WH, Rose R. The role of fatty acids and soaps in aphid control on conifers. Zeitschrift fur Angewandte Entomologie,1983:96:16-23.
16. Sims SR, Balusu RR, Ngumbi EN, Appel AG. Topical and vapor toxicity of saturated fatty acids to the German cockroach (Dictyoptera: Blattellidae). Journal of Economic Entomology,2014:107:758-763.
17. Robertson JL, Worner SP. Population toxicology: Suggestions for laboratory bioassays to predict pesticide efficacy. Journal of Economic Entomology,1990:83:8-12.
18. Kim M, Shin D, Suh E, Cho K. An assessment of the chronic toxicity of fenpyroximate and pyridaben to *Tetranychus urticae* using a demographic bioassay. Applied Entomology and Zoology, 2004: 39:401-409.
19. Kim M, Sim C, Shin D, Suh E, Cho K. Residual and sublethal effects of fenpyroximate and pyridaben on the instantaneous rate of increase of *Tetranychus urticae*. Crop Protection,2006:25:542-548.
20. Li YY, Fan X, Zhang GH, Liu YQ, Chen HQ, Liu H *et al*. Sublethal effects of bifenazate on life history and population parameters of *Tetranychus urticae* (Acari: Tetranychidae). Systematic and Applied Acarology,2017:22:148-158.
21. McMurtry JA, de Moraes GJ, Sourassou NF. Revision of the life styles of phytoseiid mites (Acari: Phytoseiidae) and implications for biological control strategies. Systematic and Applied Acarology,2013:184:297-320.
22. Messelink GJ, Van Steenpaal EF, Ramakers PMJ. Evaluation of phytoseiid predators for control of western flower thrips on greenhouse cucumber. BioControl,2006:51:753-768.
23. Abou-Awad BA, Hafez SM, Farhat BM. Biological studies of the predacious mite *Amblyseius swirskii*, a predator of the broad mite *Polyphagotarsonemus latus* on pepper plants (Acari: Phytoseiidae: Tarsonemidae). Archives of Phytopathology and Plant Protection,2014:47:349-354.
24. Nemati A, Riahi E, Moghadam KA, Gwiazdowicz DJ, Bahari MR, Amini P. Comparison of different pollen grains and a factitious prey as food sources for *Amblyseius swirskii* (Acari: Phytoseiidae). Systematic and Applied Acarology,2019:24:2427-2438.
25. Fahim SF, El-Saiedy EM. Life table parameters of *Amblyseius swirskii* and *Neoseiulus californicus* (Acari: Phytoseiidae) reared on two strawberry cultivars. International Journal of Acarology,2021:47: 568-574.

26. Calvo FJ, Bolckmans K, Belda JE. Control of *Bemisia tabaci* and *Frankliniella occidentalis* in cucumber by *Amblyseius swirskii*. BioControl,2011:56:185-192.
27. Piyani AR, Shishehbor P, Kocheili F, Riddick EW. Comparison of natural prey *Tetranychus turkestani*, date palm pollen, and bee pollen diets on development, reproduction, and life table parameters of the predator *Amblyseius swirskii*. Acarologia,2021:61:890-900.
28. Pavela R, Benelli G. Essential oils as ecofriendly biopesticides? Challenges and constraints. Trends Plant Science,2016:21:1000-1007.
29. Abbott WS. A method of computing the effectiveness of an insecticide. Journal of Economic Entomology,1925:18:265-267.
30. Chi H, Liu H. Two new methods for the study of insect population ecology. Bulletin of the Institute of Zoology,1985:24:225-240.
31. Chi H. Life-table analysis incorporating both sexes and variable development rates among individuals. Environmental Entomology,1988:17:26-34.
32. Chi H. TWO SEX-MS Chart: A computer program for the age- stage, Two-sex life table analysis, 2017. http://140.120.197.173/Ecology/Download/TwosexMSChart.zip
33. Huang YB, Chi H. Life tables of *Bactrocera cucurbitae* (Diptera: Tephritidae): with an invalidation of the jackknife technique. Journal of Applied Entomology,2013:137:327-339.
