Behavioral response of *Panonychus citri* (McGregor) (Acari: Tetranychidae) to synthetic chemicals and oils

Muhammad Asif Qayyoum Corresp., Equal first author, 1, 2, Zi-Wei Song Equal first author, 1, Bao-Xin Zhang 1, Dun-Song Li Corresp., 1, Bilal Saeed Khan 3

1 Guangdong Provincial Key Laboratory of High Technology for Plant Protection/Plant Protection Research Institute, Guangdong Academy of Agricultural Sciences, Guangzhou City, Guangdong, China

2 Department of Plant Protection, Ghazi University, Dera Ghazi Khan, Dera Ghazi Khan, PUNJAB, Pakistan

3 Department of Entomology, University of Agriculture Faisalabad, FAISALABAD, PUNJAB, Pakistan

Corresponding Authors: Muhammad Asif Qayyoum, Dun-Song Li
Email address: asifqayyoum@gdppri.com, dsli@gdppri.cn

Background *Panonychus citri* (McGregor) (Acari: Tetranychidae) population outbreaks after the citrus plantation's chemical application is a common observation. Dispersal behavior is an essential tool to understand the secondary outbreak of *P. citri* population. Therefore, in the current study, the dispersal activity of *P. citri* was observed on the leaf surfaces of *Citrus reticulata* (Rutaceae) treated with SYP-9625, abamectin, vegetable oil, and EnSpray 99. Method Mites were released on the first (apex) leaf of the plant (adaxial surface) and data were recorded after 24 h. The treated, untreated, and half-treated data were analyzed by combining the leaf surfaces (adaxial right, adaxial left, abaxial right, and abaxial left). All experiments were performed in open-air environmental conditions. Results The maximum number of mites was captured on the un-treated or half-treated surfaces due to chemicals repellency. Chemical bioassays of the free-choice test showed that all treatments significantly increased the mortality of *P. citri* depending on application method and concentration. A significant number of mites repelled away from treated surfaces and within treated surfaces except adaxial left and abaxial right surfaces at LC$_{30}$. In the no-choice test, SYP-9625 gave maximum mortality and dispersal by oils than others. No significant differences were observed within the adaxial and abaxial except abaxial surface at LC$_{30}$. Therefore, the presence of tested acaricides interferes with *P. citri* dispersal within leaf surfaces of plantations depending on the mites released point and a preferred site for feeding.
Behavioral response of *Panonychus citri* (McGregor) (Acari: Tetranychidae) to synthetic chemicals and oils

Muhammad Asif Qayyoum\(^1,2\), Zi-Wei Song\(^1\*) , Bao-Xin Zhang\(^1\), Dun-Song Li\(^1\*) , Bilal Saeed Khan\(^3\)

\(^1\) Guangdong Provincial Key Laboratory of High Technology for Plant Protection/Plant Protection Research Institute, Guangdong Academy of Agricultural Sciences, 7 Jinying Road, Tianhe District, Guangzhou 510640, China.

\(^2\) Department of Plant Protection, Ghazi University, Dera Ghazi Khan, Punjab province, Pakistan.

\(^3\) Department of Entomology, University of Agriculture, Faisalabad, Punjab province, Pakistan.

Corresponding Authors:

Zi-Wei Song, Dun-Song Li, Muhammad Asif Qayyoum

Guangdong Provincial Key Laboratory of High Technology for Plant Protection/Plant Protection Research Institute, Guangdong Academy of Agricultural Sciences, 7 Jinying Road, Tianhe District, Guangzhou 510640, China.

Email address: asifqayyoum@gmail.com/asifqayyoum@gdppri.com; zweiseong@139.com; dсли@gdppri.cn

Abstract

**Background**

*Panonychus citri* (McGregor) (Acari: Tetranychidae) population outbreaks after the citrus plantation's chemical application is a common observation. Dispersal behavior is an essential tool to understand the secondary outbreak of *P. citri* population. Therefore, in the current study, the dispersal activity of *P. citri* was observed on the leaf surfaces of *Citrus reticulata* (Rutaceae) treated with SYP-9625, abamectin, vegetable oil, and EnSpray 99.

**Method**

Mites were released on the first (apex) leaf of the plant (adaxial surface) and data were recorded after 24 h. The treated, untreated, and half-treated data were analyzed by combining the leaf surfaces (adaxial right, adaxial left, abaxial right, and abaxial left). All experiments were performed in open-air environmental conditions.

**Results**

The maximum number of mites was captured on the un-treated or half-treated surfaces due to chemicals repellency. Chemical bioassays of the free-choice test showed that all treatments significantly increased the mortality of *P. citri* depending on application method and concentration. A significant number of mites repelled away from treated surfaces and within
treated surfaces except adaxial left and abaxial right surfaces at LC$_{30}$. In the no-choice test, SYP-9625 gave maximum mortality and dispersal by oils than others. No significant differences were observed within the adaxial and abaxial except abaxial surface at LC$_{30}$. Therefore, the presence of tested acaricides interferes with $P. citri$ dispersal within leaf surfaces of plantations depending on the mites released point and a preferred site for feeding.

**Introduction**

The citrus red mite, *Panonychus citri*, is a serious pest of the citrus growing region all over the world (Gotoh & Kubota, 1997; Kasap, 2009; Faez et al., 2018b; Korhayli et al., 2018) as well as in China (Yuan et al., 2010; Fang et al., 2013; Liu et al., 2019). The immature and adult stages feed on leaves and fruit by giving stippling damage, which inhibits the photosynthesis process and leads shoot dieback and leaf/fruit dropping (Kranz et al., 1978). Server infestation in the field may cause irritation and allergic reactions to citrus workers (Fernández-Caldas et al., 2014).

The chemicals application is a preferred method to control *P. citri* by the farmers in citrus orchards (Gotoh & Kubota, 1997; Chen et al., 2009; Kasap, 2009; Fadamiro et al., 2013; Faez et al., 2018a,b; Karmakar, 2019; Liu et al., 2019). SYP-9625 and abamectin are commonly used among synthetic chemicals against citrus pests in China (Gu et al., 2010; Hu et al., 2010; Liu et al., 2018; Chen et al., 2019). It is essential to find alternative products (Isman, 2008; Tak & Isman, 2017) for synthetic chemicals due to serious threats to non-target organisms and the environment (Kumral et al., 2010; Chen & Dai, 2015). Agricultural mineral oils (EnSpray 99) are compatible with predatory mites application and effective against horticultural crop pests (Wang et al., 2004; Chen & Zhan, 2007; Xue et al., 2009a,b; Teifemg et al., 2011; Zhuang et al., 2015). Vegetable oils are also considered an alternative due to toxicity and repellency against target pests (Koublanis et al., 1984; Ismail et al., 2011; Oliveira et al., 2017). Vegetable oil extracted from kitchen/household waste (vegetable remaining) were used in this study. Guangdong Institute of Applied Biological Resources, China, provided this kitchen vegetable waste oil (as a trial product).

Environmental contamination such as pesticides can influence mites behavioral activities on leaves or plants (Ibrahim & Yee, 2009; Lima et al., 2013; Cordeiro et al., 2014; Monteiro et al., 2019a). The behavioral changes due to chemicals affect pest management strategies (Guedes et al., 2016). The population outbreaks of plant-feeding mites after the chemical application on the horticultural crops are very common (AliNiazee & Cranham, 1980; Zwick & Field, 1987). The abrupt increase of the mites population has many suggestions by the researchers; the most critical explanation suggests the impact of chemicals on the natural enemies (AliNiazee & Cranham, 1980; Dittrich et al., 1980; Zwick & Field, 1987). Iftner & Hall (1983) reported that increasing the chemical application rates in the absence of natural enemies also increases pest numbers. Since, the impact of agrochemicals on target pest or insect can be assessed through the application rate (lethal and sublethal), application timing, and mode of action. The use of the sublethal effect of chemicals is considered a more accurate approach to measure toxicity, which
changes individuals behavioral responses that survive from toxic exposure (Desneux et al., 2007; Biondi et al., 2013; Turchen et al., 2016; Alves et al., 2018).

