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Article

Sublethal effects of bifenazate on life history and population parameters of *Tetranychus urticae* (Acari: Tetranychidae)

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Abstract

Traditional estimating only by measuring the lethal effect of acaricides may underestimate the total effects of acaricides on the pest mites. In order to investigate the sublethal effect of bifenazate on life history and population parameters of the two-spotted spider mite, *Tetranychus urticae* Koch, the newly emerged females were treated with two lethal concentrations of bifenazate: LC_{10} (4.92 μg/mL) and LC_{20} (8.77 μg/mL). Subsequently, the development and fecundity of the progeny generations were observed. Compared to the control, exposure to the 10% lethal concentrations (LC_{10}) and LC_{20} of bifenazate severely affected the parental generation of *T. urticae*, including survival rate (reduced 9% and 13%), oviposition period (reduced 77.6% and 83.1%), fecundity per female (decreased 89.2% and 76.9%) and longevity (decreased 79.2% and 83.1%). Besides, the population parameters of the progeny generation from the treated females were also investigated. The results showed that the progeny generation had lower intrinsic rate of increase (r_m) and finite rate of increase (λ), longer mean generation time (T_c) compared to the control. The results suggested that the sublethal effects of bifenazate on population growth of *T. urticae* were significant, and the results of this study could be used as a guide for the rational use of bifenazate in the field for better managing pest mites.

Key words: two-spotted spider mite, bifenazate, survival, development, fecundity

Introduction

The two-spotted spider mite, *Tetranychus urticae* Koch, which infests more than 1100 species of host plants, is the most important polyphagous spider mite and a vital pest in temperate regions for many crops (Hamedi *et al.* 2011; Amini *et al.* 2016; Migeon & Dorkeld 2016). Although biological control of *T. urticae* has been proven to be successful in many crops growing in greenhouses, acaricides have always played the central role in its control in field crops, owing to their lower cost and strong effects (Sanderson & Zhang 1995; Van Leeuwen *et al.* 2010; Jafari *et al.* 2016). When applied to the field, pesticides not only bring direct acute lethal effect on insects and mites, but also affect the life history traits of individuals surviving through the pesticide treatments. It has been reported that exposure to the sublethal dose of spiromesifen reduced the fecundity or fertility of *T. urticae* (Marcic *et al.* 2010), and exposure to the sublethal concentration of clofentezine decreased the hatchability of eggs produced by the surviving females of *T. viennensis* (Li *et al.* 2006). In addition, exposure to the sublethal concentration of acaricides also affected the population parameters of tetranychid mites and their phytoseiid predators (Hamedi *et al.* 2009; He *et al.* 2011; Pakyari & Enkegaard 2015).

Bifenazate belongs to the group of hydrazine derivatives (Van Leeuwen *et al.* 2010), and is being used worldwide for control of spider mites on several crop systems (Dekeyser 2005; Van Leeuwen *et al*., 2015). Recent studies reported that the resistance of *T. urticae* to bifenazate is tightly linked to the mutations in the mitochondrial cytochrome b (cytb) and the Q_0 site of cytb complex III of the electron transport chain (Van Leeuwen *et al.* 2008; Van Nieuwenhuyse *et al.* 2009). Reciprocal crosses between the susceptible and resistant mites showed that the resistance was only inherited maternally (non-Mendelian), supporting a hypothesis called mitochondrial control (Van Leeuwen *et al.* 2006).

Life table, in ecology, is a table for simply and intuitively reflecting the population survival and death process (Chi 1988). It is suggested that life table analysis is the best method to evaluate the lethal and sublethal effects of an acaricide (Kim *et al.* 2006; Mohammadi *et al.* 2016). The current study was focused on the sublethal effects of bifenazate on the females of pre-ovipositional stage of the two-spotted spider mite, as well as the population parameters of their progeny. Our results can serve as a reference to determine the rational use of bifenazate as an effective acaricide to manage the two-spotted spider mite in the field.

Materials and methods

Mite cultures

The two-spotted spider mite was introduced from the Key Laboratory of Grassland Ecosystem of Education Ministry, College of Grassland Science, Gansu Agricultural University in 2011. After introduction to our laboratory, the mites were reared on cowpea *Vigna unguiculata* in a climate chamber under 25 ± 1 ºC, 75 ± 5 % RH, and a photoperiod of L:D = 14:10 h. Before this experiment, the mites had never contacted with bifenazate or any other acaricides.

Concentration response bioassay

Bifenazate, commercial formulation Acramite® (suspension concentrate, 43%, Chemtura, USA) used in this study was purchased from Beijing NewGreen Environ-Tech. Co., Ltd. The toxicity of bifenazate against females of *T. urticae* was determined using leaf-residues method (Hamedi *et al.* 2010; Mahmoudvand *et al.* 2011). Based on the recommended concentration in the field by its manufacturer, bifenazate were diluted to six concentration gradients (430, 215, 107.5, 53.75, 26.88, and 13.44 µg·a.i./mL) with distilled water. The cowpea leaf discs (3 cm in diameter) were placed into the diluted liquid for 5 s and then allowed them to be naturally dried. The leaf discs treated by distilled water only served as control. Then the leaf discs were placed in Petri dish (8.5 cm in diameter × 2 cm in height, with the sponge and a layer of absorbent cotton inside). Thirty mated female mites of pre-oviposition period (each newly emerged female was paired with a male adult for 12 h) were transferred on the surface of each leaf disc. A bioassay with six concentrations of bifenazate and a control was replicated five times. After 24 h, the mortality of the tested mites was recorded under binoculars. Mites that failed to move after a gentle touch by a camel hair brush were considered as dead.

