Chapter

# Biological Control of Tetranychidae by Considering the Effect of Insecticides

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## Abstract

Spider mites (family Tetranychidae) are important pests of many agricultural, medicinal and ornamental plants worldwide. They possess needle-like chelicerae which pierce plant cells, often feeding on chloroplasts on the under surface of the leaf and cause upper leaf surfaces develop whitish or yellowish stippling. Additionally spider mites produce silk webbing which covers the leaves. In this chapter we present common control methods of these mites including biological control with emphasizing on the prey preference, switching behavior and mutual interference of a biological control agent, *Phytoseius plumifer* (Canestrini and Fanzago). Additionally the side effects of two acaricides, abamectin and fenpyroxymate, on this predator will be discussed.

**Keywords:** Phytoseiidae, *Tetranychus urticae*, sublethal dose, abamectin, fenpyroxymate

## 1. Introduction

Spider mites (family Tetranychidae) contains many species that are important pests of agricultural crops. According to Migeon & Dorkeld [1], who provided a database for spider mites of the world, 1300 species had been described until now. Practically all the major food crops and many ornamental plants are subject to attack [2]. Tetranychid mites feed by penetrating the plant tissue with sharp cheliceral stylets and removal of the cell contents. The chloroplasts disappear and the small amount of remaining cellular material coagulates to form an amber mass. The amount of chlorophyll in the leaves may be decreased as much as 60 percent. The mite feeding also causes inhibition of photosynthesis. Small chlorotic spots can be found at feeding sites as the mesophyll tissue collapses due to the destruction of 18–22 cells per minute. Additionally they produce silk webbing which covers the leaves. Continued feeding leads to irregular spots formed by the integration of primary suction spots; finally the leaves turn yellow, gray or bronze. In the case of sever infestation the death of plants occur [3].

A rapid rate of mite development and high reproductive abilities allow spider mites to reach harmful population levels very quickly when the conditions for growth are permissive. A great number of experimental work has been directed toward the control of these mites since they have become resistant to a number of pesticides and their control has become very difficult. Moreover, chemical

suppression of mite populations leads to residues on crops, environmental contaminations and toxicity to humans and non-target organisms. For these reasons, research has increasingly been performed to identify alternative methods to chemical control [4].

## 2. Tetranychidae control Methods

### 2.1 Chemical control

Prior to world war II, spider mites were minor pests of agricultural crops. This changed rapidly after war, with the extensive use of chemical pesticides, such as DDT [5]. The chemical acaricides used to control Tetranychidae are characterized by a large variety of chemical structures and mode of actions which were reviewed by Attia et al. [6], Knowles [7] and Dekeyser [8]. A pesticide may have both direct and indirect effects on Tetranychidae. Some may kill immediately, while other pesticides take longer to kill. Others may affect mite performance by inhibiting movement and reducing searching ability or lowering oviposition rates. In addition some pesticides (such as carbaryl and DDT) have a stimulatory effect on spider mite reproduction when present in low concentrations. The stimulatory effect on mite reproduction is called hormoligosis. Hormoligosis is an ongoing problem, although it may not be recognized [9]. The chemical control of these mites has become increasingly difficult because of their short life cycle, abundant progeny and arrhenotokous reproduction system. The repeated use of pesticides can lead to the development of resistant population and also can disrupt the natural control of Tetranychidae. Because of its resistance to a large number of chemical compounds, the two-spotted spider mite, *Tetranychus urticae* Koch, is considered most resistant species nearly in all over the world [10].

### 2.2 Cultural control

Cultural control involve all agronomic practices that are intended to reduce pest population. Cultural practices include changing the time of planting and harvest to avoid or minimize pest damage. It is known that high humidity reduce the reproductive potential of Tetranychidae whose optimal environment is hot and dry air [11]. Proper management of temperature and humidity can be useful to reduce pests' populations in greenhouses. Managing fertilizer applications is another important cultural practice. Large quantities of nitrogen or deficiency of potassium can increase the amount of soluble nitrogen available in the plant so that cause population increase of *T. urticae* [11]. In our previous work on the effect of fertilizer Fosfalim-k application on cucumber and its effect on population growth of *T. urticae* we showed that its application in the recommended dose had a controlling effect [12].

Another example of cultural control is dust management. Dust management is important for control of Tetranychidae, especially in climates that crop irrigation occurs. Whether the dust makes the foliage more suitable for spider mites or interferes with the spider mites predators' performance is in controversy. The elimination of crop residues is another way that can destroy pests and prevent transferring to subsequent crops. Crop rotation and polycropping are other methods that can be used to manage pest population. It is not clear that polycropping is useful in phytophagous mites control but if natural enemies are retained in the crops it could be helpful [9]. In our previous work we showed that the intercropping of sunflower and soybean increased natural enemies compared with monocultures [13].