Dispersal behaviors define as any movement from one place to another for the survival of any organism due to environmental stress or non-viable to live (e.g., lack of food or surrounding climatic constraints) (Clobert et al., 2001; Ims & Hjermann, 2001). Dispersal movement done in three stages; emigration, a vagrant stage, and immigration (Ronce, 2007), which depend on the species life cycle, sex, environmental variations, space, and time (Dunning Jr et al., 1995; Hanski, 1998, 1999; Turchin, 1998; Bergman et al., 2000; Bowler & Benton, 2005).

The dispersal behavior of mites uses active or passive dispersal mechanisms (Evans, 1992; Sabelis & Afman, 1994; Tixier et al., 1998; Perotti & Braig, 2009). Active dispersal (walking) is the most preferred mechanism in mites due to morphological characteristics and short-range travel (Strong et al., 1999; Melo et al., 2014; Monteiro et al., 2019a). Like most of the tetranychids, Panonychus citri also do passive dispersal by silk threads (aerial dispersal) to overcome crowding, food depletion (Bell et al., 2005), and light-dependent (Pralavorio et al., 1989). In this study, we evaluated the lethal and sublethal effects of selected pesticides on the dispersal pattern of P. citri by treating the leaf surfaces. We hypothesized that P. citri response towards chemicals treatment may be a reason for the population outbreak in the field conditions.

**Materials & Methods**

*Mite Culture*

Mite culture was regularly maintained since 2019, on lemon leaves with the water-saturated sponge. The culture was reared in the growth chamber with a 16:8h (Light: Dark) photoperiod and 26±1 °C temperature. One to three-day-old adult females (He et al., 2011; Alves et al., 2018) were used for said experimentation reared in the laboratory for several generations (more than 50 generations). The one to three-day-old adult females were used due to fully developed adulthood and ready for egg-laying after 4 to 5 days. The mite culture was shifted to the open-air environment one month before the experiment to acclimatize.

*Plants*

Citrus plants (Citrus reticulata) approximately 1-2 months old were used after shifting to the pots. The plants with 7 to 8 leaves were used by leaving six leaves (3 on the right and left side) and cutting them. All plants were washed three times with water to be sure not to have any arthropods on them. The bottom of each plant stem was wrapped with wet tissue paper and maintained wet to keep mites on the plant. All plants were manured and watered accordingly under reasonable conditions during January.

*Chemicals*

SYP-9625 30% EC and Abamectin 5%EC, EnSpray 99% EC (EnSpray 99), and vegetable oil 99% were used in this research. Chemicals and EnSpray were bought from the local market. The degummed vegetable oil was extracted from household daily kitchen vegetable waste that was provided by the Institute of Zoology, Guangdong Academy of Sciences.

Each chemical toxicity was calculated using a modified leaf dip bioassay (Wang et al., 1971; Nauen, 2005) previously in the laboratory. The selection concentrations of each chemical were...
made with 10% to 90% corrected mortality after 24 h. Lethal and sublethal concentrations of each chemical were calculated by probit analysis using SPSS version 22.0 software (Weinberg & Abramowitz, 2016). In this experiment, we used LC$_{30}$ (0.065%, 0.049%, 0.024% and 0.08%) and LC$_{50}$ (0.196%, 0.110%, 0.051% and 0.024%) for SYP-9625, Abamectin, Vegetable oil and EnSpray 99, respectively.

**Experimental methodology**

The method adopted by Iftner and Hall (1983) was followed for the current experiment. Letters were assigned to leaves surfaces as; adaxial right (ADR), adaxial left (ADL), abaxial right (ABR), and abaxial left (ABL). We used a free choice and no choice method by dividing it into nine small experiments, as shown in Fig. 1. Chemicals were applied to the treated leaf surface with a hand sprayer. Untreated part of leaflet or surfaces was protected from chemicals spraying by cardboard shield and plastic bags. Each plant's ground surface was covered with plastic with double side sticky tape on the edge. The right adaxial surface was selected for easy to release mites (20 mites x 3 surfaces) and identified mites location from the inoculated surface after 30 minutes of chemicals application. Mites were captured 24 hours by location as per the experimental layout. The mites on the leaf surface, wet tissue paper (chemically treated), and plastic cover (chemical sprayed) were considered as dead. The mites not found as live or dead were considered missing mites. The experiments were used with three replications. The treated, un-treated, and half-treated data were combined for leaf surfaces (ADR, ADL, ABR, and ABL) further analysis. All experiments were performed in open-air environmental conditions.

**Statistical analysis**

The mean number of mites (LC$_{30}$ vs LC$_{50}$, Treated vs Un-treated, Treated vs Half-treated, and Adaxial vs Abaxial) were analyzed using an independent sample t-test. The difference between control and treatments captured mites means were analyzed using the general linear model (GLM) for ANOVA with Tukey’s HSD test ($P<0.05$). All statistical analysis procedures were calculated with Minitab® 17.3.1 version (Minitab, 2016). Graphical representation was done using GraphPad prism® (Motulsky, 2007) and OriginPro (Edwards, 2002).

A correlation analysis was conducted by comparing toxicity (% mortality) and % mites present on treated, un-treated, and half-treated surfaces to better understand the relationship between the behavioral responses of *P. citri*. Pearson correlation ($r$) and calculating $t$ distribution value formulas were used in R.

$$r = \frac{\sum (x-mx)(y-my)}{\sqrt{\sum (x-mx)^2 \sum (y-my)^2}}$$

$$t = \frac{r}{\sqrt{1-r^2}} \sqrt{n-2}$$

$n$ is the length of factor ($df = n-2$) in two vectors ($x$ (toxicity) and $y$ (mites observed on treated or untreated or half treated surfaces)) while $mx$ and $my$ are the means of vectors. The significant level can be determined by the $t$-value.
**Results**

**Toxicity**

Compared to control, acute toxicity of treatments was found significantly different within each dose in all experiments except in exp. no. 8 at LC$_{30}$. There was significant difference between doses within abamectin (For exp. no. 3; $t_{-5.56} = -5.00; P = 0.007$), SYP-9625 (For exp. no. 4; $t_{-7.78} = -3.50; P = 0.025$) and EnSpray (For exp. no. 4; $t_{-8.89} = -8.37; P = 0.000$) and vegetable oil (For exp. no. 8; $t_{-4.44} = -2.828; P = 0.047$) than others. Differences in toxicity (from LC$_{30}$ to LC$_{50}$) of chemicals to adult (female) *P. citri* occurred among experiments depending on application methods, with ranges in SYP-9625, abamectin, vegetable oil, and EnSpray of 1.156 – 2.399-fold, 1.33 – 5.556 fold, 1.249 – 5.005 fold and 0 – 8.889 fold, respectively. Maximum toxicity (%) was observed in the no-choice experiment (the whole plant treated – exp. no. 9), and SYP-9625 more toxic (except in exp. no. 2) than others in all experiments (Table 1).

**Re-captured Panonychus citri**

According to Fig. 1, the experimental layout is further divided into three parts; Treated vs Untreated (Experiments 1-6), Treated vs Half-treated (Experiments 7-8), and the whole plant treated (Adaxial vs Abaxial) (Experiment 9).