Sublethal effects of bifenazate on the survival and reproduction of T. urticae *females*

Bifenazate was diluted with distilled water to 10% lethal concentration (4.92 µg/mL) and 20% lethal concentration (8.77 µg/mL) based on above bioassay. The cowpea leaf discs (3 cm in diameter) were put into the diluted liquid for 5 s and then allowed them to be dried, and the leaf discs were placed into Petri dishes. One newly emerged mated female was transferred to the surface of each leaf disc. In total 100 females were treated for each concentration of bifenazate. After 24 h, the survived female was transferred to new clean leaf discs without bifenazate, where a male mite was added for mating (the males was re-added if the previous male mite died). The numbers of females survived and eggs were recorded every 24 h, until all females died naturally. The leaf disc treated with distilled water only served as the control.

Sublethal effects of bifenazate on development and population parameters of the progeny generations

To evaluate further effects of bifenazate on the treated females, 100 eggs of each treatment (LC_{10}, LC_{20} and control) were collected randomly (Hamedi *et al.* 2011), and placed on the surface of the leaf disc individually. The survivorship, growth and development were checked every 24 h. After eclosion, males and females were paired. In case there were no enough males to pair with females, males from the stock colony were also used (these males did not included in life table analysis). If the male died or escaped, another male was introduced. The survival of the mites and the number of eggs laid were checked daily until they die. The females that died because of improper handling or escape from the leaf disc were excluded from the data analysis.

Data analysis

Estimation of the LC_{50}, the lethal concentrations and the regression equation for the concentration mortality line were obtained using a probit program of SPSS 16.0 for Windows (SPSS, Chicago, IL, USA). The life history raw data of all individuals were analyzed based on the age-stage, two-sex life table theories (Chi & Liu 1985), which can analyze the growth process of mite population of both females and males (Chi 1988). The means and standard errors of the population parameters were estimated by using the bootstrap technology (Huang & Chi 2013). The computer program TWOSEX-MSChart (Chi 2015) was used for life table analysis. The developmental duration for immature stages and adult longevity, the reproductive period and the total female fecundity, the age-specific survival rate (l_x), the age-specific fecundity (m_x) and the population parameters: the intrinsic rate of increase from the Euler-Lotka equation: $\sum e^{-rm(x+1)} l_x m_x = 1$; finite rate of increase $\lambda = e^{rm}$; net reproduction rate $R_0 = \sum l_x m_x$; the mean generation time $T_c = (\ln R_0)/r_m$, were calculated accordingly. Means, variances and standard errors of longevity, fecundity, and duration of immature stage among different treatments were estimated with the bootstrap technique using 10,000 replications to generate less-variable results.

Results

Concentration response bioassay

The regression equation between concentration and mortality of bifenazate against females of *T. urticae* was $y = -2.49 + 1.75\,x$; [y = mortality (probit), x = logarithm of concentration (ppm)], with the correlation coefficient value of 0.9890]. The LC_{50}, LC_{20} and LC_{10} of bifenazate against *T. urticae* were 26.54, 8.77 and 4.92 µg/mL, respectively. No mortality was observed in the controls.

Sublethal effects of bifenazate on the survival and reproductions of T. urticae *females*

The results showed the 10% lethal concentration (LC_{10}) and LC_{20} of bifenazate significantly affected the female oviposition periods, average oviposition, and longevity (Table 1). The number of females that laid eggs (ovipositing individual) and the survival rate were distinctly reduced after exposure to bifenazate at LC_{10} and LC_{20}. After a 24 h exposure to bifenazate, the proportion of females that survived from treatment was 0.91 (LC_{10}) and 0.87 (LC_{20}), while there were no dead females in control; after 10 days the survival rate in both LC_{10} and LC_{20} treatments were lower than 0.1, far below the control (Figure 1). The fecundity of the treated female was obviously less than the control, and fecundity of female treated with LC_{20} of bifenazate was higher than that with LC_{10} during 5 to 10 d (Figure 2).