### 2.3 Host plant resistance

Host plant resistance along with cultural control, is a component of any pest management program. Resistance of plants to pests enables them to avoid or inhibit host selection, inhibit oviposition and feeding, reduce pest survival and development and tolerate or recover from injury of pests that would cause greater damage to other plants of the same species under similar environmental conditions [14, 15]. Three mechanisms of plant resistance to pests have been categorized by Horber [16]: antixenosis, antibiosis and tolerance. Antixenosis describe the inability of a plant to serve as a host to a pest. The basis of this resistance mechanism can be morphological (e.g. leaf hairs, surface waxes and tissue thickness) or chemical (e.g. repellents or antifeedants). Antibiosis is the mechanism that describe the negative effects of a resistant plant on the biology of a pest which has colonized on the plant (e.g. adverse effects on development, survival and reproduction). Both morphological and chemical characteristics of plants can induce antibiosis. Tolerance is the degree to which a plant can tolerate a pest population that under similar conditions would severely damage a susceptible plant [17]. Resistance against spider mites is known to occur in many crops, including melon, pepper, soybean, cotton, cucumber, bean, eggplant and tomatoes. Resistant cultivars can be discovered by comparing mite populations on different crop varieties grown under the same conditions with equivalent initial mite populations [9]. We discovered the antibiosis mechanism of resistance to *T. urticae* in pepper varieties (unpublished data).

### 2.4 Biological control

Biological control is the use of natural enemies to manage pests' populations. Natural enemies are very important agents in reducing or regulating populations of pests and include parasitoids, predators and pathogens. A parasitoid is an organism that spends its larval stage in or on another organism, also known as a host. The larval parasitoid feeds only on the host as it develops, eventually killing the host. There are no report of mite's parasitoids. Predators are free living organisms, each of which will consume a number of pests (prey) in their lifespan. More than 65 predators have been recorded for European red mite, *Panonychus ulmi* (Koch), alone. Among the more important of these biological agents are predatory mites and insects, but others include spiders and disease-producing pathogens [3]. Three major methods exist for the use of natural enemies: conservation, classical biological control and augmentation.

Conservation seeks to identify and rectify negative influences of human activities that suppress natural enemies and to enhance agricultural fields as habitats for natural enemies. In conservation, the assumption is that the species of natural enemies already exist locally and have potential to effectively control the pest if given an opportunity to do so [18]. Classical biological control involves importation, evaluation, release and permanent establishment of natural enemies in the environment from the area of origin of a foreign pest. It assume that natural enemies from the area of the pest's origin will be more effective than natural enemies in the pest's new environment [9]. Augmentation involves the mass rearing and release of natural enemies to control target pest. The natural enemies must be capable of being mass reared and must be released at an appropriate time and in sufficient number to be effective. Two approaches are taken in augmentation. Inoculation involves releasing small number of natural enemies early in crop cycle with the expectation that they will reproduce and their offspring will provide pest control for an extended period of time. Inundation involves releasing large number of natural enemies for immediate control of pest when insufficient reproduction of the released natural enemies is likely to occur [18].

We found predatory mites from families Phytoseiidae, Ameroseiidae, Parasitidae, Stigmaeidae, Anystidae and Bdellidae as natural enemies of Tetranychidae during our sampling from Northwestern Iran (2007–2008). Among predator insects, we found *Stethorus gilvifrons* Mulsant (Col.: Coccinellidae), *Oenopia conglobata* (Linnaeus) (Col.: Coccinellidae), *Exochomus quadripustulatus* (Linnaeus) (Col.: Coccinellidae), *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae), *Scolothrips* sp. (Thysanoptera: Thripidae) and *Orius horvathi* Reuter (Het.: Anthocoridae). Among the predatory mites that we found, here we describe, *Phytoseius plumifer* (Acari: Phytoseiidae), which we have been worked on it.

Predaceous mites of the family Phytoseiidae are important natural enemies of several phytophagous mites and other pests on various crops. Phytoseiid mites occur throughout the world. Several authors have considered *Phytoseius plumifer* among the most important predators of phytophagous mites infesting fruit trees [19]. Before using natural enemies in biological control programs, it is essential to evaluate their efficiency and therefore, knowledge of the behavioral attributes of *P. plumifer* is essential for understanding the efficiency of this predator in the biological control of two-spotted spider mite.