Mites dispersal within the ADR surface were observed 40% to 82.24% (LC$_{30}$) and 53.7 to 94.067% (LC$_{50}$) from treated to untreated. The difference between treated and untreated was significantly recognizable. A significant difference was observed in all treatments between the mean number of mites captured on the treated and un-treated on the ADR: SYP-9625 ($t_{-9.22} = -5.56; P = 0.000$), Abamectin ($t_{-7.667} = -8.37; P = 0.000$), vegetable oil ($t_{-10.78} = -9.17; P = 0.000$) and EnSpray ($t_{-8.89} = -8.37; P = 0.000$) except control ($t_{-8.11} = -5.78; P = 0.097$), at LC$_{30}$ while similar results found by applying the LC$_{50}$ doses. The number of mites captured on the treated ADR surface was lower than the number of mites captured on the untreated surface. A maximum number of mites were observed under the un-treated ADR surface at LC$_{30}$ dose of vegetable oil than in the others (Fig. 2).

On the Adaxial surface of left side (ADL), a significant difference was observed within all treatments between the mites captured on the treated and un-treated ADL surfaces: control ($t_{-2.778} = -2.94; P = 0.015$ and $t_{-2.778} = -2.94; P = 0.015$), SYP-9625 ($t_{-6} = -3.45; P = 0.006$ and $t_{-10.22} = -8.72; P = 0.000$), Abamectin ($t_{-5.778} = -6.28; P = 0.000$ and $t_{-7.78} = -5.29; P = 0.001$), vegetable oil ($t_{-4.22} = -2.37; P = 0.042$ and $t_{-4.67} = -3.78; P = 0.004$) and EnSpray ($t_{-4.33} = -3.99; P = 0.002$ and $t_{-9.11} = -4.77; P = 0.001$) on the LC$_{30}$ and LC$_{50}$ doses respectively. A higher number of mites captured on the un-treated surface at LC$_{50}$ of SYP-9625 than others (Fig. 3).

The *Panonychus citri* less visited the abaxial surface than the adaxial surface, so a small number of mites (Mean±SE) were captured but enough for the difference between treated and untreated surfaces. At LC$_{30}$ doses, the data collected from abaxial surface of right side (ABR) was significantly different on treated and untreated surfaces: Abamectin ($t_{-1.889} = -6.8; P = 0.000$), EnSpray ($t_{-1.889} = -3.3; P = 0.005$) and control ($t_{-1.444} = -2.25; P = 0.041$). By treating ABR
with lethal concentrations (LC$_{50}$) was significantly different on treated and untreated surfaces by treated with vegetable oil ($t_{3.222} = -4.24$; $P = 0.002$) while SYP-9625, abamectin, and EnSpray 99 were similar between the replication within treated or untreated. The number of mites found maximum on the un-treated ABR surface treated with LC$_{50}$ of abamectin (6.78±0.813) (Fig. 4).

The difference between treated and un-treated was observed significant within all treatments: SYP-9625 ($t_{2} = -4.1$; $P = 0.003$), abamectin ($t_{3.11} = -4.37$; $P = 0.002$), vegetable oil ($t_{2} = -4.94$; $P = 0.001$) and EnSpray 99 ($t_{2.33} = -3.61$; $P = 0.006$) except control at LC$_{30}$ doses on the abaxial surface of left side (ABL). No mites were observed after treatment with LC$_{50}$ doses on ABL except vegetable oil ($t_{3.33} = -4.87$; $P = 0.001$) and control (non-significant). Maximum number of mites found on un-treated surfaces depending on the concentration of chemicals (Fig. 5).

On the adaxial surfaces, difference between treated and half-treated surfaces were found similar (non-significant) at LC$_{30}$ except on vegetable oil application ($t_{4.33} = 2.8$; $P = 0.038$) while at LC$_{50}$, all treatments found significant different (For SYP-9625: $t_{8.5} = 8.77$, $P = 0.000$; abamectin: $t_{9.167} = 10.51$, $P = 0.000$; vegetable oil: $t_{6.167} = 9.43$, $P = 0.000$; EnSpray: $t_{8.5} = 7.54$, $P = 0.001$) (Fig. 6).

In no choice test (whole plant treated), a significant difference was observed within all treatments (between adaxial and abaxial surfaces): SYP-9625 ($t_{4} = -6.71$; $P = 0.001$), Abamectin ($t_{3.17} = 2.53$; $P = 0.035$), vegetable oil ($t_{8} = -5.37$; $P = 0.003$) and EnSpray 99 ($t_{7.67} = -3.04$; $P = 0.029$) except control ($t_{1.33} = -1.15$; $P = 0.285$) at LC$_{30}$ doses while all treatments found no difference between adaxial and abaxial surfaces at LC$_{50}$ doses (Fig. 8).

Correlation analysis

The correlation between toxicity vs treated and toxicity vs un-treated on both surfaces, either right or left, were found negatively correlated except EnSpray and abamectin (Toxicity vs Treated) at LC$_{30}$ and LC$_{50}$, respectively (Supplementary Table 1).

The relationship between toxicity and treated surfaces was positively correlated at LC$_{30}$ on adaxial (SYP-9625, abamectin, and EnSpray) and abaxial surfaces (abamectin and EnSpray). There was a significant correlation between toxicity and sublethal half-treated abaxial surfaces of SYP-9625, abamectin, and EnSpray 99. There was a positive correlation between toxicity and lethal half-treated adaxial surface for vegetable oil and EnSpray 99. In contrast, on the abaxial surface, only SYP-9625 was found positively correlated (Supplementary Table 2). In a no-choice experiment (the whole plant treated), a positive correlation was observed by treatment with vegetable oil (toxicity vs adaxial) at both concentrations (Supplementary Table 3).

Discussion

Mites disperse themselves by walking (Sabelis & Dicke, 1985) to find a suitable site for colonization and feeding (Tixier et al., 2000; Aguilar-Fenollosa et al., 2016; Moerman, 2016;
Mukwevho et al., 2017; Sousa et al., 2019). One major factor for dispersal is environmental contamination, due to pesticide application (Lima et al., 2015; Guedes et al., 2016; Mohammed et al., 2019; Monteiro et al., 2019b). This study aimed to determine whether synthetic chemicals and oils respond similarly to the dispersal and colonization behavior of *Panonychus citri*. The physio-morphic characteristics of leaf such as leaf surfaces and leaf domatia play an essential role in habitat selection (O’Dowd & Pemberton, 1994, 1998; Tixier et al., 2000; English-Loeb et al., 2002; Romero & Benson, 2004). The majority of mites (Tetranychids) prefer to feed and oviposit on the leaves' abaxial surface. In contrast, some phytophagous mites like *P. citri* and *Tetranychus urticae* are preferred on both surfaces (Azandeme-Hounmalon et al., 2014). This mites distribution from treated surfaces due to chemical cues (Domingos et al., 2010; Melo et al., 2011) and maybe their phylogenetical responses (Rollo et al., 1994; Nilsson & Bengtsson, 2004; Cisak et al., 2012; Buehlmann et al., 2014).

In the citrus growing region of South China, SYP-9625 and abamectin are commonly used against different pests, including citrus red mite (Meng et al., 2002; Fang et al., 2013; Huixia et al., 2013; Liao et al., 2016; Dou et al., 2017). SYP-9625 is commonly used against phytophagous mites with minimum hazard to animals (Li et al., 2010; Chai et al., 2011; Huixia et al., 2013; Yu et al., 2016; Liu et al., 2018; Ouyang et al., 2018; Chen et al., 2019). Liu et al. (2018) reported that SYP-9625 gave maximum mortality and dispersed against *P. citri* in the no-choice test, similar to our results and against *Tetranychus citri* (Chen et al., 2019). Abamectin showed less repellency than SYP-9625 against *P. citri* (Dou et al., 2017) due to resistance development (NATESC, 2003; Hu et al., 2010; Liao et al., 2016).