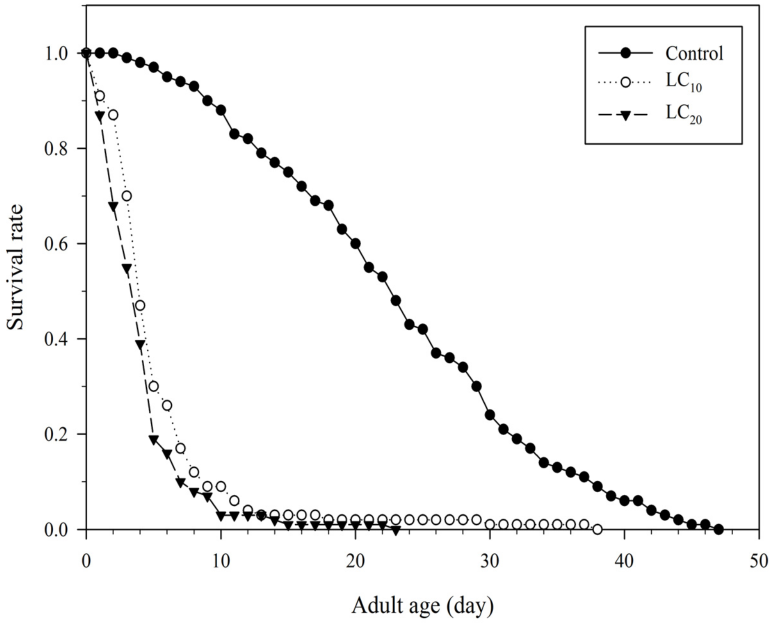

FIGURE 1. Survival rate of *T. urticae* females survived from the exposure with LC_{10} and LC_{20} of bifenazate.

TABLE 1. Oviposition per female, oviposition period, female longevity and survival of *T. urticae* females treated with LC_{10} and LC_{20} of bifenazate, estimated using all individuals and the bootstrap technique.

Treatments	Survival rate (%, 24 h)	Oviposition individual	Oviposition period (day)	Average oviposition per female (egg)	Female longevity (day)
LC_{20}	87	24	3.19±0.37b	34.46±7.29b	3.87±0.34b
LC_{10}	91	44	4.25±0.41b	16.09±5.64c	5.00±0.53b
Control	100	100	18.94±0.89a	149.46±6.52a	22.89±1.01a

Means followed by a lower case letter were estimated using the bootstrap technique. The same letter within a column indicates no significant difference among treatments.

Sublethal effects of bifenazate on development and populatin parameters of the progeny generations

The preadult survival rate of progeny generation in both LC_{10} and LC_{20} of bifenazate treatment were significantly lower than that of the control. The duration of immature stages of females of the progeny generation were significantly prolonged both in the treatments of LC_{10} and LC_{20} of bifenazate compared with the control, whereas the oviposition period, female average oviposition and female longevity were not significantly different from the control (Table 2). The duration of immature stages of the male of the progeny generation in treatment of LC_{10} was significantly prolonged compared with the control, whereas that of LC_{20} had no significant difference with that of the control. On the contrary, the male adult longevity of progeny generation in treatment of LC_{20} was significantly shortened compared to the control, whereas that of LC_{10} had no significant difference with that of the control (Table 2).

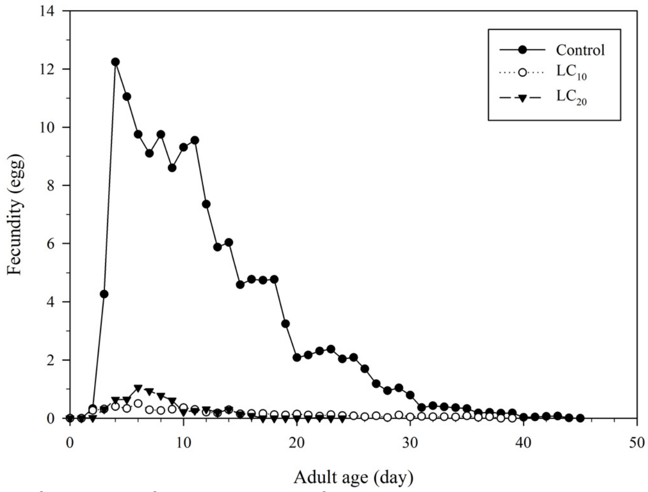

FIGURE 2. Fecundity of *T. urticae* females survived from the exposure with LC_{10} and LC_{20} of bifenazate.

TABLE 2. Developmental durations of immature stages, oviposition periods, longevity of offspring from female *T. urticae* treated with LC_{10} and LC_{20} of bifenazate, estimated using all individuals and the bootstrap technique.

Treatments	Duration of the immature stages (day)		Preadult survival rate	Adult longevity (day)		Oviposition period (day)	Average oviposition per female (egg)	Survival rate of female (%)
	Female	male		Female	Male			
LC_{20}	12.81±0.16a	11.61±0.23ab	0.4438±0.0391b	21.52±1.54	12.65±1.49b	19.98±1.34	142.29±10.98	43
LC_{10}	12.56±0.14a	12.21±0.24a	0.4735±0.0366b	20.95±1.17	15.47±2.72ab	19.10±1.01	138.78±8.63	46
Control	12.09±0.14b	11.62±0.16b	0.7747±0.0355a	20.18±1.18	17.38±1.60a	17.65±1.08	144.06±8.47	52

Means followed by a lower case letter were estimated using the bootstrap technique. The same letter within a column indicates no significant difference among treatments.

The r_m and λ of population treated with the LC_{10} and LC_{20} of bifenazate were both significantly decreased, and the progeny generation had a longer T_c, which these three population parameters of progeny generation treated between LC_{10} and LC_{20} of bifenazate were not different significantly (Table 3). The value of R_0 of progeny population treated with the 20% lethal concentration was reduced significantly. Nevertheless, the value of R_0 of population treated with the 10% lethal concentration had no significant difference from the control (Table 3). The l_x of female offspring decreased with the increasing concentrations of bifenazate, however, the l_x of male offspring of LC_{20} was higher than that of LC_{10}, although both of them were lower than l_x of male offspring of the control (Figure 3). The m_x, f_x and l_xm_x of the female offspring showed the synchronization for both two lethal concentrations compared with the control (Figure 4).