### *2.4.1 Prey stage preference, switching and mutual interference of* Phytoseius plumifer

Prey stage preference may affect prey–predator population dynamics, if the prey stage affects the development and reproduction of the predator. Prey preference by biological control agents can affect their ability to effectively control target pests too [20]. Preference may vary with the relative abundance of two prey types, in which case if the predator or parasitoid eats or oviposits in disproportionately more of the more abundant type, it is said to display switching behavior. In other words, switching is a behavioral phenomenon whereby a predator alters its preference for the prey species or type as prey relative densities change [21]. Murdoch et al. [22] found that switching could result from several different mechanisms including when (1) the predator develops a search image for the prey type with the highest relative abundance, (2) capture success on a prey type increases with increase in its relative abundance and (3) when the predator's habitat contains sub-habitats that are occupied by different prey types.

Aggregation of predators in space to prey patches causes the prey–predator interaction occur and searching efficiency to decrease with increasing predator density. Inverse density dependence in searching efficiency is known as predator interference or mutual interference. However, it was found that increasing the number of biological control agents released into an environment did not always increase the level of pest control [23]. This occurs when parasites/predators that are searching for a host/prey encounter each other, which can cause one or both to stop searching and possibly leave the area [24].

In our previous work we determined some aspects of the behavioral characteristics of *P. plumifer* on the two-spotted spider mite. We studied the preference of *P. plumifer* for different life stages of the two-spotted spider mite under choice and no-choice conditions. Switching of *P. plumifer* was tested with deutonymphs and larvae of the prey with different ratios too. Also, since the success of a predator in biological control programs is dependent on its behavior under the presence of other con-specific individuals, we investigated the mutual interference of *P. plumifer* in different densities of predator mites [25].

*2.4.1.1 Materials and methods*

*2.4.1.1.1 No-choice experiment*

In the feeding tests, we offered a total of 30 prey individuals of egg, larva, protonymph, deutonymph, male and female separately to a 24 h starved unmated female predator on soybean leaf arena and then allowed each predator to feed on the prey individuals for a total of 24 h. At the end of the experiment we estimated the number of prey individuals consumed per predator on each life stage of the prey.

*2.4.1.1.2 Choice experiment*

In this experiment we exposed total of 30 prey items i.e. equal number (5) of all stages of *T. urticae* (egg, larva, protonymph, deutonymph, male and female) to the predator females.

*2.4.1.1.3 Switching*

Switching of *P. plumifer* was tested with deutonymphs and larvae of the prey. Deutonymphs (D) and larvae (L) of *T. urticae* were presented in five different ratio treatments: 30 L:70D, 40 L:60D, 50 L:50D, 60 L:40D and 70 L:30D. The total prey number was 30. For evaluating the value of selectivity the following equation were used:

$$C = E_1 / E_2 \tag{1}$$

where $E_1$ and $E_2$ are the proportion of larvae and deutonymphs killed in 50 L:50D ratio, respectively. To find the expected ratio of killed larvae and deutonymphs in no-choice position the obtained data were analyzed by Murdoch [22] formula as follow:

$$Y = C_x / \left(1 - X + C_x\right) \tag{2}$$

where $C_x$ is $C\times$ ratio of stage and $X$ is the ratio of a prey stage on a leaf disc.

*2.4.1.1.4 Mutual interference*

In this experiment, 160 immature individuals (larvae and protonymphs) of *T. urticae* were placed on each leaf arena. In the next step, female predators at densities of 1, 2, 4, 8 and 16 per leaf arena were allowed to search the prey for 24 h. After this time period, the predators were removed from the arena and the number of eaten preys was counted. Finally, the per capita searching efficiency ($a$) of the predator at different densities was calculated according to the Nicholson [26] equation as follows:

$$a = \left(1 / PT\right) \ln\left(N_t / \left(N_t - N_a\right)\right) \tag{3}$$

where $N_t$ is the total number of available prey (160), $N_a$ is the total number of eaten preys, $P$ is the number of predators, and $T$ is the duration of the experiment (set to 1.0 for one day).

The calculated searching efficiency (*a*) was fitted against predator density (both on a logarithmic scale). The points were fitted to a linear regression by the least square method, according to the inductive model given by Hassell and Varley [27] as follows:

$$a = QP^{-m} \text{ or } \log a = \log Q - m \log P \quad (4)$$

where a is the searching efficiency of the predators, *Q* is the quest constant, and m includes only the component of interference due to behavioral interactions between predators [28].