By contrast to synthetic chemicals, plant-based derivatives (such as vegetable oils) are used as alternatives (Flamini, 2003) due to their compatibility with non-target organisms, low toxicity, negligible resistance development, and eco-friendly (Marcic, 2012). Fatty acids that are significant vegetable oil components are active ingredients that increase their toxicity against pests (Baldwin et al., 2009; Sims et al., 2014). Linoleic acid that is an important component of vegetable oil resulted in attractive responses (Rollo et al., 1994; Buehlmann et al., 2014), as *P. citri* found on treated surfaces (at LC₅₀) after 24 hours in this study. The short-chain compound (palmitic acid) in vegetable oil gave equal repellency to synthetic chemicals in previous studies (Mullens et al., 2009; Buehlmann et al., 2014). Vegetable oils gave similar responses to synthetic chemicals with a slow mode of action. They can be used as an alternative against *P. citri* with Ribeiro et al. (2014) endorsement.

EnSpray 99 exhibits minimum toxic residues on the treated fruit surfaces by losing their toxicity (Zhuang et al., 2015). The efficacy of EnSpray 99 has been reported against different pests, including citrus red mites by many researchers (Wang et al., 2004; Chen & Zhan, 2007; Tao & Xiao-fang, 2011; Teifeng et al., 2011; Zhuang et al., 2015). The EnSpray 99 contains paraffinic oil more than 60%, which was also found on the fruit residues (Ahmad et al., 2018) and effectively used against *P. citri* (Riehl & Jeppson, 1953; Trammel, 1965). The study shows that EnSpray 99 responded similarly to vegetable oil and synthetic chemicals against the repellency and dispersal of *P. citri*. The recommended concentrations ranging from 0.5 to 1.4% against *P.*
*cirti* and eriophyids (Benfatto et al., 2002; Tang et al., 2002) while Wang et al. (2004) used 14.11 mgL⁻¹ (LC₅₀) against *P. citri* in the laboratory. EnSpray 99 can be used against *P. citri* control strategies by keeping their impact on pest resistance development, environmental contamination, plant growth reduction, and chronic and acute effect on humans (Ahmed & Fakhruddin, 2018).

According to a free-choice bioassay on dispersal, all mites were significantly dispersed towards the un-treated and half-treated surfaces. According to Alves et al. (2005), untreated surfaces were significantly preferred by the *P. citri* at the adult stage for feeding and oviposition. Maximum dispersal from treated to un-treated or half-treated surfaces depended on the concentration of chemicals Iftner & Hall (1983). The dispersal towards half-treated adaxial surfaces was significantly different from vegetable oil application than others at LC₃₀, as observed by Alves et al. (2018).

The comprehensive assessments of these chemicals against *P. citri* need a more detailed study. The surface treated with these chemicals may affect natural enemies efficiency. However, the experiment carried out here did not evaluate the other factors and needed attention to more applied work.

**Conclusions**

In conclusion, *P. citri* preferred site adaxial surfaces of citrus leaves for feeding and colonization which were the best sprayed sites for acaricides. However, spraying more times and unequally, *P. citri* would disperse more quickly. Vegetable oil and EnSpray 99 were the least affecting the colonization depending on mite release point and SYP-9625 gave maximum repellency with a higher number of missing or dead mites recorded.

**Acknowledgments**

This work was funded by National Key R&D Program of China (2017YFD0202000), Dean fund of Guangdong Academy of Agricultural Sciences (BZ201906), China Postdoctoral Research Foundation supported the research (229807), China Litchi and Longan Research System Foundation (CARS-32-12), and Discipline team-building projects of Guangdong Academy of Agricultural Sciences in the 13th Five-year period were the support funding agencies for this research work.

**References**

Aguilar-Fenollosa E, Rey-Caballero J, Blasco JM, Segarra-Moragues JG, Hurtado MA, Jaques JA. 2016. Patterns of ambulatory dispersal in *Tetranychus urticae* can be associated with host plant specialization. *Experimental and Applied Acarology* 68:1–20.

Ahmad MM, Wani AA, Sofi M, Ara I. 2018. Mineral oil residues in soil and apple under temperate conditions of Kashmir, India. *Environmental Monitoring and Assessment* 190. DOI: 10.1007/s10661-018-6586-6.

Ahmed F, Fakhruddin ANM. 2018. A review on environmental contamination of petroleum hydrocarbons and its biodegradation. *International journal of environmental sciences and natural resources* 11:1–7. DOI: 10.19080/IJESNR.2018.11.555811.

AliNiazee MT, Cranham JE. 1980. Effect of four synthetic pyrethroids on a predatory mite, *Typhlodromus pyri*. on apples in southeast England. *Environ Entomol* 9:436–439.

Alves EB, Casarin NF, Omoto C. 2005. Mecanismos de dispersão de *Brevipalpus phoenicis* (Geijskes) (Acari: Tenuipalpidae) em pomares de citros. *Neotropical Entomology* 34:89–96.
Alves EB, Casarin NFB, Omoto C. 2018. Lethal and sublethal effects of pesticides used in Brazilian citrus groves on *Panonychus citri* (Acari: Tetranychidae). *Arquivos do Instituto Biológico* 85.

Azandeme-Hounmalon GY, Fellous S, Kreiter S, Fiaboe KKM, Subramanian S, Kungu M, Martin T. 2014. Dispersal behavior of *Tetranychus evansi* and *T. urticae* on tomato at several spatial scales and densities: implications for integrated pest management. *Plos One* 9.

Baldwin RW, Koehler PG, Pereira RM. 2009. Toxicity of fatty acid salts to German and American cockroaches. *Indian Journal of Natural Products and Resources* 8:1384–1388. DOI: 10.1093/jee/101.4.1384.

Begon M, Towsend CR, Harper JL. 2007. Organismos. In: Begon M, Towsend CR, Harper JL (eds.) *Ecologia: de indivíduos a ecossistemas*. Artmed, Porto Alegre, RS., 162–185.

Bell JR, Bohan D a, Shaw EM, Weyman GS. 2005. Ballooning dispersal using silk: world fauna, phylogenies, genetics and models. *Bulletin of entomological research* 95:69–114. DOI: 10.1079/BER2004350.

Benfatto D, Giudice V Lo, Conti F, Tumminelli R. 2002. Spray oil evolution in Italian citrus groves. In: Beattie GA., Watson DM, Stevens ML, Rae DJ, Spooner-Hart RN eds. *Spray oils beyond 2000: sustainable pest and disease management*. University of Western Sydney, Sydney, Australia, 419.

Bergman CM, Schaefer JA, Luttich SN. 2000. Caribou movement as a correlated random walk. *Oecologia* 123:364–374.

Biondi A, Zappalà L, Stark JD, Desneux N. 2013. Do biopesticides affect the demographic traits of a parasitoid wasp and its biocontrol services through sublethal effects? *PLoS One* 8:e76548.

Bowler DE, Benton TG. 2005. Causes and consequences of animal dispersal strategies: relating individual behaviour to spatial dynamics. *Biological Reviews* 80:205–225.

Buehlmann C, Graham P, Hansson BS, Knaden M. 2014. Desert ants locate food by combining high sensitivity to food odors with extensive crosswind runs. *Current Biology* 24:960–964. DOI: 10.1016/j.cub.2014.02.056.

Chai B, Liu C, Li H, Zhang H, Liu S, Huang G, Chang J. 2011. The discovery of SYP-10913 and SYP-11277: novel strobilurin acaricides. *Pest Manag Sci* 67:1141–1146. DOI: 10.1007/s10493-019-00359-3.

Chen JC, Gong YJ, Shi P, Wang ZH, Cao LJ, Wang P, Wei SJ. 2019. Field-evolved resistance and cross-resistance of the two-spotted spider mite, *Tetranychus urticae*, to bifenazate, cyenopyrafen and SYP-9625. *Experimental and Applied Acarology* 77:545–554. DOI: 10.1007/s10493-019-00359-3.