TABLE 3. Population parameters, mean ± the standard error, of offspring *T. urticae* from female treated with LC_{10} and LC_{20} of bifenazate, estimated using all individuals and the bootstrap technique.

Treatments	R_0	r_m	λ	T_c
LC_{20}	42.72±6.09b	0.1773±0.0073b	1.1940±0.0087b	21.12±0.29a
LC_{10}	51.47±5.93ab	0.1915±0.0060b	1.2111±0.0073b	20.55±0.24a
Control	65.85±7.07a	0.2110±0.0059a	1.2350±0.0073a	19.82±0.28b

R_0, net reproductive rate; r_m, the intrinsic rate of increase; λ, finite rate of increase; T_c, mean generation time. Means followed by a lower case letter were estimated using the bootstrap technique. The same letter within a column indicates no significant difference among treatments.

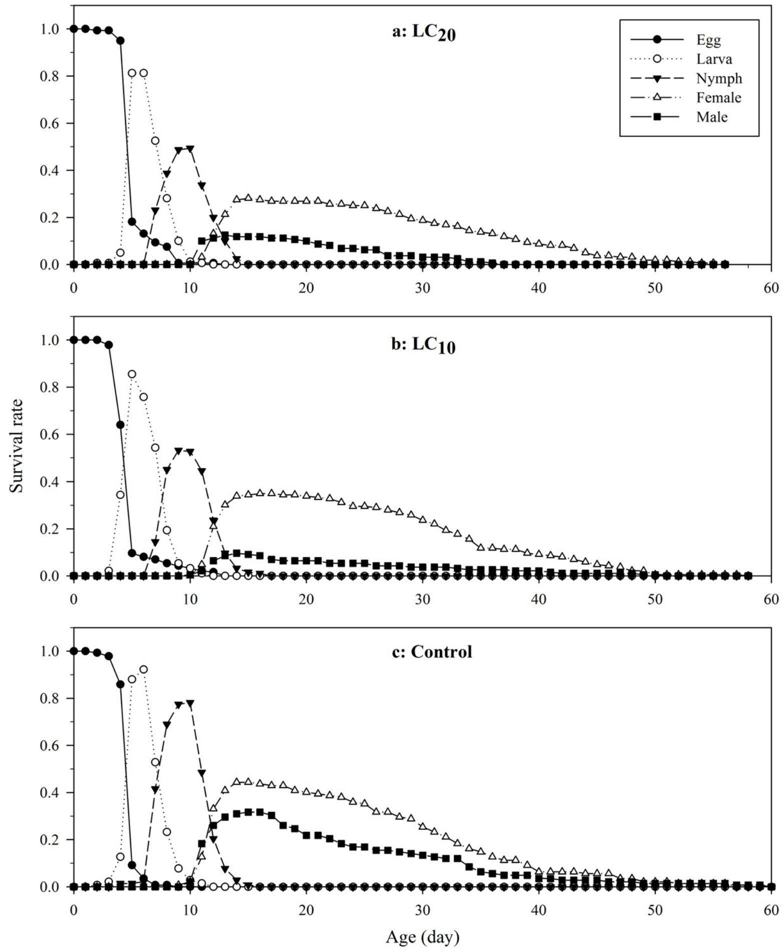

FIGURE 3. Age-stage specific survival rate of offspring from *T. urticae* females treated with LC_{10} and LC_{20} of bifenazate**. a, b** and **c:** Survival rates of offspring from *T. urticae* females treated with LC_{20}, LC_{10} of bifenazate and distilled water, respectively.

Discussion

Bifenazate had acaricidal activity against *T. urticae* (Ochiai *et al.* 2007), and the resistance mechanism of *T. urticae* to bifenazate was thoroughly illuminated by several studies (Van Leeuwen *et al.* 2007; Van Leeuwen *et al.* 2008; Van Nieuwenhuyse *et al.* 2009; Van Leeuwen *et al.* 2011). Our study here is the first comprehensive investigation on the sublethal effects of bifenazate on life table parameters of progeny generation of *T. urticae*. Our results demonstrated that bifenazate had a strong adulticidal activity on *T. urticae*, which was in accordance with the previous report (Ochiai *et al.* 2007). Furthermore, our results found that LC_{10} and LC_{20} of bifenazate could reduce the survival rate, oviposition period, average oviposition and longevity of the female of *T. urticae*. This was also consistent with previous studies. For example, Marcic (2005) concluded that females of *T. urticae* survived from the treatment of tebufenpyrad at protonymphal or deutonymphal stage had the lower fertility, and the females of two-spotted spider mite treated with the sublethal concentration/dose of spirodiclofen (Marcic 2007), spirotetramat (Marcic *et al.* 2012), *Beauveria bassiana* (Seyed-Talebi *et al.* 2012), fenpyroximate and pyridaben (Kim *et al.* 2006) had shorter or lower longevity, reproduction period and fecundity than the controls.