*2.4.1.2 Results*

Our results indicated that in our no-choice preference experiments the predation preference of this predator on the different stages of *T. urticae* was as follow: eggs >protonymphs>larvae>males>deutonymphs>females of *T. urticae*. The preferred stage of two-spotted spider mite in choice preference experiments was protonymph. There was no tendency to the adult females of *T. urticae* in our results maybe because of their big size and the feeding rate was zero. Females of the predator killed more larvae than deutonymphs in switching experiments and they preferred larval stage compared to deutonymphs. There was positive switching behavior of predator for larval stage of prey at all ratios except 40%Larva: 60%Deutonymph (**Figure 1**) maybe because of their smaller size.

The values of total predation rate of *P. plumifer* were significantly different at different densities of the predator and the highest and lowest values of this parameter were recorded at 16 and 1 density of this predator, respectively. Furthermore, the per capita predation rate decreased to 1/4 with increasing the predator density from 1 to 16 and consequently the per capita searching efficiency also decreased significantly. According to results of Murdoch et al. [22] mechanisms one and two appear likely for our predator and capture increases on a prey type with increasing in its relative abundance.

The linear relationship between the natural logarithm of the predator density and the natural logarithm of per capita searching efficiency in mutual interference analysis has been demonstrated a negative slope. The negative value of the


**Figure 1.**
*Switching behavior of* Phytoseius plumifer *females to different ratios of larval stage and deutonymph of* Tetranychus urticae.

interference coefficient in the mutual interference analysis showed an inverse relationship between the predator density and per capita searching efficiency and this fact revealed that the searching efficiency of *P. plumifer* significantly decreased with increasing predator density as a result of mutual interference. For most augmentative biological control agents, there is an optimal release rate that produces effective control of a pest species. Increasing the release rate above the optimal rate does not improve the control of pest species and is potentially economically detrimental [29]. In our study although with an increasing number of predators, greater numbers of preys have been consumed but, a doubling in the number of predator employed for *T. urticae* predation did not result in a doubling in the number of mite consumed, because of mutual interference. A significant decrease of the number of prey consumed per predator with an increased predator density suggests that interference among predators also increase at higher predator density. This is probably due to a closed experimental arena with limited predation time and high probability of mutual interference. However, under field conditions, factors such as large searching areas, the effects of other predator species, spatial complexity, and weather may affect the effectiveness of natural enemies [30].

### *2.4.2* Phytoseius plumifer *performance feeding on corn pollen*

Although phytoseiid mites have been mainly described as predators of mites and small insects, several species can feed and reproduce on pollen as well. The potential of phytoseiids to regulate phytophagous mites at low equilibrium densities has been more attended recently and studies have examined some of the characteristics that contribute to the survival of populations at low prey densities, such as feeding on pollens [31]. Pollen is utilized as an easy food source for phytoseiid mites rearing and also has been recognized as an important factor in the successful biological control of spider mites [32].

McMurtry and Croft [31] categorized the life style of phytoseiids based on feeding habitats and related biological and morphological traits. The life styles are: Type I, specialized predators of *Tetranychus urticae*; Type II, selective predators of tetranychids; Type III, generalist predators that may feed on pollen but perform better on prey; Type IV, specialized pollen feeders-generalist predators. *Phytoseius* species are categorized as Type III predators. Knowledge of the nutritional value of different plant pollens for *P. plumifer* could be important not only for mass rearing of the mite, but also for a better understanding of its population dynamics in the field.

In our previous work we described the effect of corn pollen on the life table parameters of *P. plumifer* at laboratory conditions according to Carey [33] method. We showed that *P. plumifer* can develop and reproduce on corn pollen under laboratory conditions, so the predator can persist in the field when its main prey is scarce or absent. Survival rate was 97% at immature stages and adult females appeared in 10th day and started laying eggs. On day 16 a sharp decline observed in survival curve and all of individuals died until 20th day (**Figure 2**). By comparing with Hamedi et al. [34] results we can conclude that corn pollen as lonely food source increases longevity of immature stages and decreases longevity and fecundity of adults of the predator considerably, although the predator can develop and reproduce successfully.