Chen Z, Ran C, Zhang L, Dou W, Wang J. 2009. Susceptibility and esterase activity in citrus red mite *Panonychus citri* (McGregor) (Acari: Tetranychidae) after selection with phoxim. *International Journal of Acarology* 35:33–40. DOI: 10.1080/0167750802655293.

Chen Z, Zhan H. 2007. Effects of 99% EnSpray EC on controlling leaf folder (*Cnaphalocrocis medinalis* G.), strip borer (*Chilo suppressalis* W.) and planthopper in rice CHEN. *Guangxi Agricultural Sciences*:415–417.

Cisak E, Wójcik-Fatla A, Zajac V, Dutkiewicz J. 2012. Repellents and acaricides as personal
protection measures in the prevention of tick-borne diseases. *Annals of Agricultural and Environmental Medicine* 19:625–630.

Clobert J, Danchin E, Dhondt AA, Nichols JD. 2001. *Dispersal*. Oxford: Oxford University Press.

Clobert J, Le Galliard J, Cote J, Meylan S, Massot M. 2009. Informed dispersal, heterogeneity in animal dispersal syndromes and the dynamics of spatially structured populations. *Ecology letters* 12:197–209.

Cordeiro GEM, Corre AS, Guedes RNC. 2014. Insecticide-Mediated shift in ecological dominance between two competing species of grain beetles. 9:1–9. DOI: 10.1371/journal.pone.0100990.

Desneux N, Decourtye A, Delpuech J-M. 2007. The sublethal effects of pesticides on beneficial arthropods. *Annu. Rev. Entomol.* 52:81–106.

Dittrich V, Cranham J, Jepson L, Helle W. 1980. Revised method for spider mites and their eggs (eg *Tetranychus spp.* and *Panonychus ulmi* Koch), FAO method no. 10a. *FAO Plant Prod Prot Pap* 21:49–53.

Domingos CA, Melo JWDS, Gondim MGC, de Moraes GI, Hanna R, Lawson-Balagbo LM, Schausberger P. 2010. Diet-dependent life history, feeding preference and thermal requirements of the predatory mite *Neoseiulus baraki* (Acari: Phytoseiidae). *Experimental and Applied Acarology* 50:201–215. DOI: 10.1007/s10493-009-9308-5.

Dou W, Xia W-K, Niu J-Z, Wang J-J. 2017. Abamectin treatment affects glutamate decarboxylase expression and induces higher GABA levels in the citrus red mite, *Panonychus citri*. *Experimental and Applied Acarology* 72:229–244.

Dunning Jr JB, Stewart DJ, Danielson BJ, Noon BR, Root TL, Lamberson RH, Stevens EE. 1995. Spatially explicit population models: current forms and future uses. *Ecological Applications* 5:3–11.

Edwards PM. 2002. Origin 7.0: scientific graphing and data analysis software. *Journal of chemical information and computer sciences* 42:1270–1271.

Evans GO. 1992. Principles of acarology.

Fadamiro HY, Akotsen-Mensah C, Xiao Y, Anikwe J. 2013. Field evaluation of predacious mites (Acari: Phytoseiidae) for biological control of citrus red mite, *Panonychus citri* (Trombidiformes: Tetranychidae). *Florida Entomologist*:80–91.

Faez R, Fathipour Y, Ahadiyat A, Shojai M. 2018a. How Quantitative and Qualitative Traits of Thomson Navel Orange Affected by Citrus Red Mite, *Panonychus citri*. *Journal of Agricultural Science and Technology* 20:1431–1442.

Faez R, Shojaei M, Fathipour Y, Ahadiyat A. 2018b. Effect of initial infestation on population fluctuation and spatial distribution of *Panonychus citri* (Acari: Tetranychidae) on Thomson navel orange in Ghaemshahr, Iran. *Persian Journal of Acarology* 7.

Fang X, Ouyang G, Lu H, Guo M, Meng X, Liu H. 2013. The effects of different control measures on *Panonychus citri* and arthropod enemies in citrus orchards. *Chinese Journal of Applied Entomology* 50:413–420.

Fernández-Caldas E, Puerta L, Caraballo L, Lockey RF. 2014. Mite Allergens. In: *Allergens and Allergen Immunotherapy*. Taylor & Francis, 181–201.

Flamini G. 2003. Acaricides of natural origin, personal experiences and review of literature.
Gotoh T, Kubota M. 1997. Population dynamics of the citrus red mite, Panonychus citri (McGregor) (Acari: Tetranychidae) in Japanese pear orchards. Experimental and Applied Acarology 21:343–356. DOI: 10.1023/A:1018467526187.

Gu Q, Chen W, Wang L, Shen J, Zhang J. 2010. Effects of sublethal dosage of abamectin and pyridaben on life table of laboratory populations of Tetranychus turkestani (Acari: Tetranychidae). Acta Entomologica Sinica 53:876–883.

Guedes RNC, Smagghe G, Stark JD, Desneux N. 2016. Pesticide-induced stress in arthropod pests for optimized integrated pest management programs. Annual review of entomology 61:43–62.

Hanski I. 1998. Metapopulation dynamics. Nature 396:41–49.

Hanski I. 1999. Metapopulation ecology. Oxford University Press.

He HG, Jiang HB, Zhao ZM, Wang JJ. 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. DOI: 10.1080/01647954.2010.491798.

Hu J, Wang C, Wang J, You Y, Chen F. 2010. Monitoring of resistance to spirodiclofen and five other acaricides in Panonychus citri collected from Chinese citrus orchards. Pest Manag Sci 66:1025–1030. DOI: 10.1002/ps.1978.

Huxia T, Chun R, Hongjun L. 2013. Efficacy Trials of 15% SYP-11277 Solution on Panonychus citri. Pesticide Science and Administration:25.

Ibrahim Y Bin, Yee TS. 2009. Influence of Sublethal Exposure to Abamectin on the Biological Performance of Neoseiulus longispinosus (Acari: Phytoseiidae). Journal of Economic Entomology 93:1085–1089. DOI: 10.1603/0022-0493-93.4.1085.

Iftner DC, Hall FR. 1983. Effects of Fenvalerate and Permethrin on Tetranychus urticae Koch (Acari: Tetranychidae) dispersal behavior. Environmental Entomology 12:1782–1786. DOI: 10.1093/ee/12.6.1782.

Ims RA, Hjermann DØ. 2001. Condition-dependent dispersal. In: Dispersal. Oxford: Oxford University Press, 203–216.

Ismail MSM, Ghallab M, Soliman MFM, AboGhalia AH. 2011. Acaricidal activities of some essential and fixed oils on the two-spotted spider mite, Tetranychus urticae. Egyptian Academic Journal of Biological Sciences, B. Zoology 3:41–48. DOI: 10.21608/eajbsz.2011.14314.

Isman MB. 2008. Botanical insecticides: for richer, for poorer. Pest Management Science: formerly Pesticide Science 64:8–11.

Karmakar S. 2019. A study on different biochemical components of papaya (Carica papaya) leaves consequent upon feeding of citrus red mite (Panonychus citri). In: Biotechnology and Biological Sciences: Proceedings of the 3rd International Conference of Biotechnology and Biological Sciences (BIOSPECTRUM 2019), August 8-10, 2019, Kolkata, India. CRC Press, 69.

Kasap İ. 2009. The biology and fecundity of the citrus red mite Panonychus citri (McGregor) (Acari: Tetranychidae) at different temperatures under laboratory conditions. Turkish Journal of Agriculture and Forestry 33:593–600.

Korhayli S, Barbar Z, Aslan L. 2018. Population Dynamics of the Phytophagous Mites’ Predators in Lemon Orchards in Lattakia Governorate, Syria. Arab Journal Of Plant
Koulbanis C, N’guyen QL, Zabotto A, Plot J, Koulbanis IC, Guyen LNQ, Zabotto A, Plot J. 1984. Mixture of vegetable oils based on jojoba oil and cosmetic compositions comprising the mixture.