34. Motazedian N, Ravan S, Bandani A. Toxicity and repellency effects of three essential oils against *Tetranychus urticae* Koch (Acari: Tetranychidae). Journal of Agricultural Science and Technology,2011:14:275-284.
35. Momen FM, Abdel Rahman HA, Samour EA, Aly SM, Fahim SF. Acaricidal activity of *Melissa officinalis* oil and its formulation on *Tetranychus urticae* and the predatory mite *Neoseiulus californicus* (Acari: Tetranychidae and Phytoseiidae). Acta Phytopathologica et Entomologica Hungarica,2014:49:95-115.
36. El-Gengaihi S, Amer S, Mohamed S. Biological activity of Thyme oil and Thymol against *Tetranychus urticae* Koch. Anzeiger für Schadlingskunde, Pflanzenschutz, Umweltschutz,1996:69:157-159.
37. Refaat M, Momen M, Amer SAA. Acaricidal activity of sweet basil and french lavender essential oils against two species of mites of the family Tetranychidae (Acari: Tetranychidae). Acta Phytopathologica et Entomologica Hungarica,2002:37:287-298.
38. Esmaeily M, Bandani A, Zibaee I, Sharifian I, Zare S. Sublethal effects of *Artemisia annua* L. and *Rosmarinus officinalis* L. essential oils on life table parameters of *Tetranychus urticae* (Acari: Tetranychidae). Persian Journal of Acarology,2017:6:39-52.
39. Saber M, Ahmadi Z, Mahdavinia G. Sublethal effects of spirodiclofen, abamectin and pyridaben on life-history traits and life-table parameters of two-spotted spider mite, *Tetranychus urticae* (Acari: Tetranychidae). Experimental and Applied Acarology,2018:75:55-67.
40. Leviticus K, Cui L, Ling H, Jia ZQ, Huang QT, Han ZJ, Xu L. Lethal and sublethal effects of fluralaner on the two-spotted spider mites, *Tetranychus urticae* Koch (Acari: Tetranychidae). Pest Management Science,2020:76:888-893.
41. Stark JD, Banks JE. Population-level effects of pesticides and other toxicants on arthropods. Annual Review of Entomology,2003:48:505-519.
42. Martinez-Villar E, Saenz-De-Cabezon FJ, Moreno-Grijalba F, Marco V, Pérez Moreno I. Effects of azadirachtin on the two-spotted spider mite, *Tetranychus urticae* (Acari: Tetranychidae). Experimental and Applied Acarology,2005:35:215-222.
43. Freitas GSD, Santos MCD, Lira VDA, Galvão AS, Oliveira EE, Filho JGDS *et al*. Acute and non-lethal effects of coconut oil on predatory mite *Typhlodromus ornatus* (Acari: Phytoseiidae). Systematic and Applied Acarology,2018:23:1333-1341.
44. Han J, Choi BR, Lee SG, Kim S, Ahn YJ. Toxicity of plant essential oils to acaricide susceptible and-resistant *Tetranychus urticae* (Acari: Tetranychidae) and *Neoseiulus californicus* (Acari: Phytoseiidae). Journal of Economic Entomology,2010:103:1293-1298.
45. Ribeiro N, Camara C, Ramos C. Toxicity of essential oils of *Piper marginatum* Jacq. against *Tetranychus urticae* Koch and *Neoseiulus calif*ornicus (McGregor). Chilean Journal of Agricultural Research,2016:76:71-76.
46. Momen FM, Amer SAA. Influence of the sweet basil, *Ocimum basilicum* L. on some predacious mites of the family Phytoseiidae. Acta Phytopathologica et Entomologica Hungarica,2003:38:137-143.
47. Cloyd RA, Galle CL, Keith SR. Compatibility of three miticides with the predatory mites *Neoseiulus californicus* McGregor and *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae). HortScience,2006:41:707-710.
48. Lima DB, Melo JWS, Gondim JMGC, Moraes GJ. Limitations of *Neoseiulus baraki* and *Proctolaelaps bickleyi* as control agents of *Aceria guerreronis*. Experimental and Applied Acarology,2012:56:233-246.