### *2.4.3 Side effect of acaricides on phytoseiid mites with an emphasis on* Phytoseius plumifer

Use of pesticides cannot be eliminated in a short period of time in perennial crops because phytoseiid mites, as the most important predators of phytophagous mites, might not be able to maintain the spider mite populations below the

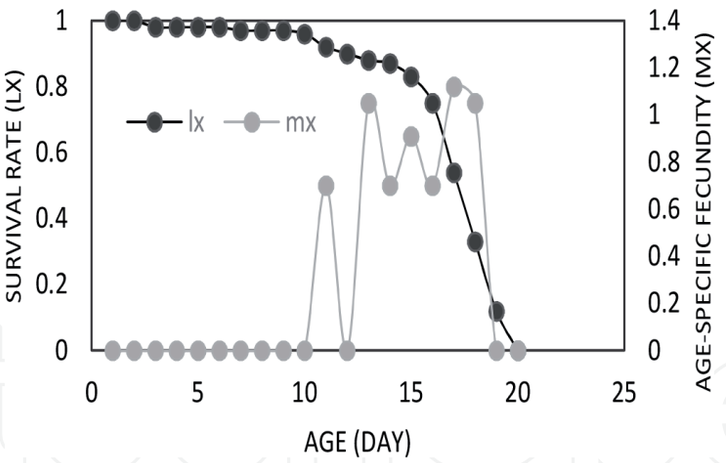


**Figure 2.**
*The age specific survival ($l_x$) and age-specific fecundity ($m_x$) (♀/♀) of* Phytoseius plumifer *on corn pollen.*

economically acceptable level on their own. Therefore successful utilization of biological control agents could depend on the compatibility of the natural predators with pesticides [35]. Most of the phytoseiid mites that naturally occur on plants, even in the absence of tetranychids, are generalist predators [36] and must be preserved using selective plant protection products [37]. Studying the side-effects of pesticides on natural enemies, including predaceous mites is an important task in pest management program, however, the use of pesticides remains necessary due to inadequate control achieved by natural enemies. The combination of biological and chemical control as an IPM program is only possible when the side-effects of pesticides on natural agents are well known [38].

Any indirect effects, which are referred to as sublethal, latent, or cumulative adverse effects may be associated with inhibiting longevity, fecundity, reproduction (based on the eggs laid by females), development time, mobility, prey consumption, emergence rates, and sex ratio and effects of sublethal concentration on the subsequent generation. In our previous study, the subletal effects of two acaricides abamectin (Vermectin_ 1.8% EC, Giah, Iran) and fenpyroximate (Ortus 5% SC, Giah, Iran) on the predatory mite *P. plumifer* fed on *T. urticae* was assessed in laboratory conditions. The adult predators were exposed to the residues of these acaricides on fig leaves for $LC_{50}$ value determination based on a concentration–response analysis. Then sublethal effects of acaricides on performance of treated females and their offspring of *P. plumifer* were assessed.

*2.4.3.1 Materials and methods*

The *P. plumifer* individuals were originally collected from unsprayed (for ten years) fig orchards of Iran. The rearing method were explained comprehensively [34, 39]. All laid eggs were transferred daily from rearing arena to new arenas and were reared to adulthood and then used in the bioassay experiments. Pollen grains and *T. urticae* were used as food source in rearing and treatment arena.

*2.4.3.1.1 Concentration-response bioassay*

Concentration–response bioassay was carried out for acaricides using adult females and males at the first day of emergence. A modification of the leaf-dip technique was used [34, 39]. The sublethal concentrations consisted of $LC_{10}$, $LC_{20}$ and $LC_{30}$ were evaluated and used for assessment of sublethal effects on biological performance of *P. plumifer* [34, 39, 40].

*2.4.3.1.2 Sublethal effects of acaricides on biological performance of treated females*

Leaf discs with 3.3 cm diameter were treated with sublethal concentrations ($LC_{10, 20, 30}$) of acaricides and distilled water (as control) and then let to dry. The discs were placed on cotton pads as the same manner as rearing arena [39]. 40 less than 24-h-old unmated females were used in each concentration and stored at 27 ± 1°C, 50% RH and a photoperiod of 16:8 h (L:D). After 72 h treated mites were considered as alive if they were able to move for a distance without losing their balance during the movement and did not turn upside down. The survived females were selected for assessing sublethal effects of acaricides on them. Then each female was exposed to an untreated male from stock colony. Mortality and oviposition were recorded daily until the death of the last female in both treatments and controls. The dead males were replaced with new ones through the experiments.

*2.4.3.1.3 Sublethal effects of acaricides on the developmental and biological performance of the offspring from treated females*

The eggs laid by the treated and untreated (control) females were collected daily and life-table parameters of both groups were determined and compared to evaluate any possible carry-over activity of acaricides on the offspring. The subsequent generation were checked daily from eggs to dead of the last female. Development time, mortality, oviposition parameters and voracity were recorded daily and life-table parameters were taken until the death of the last female.