Kranz J, Schmutterer H, Koch W. 1978. Diseases, pests, and weeds in tropical crops. *Soil Science* 125:272.

Kumral NA, Cobanoglu S, Yalcin C. 2010. Acaricidal, repellent and oviposition deterrent activities of *Datura stramonium* L. against adult *Tetranychus urticae* (Koch). *Journal of Pest Science* 83:173–180. DOI: 10.1007/s10340-009-0284-7.

Li Y, Liu C, Tian J, Zhou Y, Zhang H, Song Y. 2010. Research of novel 2-acyl cyanoacetic acid derivative SYP-10898. *Chinese Journal of Pesticide Science*:12.

Liao C-Y, Xia W-K, Feng Y-C, Li G, Liu H, Dou W, Wang J-J. 2016. Characterization and functional analysis of a novel glutathione S-transferase gene potentially associated with the abamectin resistance in *Panonychus citri* (McGregor). *Pesticide biochemistry and physiology* 132:72–80.

Lima DB, Melo JWS, Guedes RNC, Oliveira JEM, Pallini A. 2015. Acaricide-impaired functional predation response of the phytoseiid mite *Neoseiulus baraki* to the coconut mite *Aceria guerreronis*. *Ecotoxicology*. DOI: 10.1007/s10646-015-1459-z.

Lima DB, Melo JWS, Guedes RNC, Siqueira HAA, Pallini A, Gondim MGC. 2013. Survival and behavioural response to acaricides of the coconut mite predator *Neoseiulus baraki*. *Experimental and Applied Acarology* 60:381–393. DOI: 10.1007/s10493-012-9644-8.

Liu S-W, Song Y, Zhang J, Eng C, Ban L, Li B. 2018. Control Effects of SYP - 9625 30 % SC Against Different Mite Targets in Field. *Modern Agrochemicals* 17:18–21.

Liu Z, Xu C, Beattie GA, Zhang X, Cen Y. 2019. Influence of different fertilizer types on life table parameters of citrus red mite, *Panonychus citri* (Acari: Tetranychidae). *Systematic and Applied Acarology* 24:2209–2218.

Marcic D. 2012. Acaricides in modern management of plant-feeding mites. *Journal of Pest Science* 85:395–408. DOI: 10.1007/s10340-012-0442-1.

Melo JWS, Lima DB, Pallini A, Oliveira JEM, Gondim MGC. 2011. Olfactory response of predatory mites to vegetative and reproductive parts of coconut palm infested by *Aceria guerreronis*. *Experimental and Applied Acarology* 55:191–202.

Melo JWS, Lima DB, Sabelis MW, Pallini A, Gondim MGC. 2014. Behaviour of coconut mites preceding take-off to passive aerial dispersal. *Experimental and Applied Acarology* 64:429–443.

Meng H, Wang K, Jiang X, Yi M. 2002. Studies on resistance selection by abamectin and fenpropathrin and activity change of detoxicant enzymes in *Panonychus citri*. *Acta Entomologica Sinica* 45:58–62.

Minitab. 2016. Minitab statistical software, ver. 17.3. 1.

Moerman F. 2016. Eco-evolutionary responses along an experimental dispersal front, using *Tetranychus urticae* as a model species.

Mohammed AAAH, Desneux N, Monticelli LS, Fan Y, Shi X, Guedes RNC, Gao X. 2019. Potential for insecticide-mediated shift in ecological dominance between two competing aphid species. *Chemosphere* 226:651–658.

Monteiro VB, França G V, Gondim MGC, Lima DB, Melo JWS. 2019a. Walking dispersal by *Neoseiulus baraki* (Acari: Phytoseiidae) on coconut plants. *Systematic and Applied Acarology* 24:1337–1342.
Monteiro VB, Lima DB, Melo JWS, Guedes RNC, Gondim MGC. 2019b. Acaricide-Mediated Colonization of Mite-Infested Coconuts by the Predatory Phytoseiid Neoseiulus baraki (Acari: Phytoseiidae). *Journal of Economic Entomology* 112:213–218. DOI: 10.1093/jee/toy291.

Motulsky HJ. 2007. Prism 5 statistics guide, 2007. *GraphPad Software* 31:39–42.

Mukwevho L, Olckers T, Simelane DO. 2017. Establishment, dispersal and impact of the flower-galling mite *Aceria lantanae* (Acari: Trombidiformes: Eriophyidae) on *Lantana camara* (Verbenaceae) in South Africa. *Biological Control* 107:33–40.

Mullens BA, Reifenrath WG, Butler SM. 2009. Laboratory trials of fatty acids as repellents or antifeedants against houseflies, horn flies and stable flies (Diptera: Muscidae). *Pest Management Science* 65:1360–1366. DOI: 10.1002/ps.1823.

NATESC. 2003. Monitoring results of pesticide resistance of crop pests of national significance. *Pesticide Express* 331:23–24.

Nauen R. 2005. Spirodiclofen: Mode of Action and Resistance Risk Assessment in Tetranychid Pest Mites. *Journal of Pesticide Science* 30:272–274. DOI: 10.1584/jpestics.30.272.

Nilsson E, Bengtsson G. 2004. Endogenous free fatty acids repel and attract collembola. *Journal of Chemical Ecology* 30:1431–1443. DOI: 10.1023/B:JOEC.0000037749.75695.e5.

O’Dowd DJ, Pemberton RW. 1994. Leaf domatia in Korean plants: floristics, frequency, and biogeography. *Vegetatio* 114:137–148.

O’Dowd DJ, Pemberton RW. 1998. Leaf domatia and foliar mite abundance in broadleaf deciduous forest of north Asia. *American Journal of Botany* 85:70–78.

Oliveira NNFCFC, Galvão AS, Amaral EA, Santos AWOO, Sena-Filho JG, Oliveira EE, Teodoro A V., Galvao AS, Amaral EA, Santos AWOO, Sena-Filho JG, Oliveira EE, Teodoro A V. 2017. Toxicity of vegetable oils to the coconut mite *Aceria guerreronis* and selectivity against the predator *Neoseiulus baraki*. *Experimental and Applied Acarology* 72:23–34. DOI: 10.1007/s10493-017-0134-x.

Ouyang J, Tian Y, Jiang C, Yang Q, Wang H, Li Q. 2018. Laboratory assays on the effects of a novel acaricide, SYP-9625 on *Tetranychus cinnabarinus* (Boisduval) and its natural enemy, *Neoseiulus californicus* (McGregor). *Plos One* 13:e0199269.

Perotti MA, Braig HR. 2009. Phoretic mites associated with animal and human decomposition. *Experimental and Applied Acarology* 49:85–124. DOI: 10.1007/s10493-009-9280-0.

Pralavorio M, Fournier D, Millot P. 1989. Migratory activity of mites: evidence of a circadian rhythm. *Entomophaga* 34:129–134.

Riehl LA, Jeppson LR. 1953. Narrow-Cut Petroleum Fractions of Naphthenic and Paraffinic Composition for Control of Citrus Red Mite and Citrus Bud Mite1. *Journal of Economic Entomology* 46:1014–1020. DOI: 10.1093/jee/46.6.1014.

Rollo CD, Czyzewska E, Borden JH. 1989. Migratory activity of mites: evidence of a circadian rhythm. *Entomophaga* 34:129–134.

Ronce O. 2007. How does it feel to be like a rolling stone? Ten questions about dispersal evolution. *Annu. Rev. Ecol. Evol. Syst.* 38:231–253.

Sabelis MW, Afman BP. 1994. Synomone-induced suppression of take-off in the phytoseiid mite *Phytoseiulus persimilis* Athias-Henriot. *Experimental & applied acarology* 18:711–721.