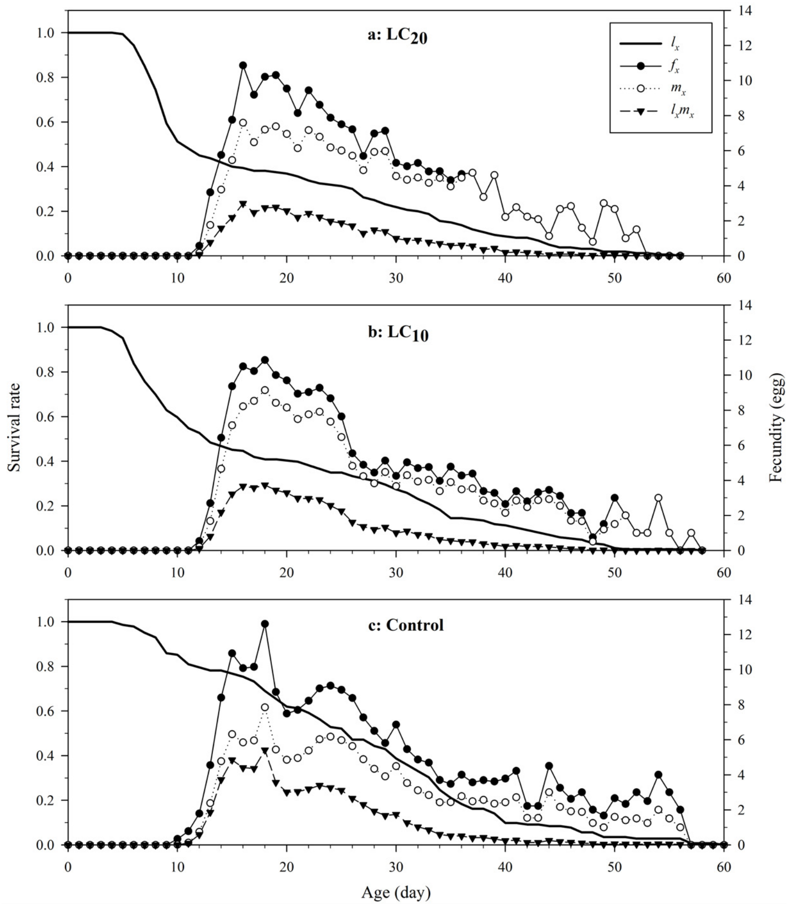

FIGURE 4. Age specific survival rate (l_x), fecundity (m_x), maternity (l_xm_x) and age-stage specific fecundity (f_x) of offspring from *T. urticae* females treated with LC_{10} and LC_{20} of bifenazate. **a**, **b** and **c**: l_x, m_x, l_xm_x and f_x of offspring from *T. urticae* females treated with LC_{20}, LC_{10} of bifenazate and distilled water, respectively.

It is known that exposure to pesticides can lead to hereditary malfunctions and malformations, and hence can lead to significant disturbances of insect or mite development in the next generation (Adamski *et al.* 2009). Our results demonstrated that exposure to lethal concentrations of bifenazate at LC_{10} and LC_{20} during the female adult stage had negative effects on the two-spotted mite population increase of progeny generation (i.e. lower r_m, and λ values, but higher T_c). According to He *et al.* (2011), exposure to sublethal concentrations of avermectin during the adult stage had negative effects on the population increase (i.e. lower r_m, R_0, and λ values, longer D_t) of the progeny generation of *Panonychus citri* (McGregor). Li *et al.* (2006) also reported that the values of r_m in offspring of abamectin-treated adult females of *Amphitetranychus viennensis* decreased significantly. However, Landeros *et al.* (2002) reported that there was a significant increase in the R_0 of *T. urticae* after applications of abamectin at LC_{10}. In this study, the mites treated with LC_{20} of bifenazate had negative effects on R_0 of the mites. LC_{20} treatment caused significant changes in the progeny including the prolonged immature stages, decreased preadult survival rate and adult male longevity.

The r_m is the most important parameter to describe the growth potential of a pest population. The results of this study showed that values of r_m of progeny generation of the treated mites significantly decreased. Although the preadult survival rate and population growth of progeny generation of treated mites was substantially lower, the female adult longevity, oviposition period and average oviposition per female were not different from those of population of the control. In other words, the surviving females of the progeny generation treated with LC_{10} and LC_{20} of bifenazate were not affected. This phenomenon may refer to the arcaricide resistance of bifenazate. Van Leeuwen *et al.* (2010) reported the progeny of *T. urticae* could absorb small amount of bifenazate from female treated with the sublethal concentration of bifenazate by maternal inheritance referring to the bifenazate resistance. In some other studies, low concentration of bifenazate caused an effect called hormesis, which is referred to biphasic dose response relationship with stimulatory effect at low doses and inhibitory effect at high doses of a stressor or pesticide (Luckey 1968; Guedes & Cutler 2014). There are two hypotheses which provided the potential mechanistic explanation for hormesis: the growth hormesis theory (Stebbing 2000), and the principle of physiological resource allocation (Weltje *et al.* 2005). According to the growth theory, this hypothesis is based on control systems and growth analysis (Stebbing 1998; Stebbing 2000). The control mechanisms that regulate growth counteract the perturbing or inhibitory effects of toxic agents (Guedes & Cutler 2014). This idea remains highly speculative, focused on growth as a life-history trait and lacking a general mechanistic underpinning (Thayer *et al.* 2005; Mushak 2007; Jager *et al.* 2013). The principle of resource allocation is based on physiological energetic models that predict trade-offs in resource allocation among different physiological processes (Forbes 2000; Guedes & Cutler 2014). Hormesis by acquisition is explained by an unlimited increase in energy uptake from the environment, when such a resource is limitless (Jager *et al.* 2013). This increased energy uptake favors growth rate, and possibly maximizes size, which increase reproduction and population growth rate (Guedes & Cutler 2014). The results of our study showed that, the LC_{10} and LC_{20} of bifenazate had no negative effects on the offspring of the treated female *T. urticae* in fecundity and longevity. This situation may be explained by resource allocation, but further studies are necessary to confirm this conjecture.