*2.4.3.1.4 Sublethal effects of acaricides on prey consumption of treated female and the subsequent generation*

For assessment of any sublethal effect on prey consumption of treated predators 20 to 30 only protonymphal stage (to decrease the adverse effect of prey webbing on predator) of *T. urticae* were placed on each treated and untreated (control) leaf disc as predator food source. Forty-eight hours after treatment, an unexposed male from the rearing arena was presented to each surviving female. Males that died during the experiments were replaced. The prey consumption of *P. plumifer* females was recorded separately for their pre-oviposition, oviposition and post-oviposition periods, because of the different rates for each one, were observed previously in our experiments [39]. Fresh preys were replaced with consumed ones in treated and untreated arena every 24 hours to maintain a constant daily food supply. Through the experiment adult male and female *P. plumifer* were kept pair. Consumption by the male measured previously as two protonymph per day, which subtracted from the total.

The eggs laid by the treated and untreated females were collected daily and moved to untreated leaf disc for assessment of sublethal effect on prey consumption of *P. plumifer* treated female's offspring from nymph to dead of the last female. Depending on the number of eggs, that laid by exposed females, approximately 10 and 30 replications were carried out for abamectin and fenpyroximate treatments, respectively. After emergence of the adults, males and females were paired and male consumption was subtracted as described previously. Individuals were checked daily and the number of protonymphs of *T. urticae* that had been consumed were counted, recorded and replaced with fresh ones until the death of the last predator. 10, 20, 30 and 20 protonymph stage of *T. urticae* were provided daily for proto- and deutonymphal stages and the pre-oviposition, oviposition and post-oviposition periods of predators, respectively. This was in excess of that required for daily consumption, as observed by our earlier experiments [39].

*2.4.3.1.5 Data analysis*

Mortality was corrected by using Abbott's Equation [41]. The $LC_{50}$, other sublethal concentrations and the regression equation were evaluated for the dose mortality line were extracted by using a probit program of SAS. The 95% confidence intervals of $LC_{50}$ obtained from 72 h acute concentration–response curves developed from the responses of adult females and males, for comparing susceptibility of them. Any deviation from the expected sex ratio of 1:1 was determined using a chi-square analysis. For comparing longevity, fecundity, and duration of each stage among different concentrations and the control, analysis of variance (ANOVA) was used. Least Significant Difference (LSD) sequential test was used for comparing the means.

Based on the procedures developed by some authors [33, 42], the following life-table parameters were calculated: gross reproductive rate (*GRR*), net reproductive rate ($R_0$), intrinsic rate of increase ($r_m$), finite rate of increase ($k$), doubling time ($D$), mean generation time ($T$), intrinsic rate of birth ($b$) and intrinsic rate of death ($d$). Jackknife method was used to generate and compare mean demographic parameter estimates with SE values [43]. For comparing life table parameters among different concentrations and controls analysis of variance (ANOVA) was used. The means were compared using LSD sequential test.

*2.4.3.2 Results*

Our results of several experiments on side effects of acaricides on predatory mite *P. plumifer* demonstrated that, to evaluate the total effects of acaricides, in spite of effects on treated predator, assessment of all effects on offspring from treated females (subsequent generation) is necessary. Otherwise the real effects of residual exposure on performance of predatory mites would have incomplete end points. Our study proved that abamectin and fenpyroximate had an adverse effect on biological performance of *P. plumifer* females and their offspring [34, 39, 40]. Many other studies showed these effects on phytoseiid mites too [38, 44–47].

*2.4.3.2.1 Sublethal effects of acaricides on mortality*

Reduction in settlement ratio of phytoseiid mites treated by abamectin reported in our study and several other studies too [34, 36, 44]. Our results along with other studies on predators of *T. urticae* showed that most mortality occurred in 3 days after exposure to abamectin while in the first day there was no effect or a few effects [36, 48–50]. Abamectin was too toxic for *P. plumifer* in our study; it caused 100% mortality in female predators in 0.1 concentration that recommended for *T. urticae* control in the field. Moreover *P. plumifer* males were more susceptible than females to abamectin and fenpyroximate residue.

*2.4.3.2.2 Sublethal effects of acaricides on eggs hatch and sex ratio of subsequent generation*

The eggs laid by treated females were hatched at least 96.08% in fenpyroximate treatment so this parameter was not affected significantly. The sex ratio of *P. plumifer* was affected by fenpyroximate and the treatment caused a reverse in sex ratio. Sex ratio was 16:8 (female:male) in subsequent generation of untreated females that changed to 10:26 (female:male) in subsequent generation of treated females with $LC_{30}$ of fenpyroximate. Increasing the number of male in comparison with female

in subsequent generation of treated female with fenpyroximate can be the other reason of decreasing the predator population after two generations [36, 39]. The sex ratio and egg hatch rate of *P. plumifer* were not significantly affected by abamectin sublethal concentrations.