Sabelis MW, Dicke M. 1985. Long range dispersal and searching behaviour. In: *Spider mites and their control*. Elsevier, 141–160.
Shi WB, Feng MG. 2006. Field efficacy of application of Beauveria bassiana formulation and low rate pyridaben for sustainable control of citrus red mite Panonychus citri (Acari: Tetranychidae) in orchards. Biological Control 39:210–217.

DOI: 10.1016/j.biocontrol.2006.06.016.

Sims SR, Balusu RR, Ngumbi EN, Appel AG. 2014. Topical and vapor toxicity of saturated fatty acids to the German cockroach (Dictyoptera: Blattellidae). Journal of Economic Entomology 107:758–763. DOI: 10.1603/ec12515.

Sousa VC, Zélé F, Rodrigues LR, Godinho DP, de la Masselière MC, Magalhães S. 2019. Rapid host-plant adaptation in the herbivorous spider mite Tetranychus urticae occurs at low cost. Current opinion in insect science.

Strong WB, Slone DH, Croft BA. 1999. Hops as a metapopulation landscape for tetranychid-phytoseiid interactions: perspectives of intra-and interplant dispersal. Experimental & applied acarology 23:581–597.

Tak J-H, Isman MB. 2017. Acaricidal and repellent activity of plant essential oil-derived terpenes and the effect of binary mixtures against Tetranychus urticae Koch (Acari: Tetranychidae). Industrial crops and products 108:786–792.

Tang ML, Chen CX, Xie ST, Zhang ZH, Yang QY. 2002. Demonstration of horticultural mineral oil–based citrus IPM programs in China. In: Spray Oils Beyond 2000: Sustainable Pest and Disease Management: Proceedings of a Conference Held from 25 to 29 October 1999 in Sydney, New South Wales, Australia. University of Western Sydney, 372.

Tao L, Xiao-fang Z. 2011. Occurrence Harm and Control of Phenacoccus fraxinus of Lanzhou. Journal of Gansu Forestry Science and Technology 36:43–45.

Teifemg Z, Chunhua S, Quizhu Y, Ailan Z, Haitao H. 2011. Efficacy of three pesticides to control Acaphylla theae and Empoasca vitis (Gothe) in tea field. Journal of Tea 37:11–13.

Tixier M-S, Kreiter S, Auger P. 2000. Colonization of vineyards by phytoseiid mites: their dispersal patterns in the plot and their fate. Experimental & applied acarology 24:191–211.

Tixier MS, Kreiter S, Auger P, Weber M. 1998. Colonization of Languedoc vineyards by phytoseiid mites (Acari: Phytoseiidae): Influence of wind and crop environment. Experimental and Applied Acarology 22:523–542. DOI: 10.1023/A:1006085723427.

Trammel K. 1965. Properties of petroleum oils in relation to toxicity to citrus red mite eggs. Journal of Economic Entomology 58:595–601. DOI: 10.1093/jee/1.4.277.

Turchen LM, Golin V, Butnariu AR, Guedes RNC, Pereira MJB. 2016. Lethal and sublethal effects of insecticides on the egg parasitoid Telenomus podisi (Hymenoptera: Platygastridae). Journal of economic entomology 109:84–92.

Turchin P. 1998. Quantitative analysis of movement. Sinauer assoc. Sunderland (mass.).

Wang Q, Gu X, Bei Y. 2004. Activities of EnSpray, a petroleum spray oil, on insect pests and joint actions of its mixtures. Acta Agriculturae Zhjiangensis 16:321–323.

Wang S, Tang X, Wang L, Zhang Y, Wu Q, Xie W. 1971. Effects of sublethal concentrations of bifenthrin on the two-spotted spider mite, Tetranychus urticae (Acari: Tetranychidae). Systematic and Applied Acarology 4:481–490.

Weinberg SL, Abramowitz SK. 2016. Statistics using IBM SPSS: An integrative approach. Cambridge university press.

Xue Y, Andrew G, Beattie C, Meats A, Spooner-Hart R, Herron GA. 2009a. Impact of nC24 agricultural mineral oil deposits on the searching efficiency and predation rate of the predatory mite Phytoseiulus persimilis Athias-Henriot (Acari: Phytoseiidae). Australian Journal of Entomology 48:258–264. DOI: 10.1111/j.1440-6055.2009.00714.x.
Xue Y, Meats A, Beattie GAC, Spooner-Hart R, Herron GA. 2009b. The influence of sublethal deposits of agricultural mineral oil on the functional and numerical responses of *Phytoseiulus persimilis* (Acari: Phytoseiidae) to its prey, *Tetranychus urticae* (Acari: Tetranychidae). *Experimental and Applied Acarology* 48:291–302. DOI: 10.1007/s10493-009-9242-6.

Yu H, Cheng Y, Xu M, Song Y, Luo Y, Li B. 2016. Synthesis, acaricidal activity and structure–activity relationships of pyrazolyl acrylonitrile derivatives. *Journal of Agricultural and Food Chemistry* 51.

Yuan M-L, Wei D-D, Zhang K, Gao Y-Z, Liu Y-H, Wang B-J, Wang J-J. 2010. Genetic diversity and population structure of *Panonychus citri* (Acari: Tetranychidae), in China based on mitochondrial COI gene sequences. *Journal of Economic Entomology* 103:2204–2213. DOI: 10.1603/ec09392.

Zhuang QG, Wang LH, Li MZ, Hou TP, Xie Y. 2015. “EnSpray 99” mineral oils for white peach scale, *Pseudaulacaspis pentagona* and phytotoxicity to “Hongyang” kiwifruit. *Acta Horticulturae* 1096:363–370. DOI: 10.17660/ActaHortic.2015.1096.42.

Zwick RW, Field GJ. 1987. Field and laboratory evaluations of fenvalerate against several insect and mite pests of apple and pear in Oregon. *Journal of economic entomology* 71:793–796.
**Table 1** (on next page)

Toxicity of *Panonychus citri* (% mortality ± SE) 24 hours within nine experiment combinations.

Capital letters indicate the differences among the LC\textsubscript{30} of treatments with control and lowercase indicates differences among the LC\textsubscript{50} of treatments with a control. Different letters in the same column are significantly different at the Tukey test (\( \alpha = 0.05 \)).
Table 1: Toxicity of *Panonychus citri* (% mortality ± SE) 24 hours within nine experiment combinations. Capital letters indicate the differences among the LC$_{30}$ of treatments with control and lowercase indicates differences among the LC$_{50}$ of treatments with a control. Different letters in the same column are significantly different at the Tukey test ($\alpha = 0.05$).