Investigations on sublethal effects of an acaricide aim to discover the negative non-lethal impacts of the acaricide on various life table parameters that might affect population dynamics (Stark & Banks 2003), and help us gain more information about the acaricide and put it to better use. Our study is the first step to explore the sublethal effect of bifenazate on progeny generation of *T. urticae*. Based on our results, the survival and the population growth of progeny generation of *T. urticae* was substantially decreased, indicating that low concentration of bifenazate could pay an important role when this arcaricide was combined with other biological control agents like natural enemies. However, future field investigation will provide more information to guide the rational use of this acaricide.

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References

Adamski, Z., Machalska, K., Chorostkowska, K., Niewadzi, M., Ziemnicki, K. & Hirsch, H.V.B. (2009) Effects of sublethal concentrations of fenitrothion on beet armyworm (Lepidoptera: Noctuidae) development and reproduction. *Pesticide Biochemistry & Physiology*, 94, 73–78.
http://dx.doi.org/10.1016/j.pestbp.2009.04.005

Amini, M.Y., Ullah, M.S., Kitagawa, A., Kanazawa, R., Takano, Y., Suzuki, T. & Gotoh, T. (2016) Scotophase interruption with LEDs and OLEDs to inhibit photoperiodic induction of diapause in *Tetranychus urticae* and *T. kanzawai* (Acari: Tetranychidae). *Systematic and Applied Acarology*, 21, 1436–1446.
http://dx.doi.org/10.11158/saa.21.10.12

Chi, H. (1988) Life-table analysis incorporating both sexes and variable development rates among individuals. *Environmental Entomology*, 17, 26–34.
http://dx.doi.org/10.1093/ee/17.1.26

Chi, H. (2015) *TWOSEX-MSChart: computer program for age stage, two-sex life table analysis*. http://140.120.197.173/ecology/ [last acessed 25 June 2015].

Chi, H. & Liu, H. (1985) Two new methods for the study of insect population ecology. *Bulletin of the Institute of Zoology Academia Sinica*, 24, 225–240.

Chi, H. & Su, H.Y. (2006) Age-stage, two-sex life tables of *Aphidius gifuensis* (Ashmead) (Hymenoptera: Braconidae) and its host *Myzus persicae* (Sulzer) (Homoptera: Aphididae) with mathematical proof of the relationship between female fecundity and the net reproductive rate. *Environmental Entomology*, 35, 10–21.
http://dx.doi.org/10.1603/0046-225X-35.1.10

Dekeyser, M.A. (2005) Acaricide mode of action. *Pest Management Science*, 61, 103–110.
http://dx.doi.org/10.1002/ps.994

Forbes, V.E. (2000) Is hormesis an evolutionary expectation? *Functional Ecology*, 14, 12–24.
http://dx.doi.org/10.1046/j.1365-2435.2000.00392.x

Guedes, R.N.C. & Cutler, G.C. (2014) Insecticide-induced hormesis and arthropod pest management. *Pest Management Science*, 70, 690–697.
http://dx.doi.org/10.1002/ps.3669

Hamedi, N., Fathipour, Y. & Saber, M. (2010) Sublethal effects of fenpyroximate on life table parameters of the predatory mite *Phytoseius plumifer. Biocontrol*, 55, 271–278.
http://dx.doi.org/10.1007/s10526-009-9239-4

Hamedi, N., Fathipour, Y. & Saber, M. (2011) Sublethal effects of abamectin on the biological performance of the predatory mite, *Phytoseius plumifer* (Acari: Phytoseiidae). *Experimental and Applied Acarology*, 53, 29–40.
http://dx.doi.org/10.1007/s10493-010-9382-8

Hamedi, N., Fathipour, Y., Saber, M. & Garjan, A.S. (2009) Sublethal effects of two common acaricides on the consumption of *Tetranychus urticae* (Prostigmata: Tetranychidae) by *Phytoseius plumifer* (Mesostigmata: Phytoseiidae). *Systematic and Applied Acarology*, 14, 197–205.
http://dx.doi.org/10.11158/saa.14.3.4