*2.4.3.2.3 Sublethal effects of acaricides on longevity of females and subsequent generation*

Our findings revealed that nymphal periods of offspring of exposed females to acaricides (fenpyroximate and abamectin) were shortened significantly. Moreover, the duration of pre-oviposition, oviposition and post-oviposition periods, and female longevity were significantly affected by sublethal concentrations of acaricides in both treated and their subsequent generation [36, 39]. This is in agreement with another research on *Neoseiulus longispinosus* (Evans, 1952) [36]. Our results indicated that longevity of treated females and their offspring were adversely affected by abamectin and fenpyroximate treatments. Reduction in female longevity of *N. longispinosus* after using abamectin, was reported too [36]. We assumed that shortened longevity of both treated females and their offspring may be partially explained by reduced food uptake as a consequence of acaricides effects [40].

*2.4.3.2.4 Sublethal effects of acaricides on reproductive performance of females and subsequent generation*

Acaricides, abamectin and fenpyroximate caused an overall reduction of *P. plumifer* population by increasing pre-oviposition period, decreasing oviposition period, decreasing fecundity in both treated female and their offspring. The number of eggs laid by treated female was so affected in both abamectin and fenpyroximate treatment. The total laid eggs were 46.57 eggs in control that decreased to 0.57 and 1.08 eggs in $LC_{20}$ and $LC_{30}$ treatment of abamectin and fenpyroximate, respectively. The treated females with $LC_{30}$ of abamectin laid no egg (**Figure 3**).

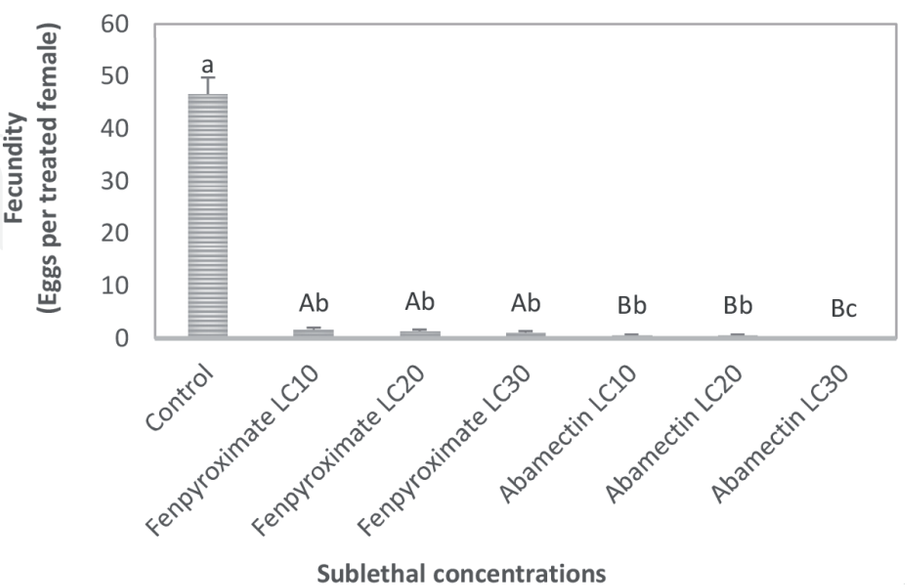


**Figure 3.**
*Effects of sublethal concentrations of acaricides (fenpyroximate and abamectin) on fecundity of* Phytoseius plumifer. *Different small letters above each bar indicate a statistically significant difference between concentrations. Different capital letters above each bar indicate a statistically significant difference between acaricides ($P < 0.05$) (LSD).*

### 2.4.3.2.5 Sublethal effects of acaricides on demographic parameters

The intrinsic rate of increase ($r_m$) is based on both survivorship and fecundity. So it has been recommended to use for evaluating the total effects of pesticides [51]. Our results along with several other studies have reported that life-table parameters of phytophagous and predatory mites were affected by sublethal concentrations of acaricides [36, 39, 45–47]. In our study, the life-table parameters showed significant differences, in population growth and reproductive performance, between offspring from females treated with sublethal concentrations of acaricides (fenpyroximate and abamectin) and untreated females of *P. plumifer* even in the