| Treatment       | Concentrations (%) | Experiments | 1          | 2          | 3          | 4          | 5          | 6          | 7          | 8          | 9          |
|-----------------|--------------------|-------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| SYP-9625        | LC$_{30}$          |             | 10 ± 0 A  | 0 ± 0 B   | 8.889 ± 1.11 A | 5.556 ± 1.11 A | 6.667 ± 0 A | 5.556 ± 2.22 A | 13.33 ± 1.925 A | 6.667 ± 0 A | 35.556 ± 5.5 |
|                 | LC$_{50}$          |             | 12.22 ± 2.22 a | 2.22 ± 1.11 b | 12.22 ± 1.11 a | 13.33 ± 1.925 a | 8.889 ± 2.22 a | 7.778 ± 1.11 a | 17.778 ± 1.11 a | 7.778 ± 1.11 a | 41.11 ± 4.3 |
| Abamectin       | LC$_{30}$          |             | 2.22 ± 1.11 BC | 2.22 ± 1.11 B | 0 ± 0 B | 2.22 ± 1.11 B | 7.778 ± 1.11 A | 3.33 ± 0 A | 10 ± 0 A | 3.33 ± 1.925 A | 12.22 ± 1.1 |
|                 | LC$_{50}$          |             | 6.667 ± 0 ab | 3.33 ± 0 b | 5.556 ± 1.111 b | 6.667 ± 0 abc | 12.22 ± 2.22 a | 4.44 ± 1.11 ab | 16.667 ± 1.925 a | 4.44 ± 1.11 ab | 22.22 ± 4.0 |
| Vegetable oil   | LC$_{30}$          |             | 7.778 ± 1.11 AB | 0 ± 0 B | 0 ± 0 B | 3.33 ± 0 A | 2.22 ± 2.22 A | 6.667 ± 1.925 AB | 1.11 ± 1.11 A | 8.889 ± 1.11 |
|                 | LC$_{50}$          |             | 13.33 ± 1.925 a | 2.22 ± 1.11 b | 2.222 ± 1.111 bc | 3.33 ± 1.925 bc | 5.556 ± 1.11 ab | 6.667 ± 0 a | 12.22 ± 1.11 a | 5.556 ± 1.11 ab | 11.11 ± 1.1 |
| EnSpray 99      | LC$_{30}$          |             | 12.22 ± 2.94 a | 8.889 ± 1.11 a | 0 ± 0 c | 8.889 ± 1.11 ab | 7.778 ± 1.11 a | 6.667 ± 1.925 a | 13.33 ± 3.849 a | 5.556 ± 1.11 ab | 7.778 ± 1.11 |
|                 | LC$_{50}$          |             | 0 ± 0 B, b | 0 ± 0 B, b | 0 ± 0 B, c | 0 ± 0 B, c | 0 ± 0 B, b | 0 ± 0 A, b | 0 ± 0 B, b | 0 ± 0 A, b | 0 ± 0 B, b |
| Control         | LC$_{30}$          |             | 0 ± 0 A, b | 0 ± 0 B, b | 0 ± 0 B, c | 0 ± 0 B, c | 0 ± 0 B, b | 0 ± 0 A, b | 0 ± 0 B, b | 0 ± 0 A, b | 0 ± 0 B, b |
|                 | LC$_{50}$          |             | F = 18.08 | F = 23 | F = 64 | F = 12 | F = 12.17 | F = 2.05 | F = 7.69 | F = 3.33 | F = 22.7 |
| Statistics      | df = 4,14          |             | P = 0.000 | P = 0.000 | P = 0.000 | P = 0.001 | P = 0.001 | P = 0.164 | P = 0.004 | P = 0.056 | P = 0.00 |
| at             | LC$_{50}$          |             | F = 7.50 | F = 7.50 | F = 35.50 | F = 10.60 | F = 8.35 | F = 4.88 | F = 11.97 | F = 5.83 | F = 33.1 |
|                |                   |             | P = 0.005 | P = 0.005 | P = 0.000 | P = 0.001 | P = 0.003 | P = 0.019 | P = 0.001 | P = 0.011 | P = 0.00 |
Figure 1

Figure 1. Systematic outline of the experimental layout.

(A) Mites were released on the right adaxial (ADR) surfaces; B) ADR and ADL; C) ABR and ABL; D) ADR and ABR; E) ADL and ABL; F) ADR and ABL; G) ABR and ADL; H) for full treated ADR and ABR, and for half treated, ADL and ABL; I) for full treated ADL and ABL, and for half treated ADR and ABR, and J) whole plant treated.

Letters were assigned to leaves surfaces as; adaxial right (ADR), adaxial left (ADL), abaxial right (ABR), and abaxial left (ABL).

Photo credit: Muhammad Asif Qayyom.
Figure 2

The number of *Panonychus citri* (Mean ± SE) re-captured after 24 hours on the adaxial surface of leaves (right side); (A) LC$_{30}$, (B) LC$_{50}$.

A significant difference was observed between treatments than control within treated (df = 4,14; For LC$_{30}$: $F = 3.37$, $P = 0.018$; for LC$_{50}$: $F = 28.01$, $P = 0.000$) and untreated surfaces (For LC$_{30}$: $F = 7.41$, $P = 0.000$; for LC$_{50}$: $F = 4.74$, $P = 0.003$). The capital letters indicate differences among the treatments (Treated or Un-Treated); lowercase indicates differences between treated and untreated surfaces, Tukey test ($\alpha = 0.05$). Significant difference “***” and non-significant difference “ns”.
Figure 3

The number of *Panonychus citri* (Mean ± SE) re-captured after 24 hours on the adaxial surface of leaves (left side); (A) LC$_{30}$, (B) LC$_{50}$.

A significant difference was observed between treatments than control within treated at LC$_{50}$ ($F = 14.67, P = 0.000$). The capital letters indicate differences among the treatments (Treated or Un-Treated); lowercase indicates differences between treated and untreated surfaces, Tukey test ($\alpha = 0.05$). Significant difference “***” and non-significant difference “ns”.
Figure 4

The number of *Panonychus citri* (Mean ± SE) re-captured after 24 hours on the abaxial surface of leaves (right side); (A) LC$_{30}$, (B) LC$_{50}$.

A significant difference was observed between treatments than control at LC$_{50}$ (For treated: $F = 10.86$, $P = 0.000$; for untreated: $F = 4.89$, $P = 0.003$). The capital letters indicate differences among the treatments (Treated or Un-Treated); lowercase indicates differences between treated and untreated surfaces, Tukey test ($\alpha = 0.05$). Significant difference “***” and non-significant difference “ns”.

![Figure 4](image-url)
Figure 5

The number of *Panonychus citri* (Mean ± SE) re-captured after 24 hours on the abaxial surface of leaves (left side); (A) LC<sub>30</sub>, (B) LC<sub>50</sub>.

A significant difference was observed between treatments than control within treated surfaces (df = 4.14; For LC<sub>30</sub>: F = 15.01, P = 0.000; for LC<sub>50</sub>: F = 29.78, P = 0.000). The capital letters indicate differences among the treatments (Treated or Un-Treated); lowercase indicates differences between treated and untreated surfaces, Tukey test (α = 0.05).

Significant difference “***” and non-significant difference “ns”.
Figure 6

The number of *Panonychus citri* (Mean ± SE) re-captured after 24 hours on the adaxial surface of leaves; (A) LC$_{30}$, (B) LC$_{50}$.

A significant difference was observed between treatments than control within treated ($df = 4.29$; at LC$_{50}$: $F = 8.55$, $P = 0.000$). The capital letters indicate differences among the treatments (Treated or Half-Treated); lowercase indicates differences between treated and half-treated surfaces, Tukey test ($\alpha = 0.05$). Significant difference “***” and non-significant difference “ns”.
Figure 7

The number of *Panonychus citri* (Mean ± SE) re-captured after 24 hours on the abaxial surface of leaves; (A) LC$_{30}$, (B) LC$_{50}$.

A significant difference was observed between treatments than control within treated (df = 4.29; at LC$_{50}$: $F = 29.61$, $P = 0.000$). The capital letters indicate differences among the treatments (Treated or Half-Treated); lowercase indicates differences between treated and half-treated surfaces, Tukey test ($\alpha = 0.05$). Significant difference “***” and non-significant difference “ns”.
Figure 8

The number of *Panonychus citri* (Mean ± SE) re-captured after 24 hours (the whole plant treated) on adaxial and abaxial surfaces. The results of LC30 (A) and LC50 (B) concentrations are presented.

A significant difference was observed between treatments than control within abaxial ($df = 4,29$; at LC$_{30}$: $F = 8.32$, $P = 0.000$). The capital letters indicate differences among the treatments (Adaxial or Abaxial surface); lowercase indicates differences between adaxial and abaxial surfaces, Tukey test ($\alpha = 0.05$). Significant difference “***” and non-significant difference “ns”.

![Diagram showing number of mites (Mean ± SE) on adaxial and abaxial surfaces for different treatments with capital and lowercase letters indicating significant differences.](image-url)