He, H.G., Jiang, H.B., Zhao, Z.M. & Wang, J.J. (2011) Effects of a sublethal concentration of avermectin on the development and reproduction of citrus red mite, *Panonychus citri* (McGregor) (Acari: Tetranychidae). *International Journal of Acarology*, 37, 1–9.
http://dx.doi.org/10.1080/01647954.2010.491798

Huang, Y.-B. & Chi, H. (2012) Age-stage, two-sex life tables of *Bactrocera cucurbitae* (Coquillett) (Diptera: Tephritidae) with a discussion on the problem of applying female age-specific life tables to insect populations. *Insect Science*, 19, 263–273.
http://dx.doi.org/10.1111/j.1744-7917.2011.01424.x

Huang, Y.B. & Chi, H. (2013) Life tables of *Bactrocera cucurbitae* (Diptera: Tephritidae): with an invalidation of the jackknife technique. *Journal of Applied Entomology*, 137, 327–339.
http://dx.doi.org/10.1111/jen.12002

Jafari, S., Fathipour, Y., Faraji, F. & Bagheri, M. (2016) Demographic response to constant temperatures in *Neoseiulus barkeri* (Phytoseiidae) fed on *Tetranychus urticae* (Tetranychidae). *Systematic and Applied Acarology*, 15, 83–99.
http://dx.doi.org/10.11158/saa.15.2.1

Jager, T., Barsi, A. & Ducrot, V. (2013) Hormesis on life-history traits: is there such thing as a free lunch? *Eco-*

toxicology, 22, 263–270.
http://dx.doi.org/10.1007/s10646-012-1022-0

Kim, M., Sim, C., Shin, D., Suh, E. & Cho, K.J. (2006) Residual and sublethal effects of fenpyroximate and pyridaben on the instantaneous rate of increase of *Tetranychus urticae*. *Crop Protection*, 25, 542–548. http://dx.doi.org/10.1016/j.cropro.2005.08.010

Landeros, J., Mora, N., Badii, M., Cerda, P.A. & Flores, A.E. (2002) Effect of sublethal concentrations of avermectin on population parameters of *Tetranychus urticae* on strawberry. *Southwestern Entomologist*, 27, 283–289.

Li, D.X., Tian, J. & Shen, Z.R. (2006) Assessment of sublethal effects of clofentezine on life-table parameters in hawthorn spider mite (*Tetranychus viennensis*). *Experimental and Applied Acarology*, 38, 255–273. http://dx.doi.org/10.1007/s10493-006-0016-0

Luckey, T.D. (1968) Insecticide hormoligosis. *Journal of Economic Entomology*, 61, 7–12. http://dx.doi.org/10.1093/jee/61.1.7

Mahmoudvand, M., Abbasipour, H., Garjan, A.S. & Bandani, A.R. (2011) Sublethal effects of hexaflumuron on development and reproduction of the diamondback moth, *Plutella xylostella* (Lepidoptera: Yponomeutidae). *Insect Science*, 18, 689–696. http://dx.doi.org/10.1111/j.1744-7917.2011.01411.x

Marcic, D. (2005) Sublethal effects of tebufenpyrad on the eggs and immatures of two-spotted spider mite, *Tetranychus urticae*. *Experimental and Applied Acarology*, 36, 177–185. http://dx.doi.org/10.1007/s10493-005-3579-2

Marcic, D. (2007) Sublethal effects of spirodiclofen on life history and life-table parameters of two-spotted spider mite (*Tetranychus urticae*). *Experimental and Applied Acarology*, 42, 121–129. http://dx.doi.org/10.1007/s10493-007-9082-1

Marcic, D., Ogurlic, I., Mutavdzic, S. & Peric, P. (2010) The effects of spiromesifen on life history traits and population growth of two-spotted spider mite (Acari: Tetranychidae). *Experimental and Applied Acarology*, 50, 255–267. http://dx.doi.org/10.1007/s10493-009-9316-5

Marcic, D., Petronijevic, S., Drobnjakovic, T., Prijovic, M., Peric, P. & Milenkovic, S. (2012) The effects of spirotetramat on life history traits and population growth of *Tetranychus urticae* (Acari: Tetranychidae). *Experimental and Applied Acarology*, 56, 113–122. http://dx.doi.org/10.1007/s10493-011-9500-2

Migeon, A. & Dorkeld, F. (2016) *Spider mites web: a comprehensive database for the Tetranychidae*. http:// www.montpellier.inra.fr/CBGP/spmweb. [accessed 7 December 2016].

Mohammadi, S., Ziaee, M. & Seraj, A.A. (2016) Sublethal effects of Biomite (R) on the population growth and life table parameters of *Tetranychus turkestani* Ugarov and Nikolskii on three cucumber cultivars. *Systematic and Applied Acarology*, 21, 218–226.