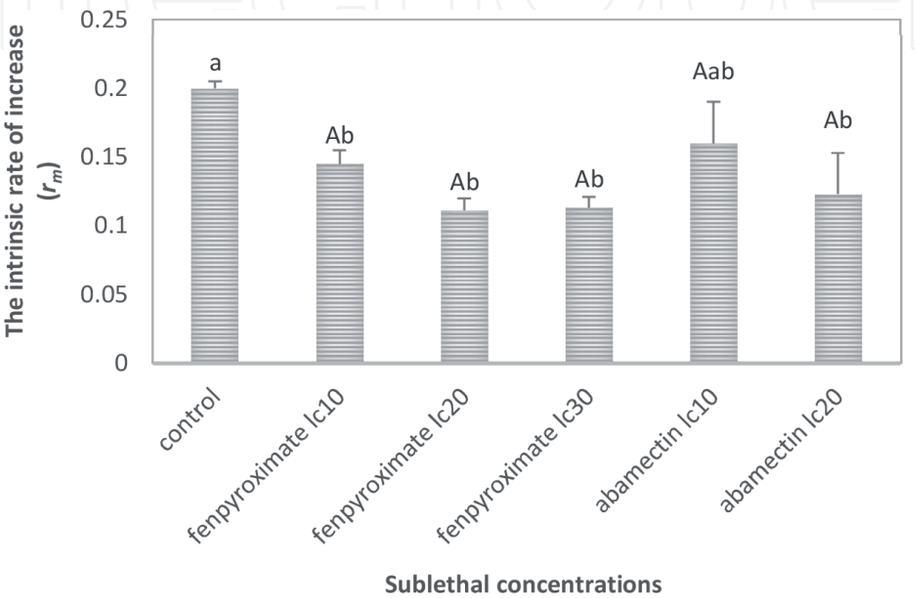


**Figure 4.**
*The intrinsic rate of increase ($r_m$) of offspring of the treated and untreated females of* Phytoseius plumifer. *Different small letters above each bar indicate a statistically significant difference between concentrations. Different capital letters above each bar indicate a statistically significant difference between acaricides (P < 0.05) (LSD).*

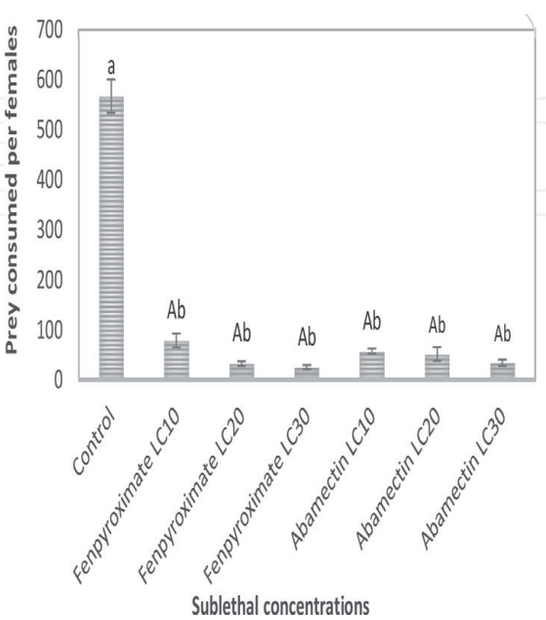


**Figure 5.**
*Total voracity of treated and untreated females of* Phytoseius plumifer. *Different small letters above each bar indicate a statistically significant difference between concentrations. Different capital letters above each bar indicate a statistically significant difference between acaricides (P < 0.05) (LSD).*

lowest concentration ($LC_{10}$). The intrinsic rate of increase ($r_m$), (**Figure 4**) the net reproductive rate ($R_0$) and the finite rate of increase ($\lambda$) of the offspring of treated females with both acaricides were markedly lower compared with the offspring of untreated females. This in turn resulted in a longer doubling time ($DT$). Moreover, in our laboratory observations the decrease in $r_m$ values in sublethal concentrations maybe due to reduction of the mating rate and mobility of the offspring from treated females than untreated ones [36, 39].

*2.4.3.2.6 Sublethal effects of acaricides on prey consumption of females and the subsequent generation*

Our study revealed that prey consumption of treated females were considerably affected by sublethal concentrations of acaricides (abamectin and fenpyroximate) (**Figure 5**). But these concentrations slightly affected the prey consumption of subsequent generation. Daily prey consumption in the oviposition period was affected more than the other periods in both treated females and their offspring by both of acaricides. Decreasing longevity is another factor that may cause reduction in total prey consumption.

## 3. Conclusion

The low concentrations of pesticides may be used in combination with biological control agents within an IPM system to reduce the selective pressure and development of resistance in pests, but this study showed that adverse effects of fenpyroximate and abamectin on *P. plumifer* were significant, indicating that this acaricide may not be advisable for combined use with *P. plumifer* in IPM programs for controlling *T. urticae*. Even the low concentrations of acaricides that was suggested could be used in combination with biological control agents [52] had considerable adverse effects on this predator.

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