Mushak, P. (2007) Hormesis and its place in nonmonotonic dose-response relationships: Some scientific reality checks. *Environmental Health Perspectives*, 115, 500–506. http://dx.doi.org/10.1289/ehp.9619

Ochiai, N., Mizuno, M., Mimori, N., Miyake, T., Dekeyser, M., Canlas, L.J. & Takeda, M. (2007) Toxicity of bifenazate and its principal active metabolite, diazene, to *Tetranychus urticae* and *Panonychus citri* and their relative toxicity to the predaceous mites, *Phytoseiulus persimilis* and *Neoseiulus californicus*. *Experimental and Applied Acarology*, 43, 181–197. http://dx.doi.org/10.1007/s10493-007-9115-9

Pakyari, H. & Enkegaard, A. (2015) Sublethal effects of abamectin and fenpropathrin on the consumption of *Tetranychus urticae* eggs by *Scolothrips longicornis*. *Systematic and Applied Acarology*, 20, 357–365. http://dx.doi.org/10.11158/saa.20.4.1

Sanderson, J.P. & Zhang, Z.Q. (1995) Dispersion, sampling, and potential for integrated control of twospotted spider mite (Acari: Tetranychidae) on greenhouse roses. *Journal of Economic Entomology*, 88, 343–351. http://dx.doi.org/10.1093/jee/88.2.343

Seyed-Talebi, F.-S., Kheradmand, K., Talaei-Hassanloui, R. & Talebi-Jahromi, K. (2012) Sublethal effects of Beauveria bassiana on life table parameters of two-spotted spider mite, *Tetranychus urticae* (Acari: Tetranychidae). *Biocontrol Science and Technology*, 22, 293–303. http://dx.doi.org/10.1080/09583157.2012.655709

Stark, J.D. & Banks, J.E. (2003) Population-level effects of pesticides and other toxicants on arthropods. *Annual Review of Entomology*, 48, 505–519.

http://dx.doi.org/10.1146/annurev.ento.48.091801.112621
Stebbing, A.R.D. (1998) A theory for growth hormesis. *Mutation Research/fundamental & Molecular Mechanisms of Mutagenesis*, 403, 249–258.
http://dx.doi.org/10.1016/S0027-5107(98)00014-1
Stebbing, A.R.D. (2000) Maia hypothesis - growth control and toxicology. *Human and Ecological Risk Assessment*, 6, 301–311.
http://dx.doi.org/10.1080/10807030009380064
Thayer, K.A., Melnick, R., Burns, K., Davis, D. & Huff, J. (2005) Fundamental flaws of hormesis for public health decisions. *Environmental Health Perspectives*, 113, 1271–1276.
http://dx.doi.org/10.1289/ehp.7811
Van Leeuwen, T., Tirry, L. & Nauen, R. (2006) Complete maternal inheritance of bifenazate resistance in *Tetranychus urticae* Koch (Acari: Tetranychidae) and its implications in mode of action considerations. *Insect Biochemistry and Molecular Biology*, 36, 869–877.
http://dx.doi.org/10.1016/j.ibmb.2006.08.005
Van Leeuwen, T., Van Nieuwenhuyse, P., Vanholme, B., Dermauw, W., Nauen, R. & Tirry, L. (2011) Parallel evolution of cytochrome b mediated bifenazate resistance in the citrus red mite *Panonychus citri*. *Insect Molecular Biology*, 20, 135–140.
http://dx.doi.org/10.1111/j.1365-2583.2010.01040.x
Van Leeuwen T., Tirry L., Yamamoto A., Nauen R. & Dermauw, W. (2015) The economic importance of acaricides in the control of phytophagous mites and an update on recent acaricide mode of action research. *Pesticide Biochemistry and Physiology,* 121, 12–21.
http://dx.doi.org/10.1016/j.pestbp.2014.12.009
Van Leeuwen, T., Van Pottelberge, S., Nauen, R. & Tirry, L. (2007) Organophosphate insecticides and acaricides antagonise bifenazate toxicity through esterase inhibition in *Tetranychus urticae*. *Pest Management Science*, 63, 1172–1177.
http://dx.doi.org/10.1002/ps.1453
Van Leeuwen, T., Vanholme, B., Van Pottelberge, S., Van Nieuwenhuyse, P., Nauen, R., Tirry, L. & Denholm, I. (2008) Mitochondrial heteroplasmy and the evolution of insecticide resistance: non-mendelian inheritance in action. *Proceedings of the National Academy of Sciences of the United States of America*, 105, 5980–5985.
http://dx.doi.org/10.1073/pnas.0802224105
Van Leeuwen, T., Vontas, J., Tsagkarakou, A., Dermauw, W. & Tirry, L. (2010) Acaricide resistance mechanisms in the two-spotted spider mite *Tetranychus urtica*e and other important Acari: A review. *Insect Biochemistry and Molecular Biology*, 40, 563–572.
http://dx.doi.org/10.1016/j.ibmb.2010.05.008
Van Nieuwenhuyse, P., Van Leeuwen, T., Khajehali, J., Vanholme, B. & Tirry, L. (2009) Mutations in the mitochondrial cytochrome b of *Tetranychus urticae* Koch (Acari: Tetranychidae) confer cross-resistance between bifenazate and acequinocyl. *Pest Management Science*, 65, 404–412.
http://dx.doi.org/10.1002/ps.1705
Weltje, L., vom Saal, F.S. & Oehlmann, J. (2005) Reproductive stimulation by low doses of xenoestrogens contrasts with the view of hormesis as an adaptive response. *Human & Experimental Toxicology*, 24, 431–437.
http://dx.doi.org/10.1191/0960327105ht551oa

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