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Effects of a juvenile hormone analog, pyriproxyfen, on *Thrips tabaci* (Thysanoptera: Thripidae)

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Abstract: Effects of a juvenile hormone analog, pyriproxyfen, on various developmental stadia of the onion thrips, *Thrips tabaci* Lindeman, were determined on cabbage leaves in the laboratory. Pyriproxyfen was applied at 0.064 or 0.128 g AI liter^{-1} on leaves (residual contact–ingestion), thrips (direct contact) and leaf–thrips (residue contact–ingestion–direct contact). Pyriproxyfen did not have any significant lethal effects on thrips pupae in any treatment. Lethal effects on thrips larvae varied depending on application method and dosage. In the leaf and the leaf–thrips treatments, few larvae and pre-pupae molted to the next stage, and none developed to adults. In contrast, in the thrips-only treatment, pyriproxyfen did not show any significant lethal effects. The developmental times of larvae and pre-pupae were prolonged when larvae were treated with pyriproxyfen, and those of pre-pupae and pupae were shortened when pre-pupae and pupae were treated. The longevity and survival rates of thrips adults were generally shorter when they contacted and ingested pyriproxyfen-treated leaves than those in water control. Significantly fewer progeny (0.22–1.15 larvae per female) were produced by females that had fed on and been in contact with the pyriproxyfen-treated leaves than by those in the water control (11.94 larvae per female). However, the number of progeny produced by the thrips females increased significantly (3.32–7.28 larvae per female) when the females were transferred to untreated leaves after feeding on treated leaves for 5 days; the daily larval hatching pattern was similar to those in water control, indicating that female adults were able to produce viable eggs when untreated food was offered.

Keywords: onion thrips; *Thrips tabaci*; insect growth regulator; juvenile hormone analog; pyriproxyfen

1 INTRODUCTION

Onion (*Allium cepa* L) is a major vegetable crop in south Texas with >6000 ha harvested with a value of >$80 million and an economic impact of >$150 million in 1999.[1] The onion thrips, *Thrips tabaci* Lindeman, along with the western flower thrips, *Frankliniella occidentalis* (Pergande), are the most important pests of onions in south Texas.[2,3] Thrips cause injury by direct feeding, and their feeding wounds provide entry points for pathogens.[4,5]

In the past few years, pyrethroid insecticides have shown reduced efficacy against onion thrips, and their efficacies also varied greatly with locations, from excellent in some areas to non-effective in others.[3] Recent field and laboratory studies indicate that some populations of *T tabaci* have become resistant to commonly used pyrethroids, including lambda-cyhalothrin and cypermethrin.[6]

Pyriproxyfen, 4-phenoxyphenyl (*RS*)-2-(2-pyridyloxy)propyl ether, is a juvenile hormone analog with relatively low mammalian toxicity that was first registered in Japan in 1991 for controlling public health pests.[7,8] It has been used for controlling a variety of insect pests including mosquitoes and other flies,[9] whiteflies, scale insects and aphids,[10–14] cockroaches,[15] lepidopterans,[7,16] ants,[17] fleas,[18] locusts and grasshoppers,[19] and thrips.[20–24]

A series of experiments was conducted to evaluate the effects of pyriproxyfen on *T tabaci*. The objective of this study was to determine the lethal and sublethal effects on survival and development of *T tabaci* larvae, pre-pupae and pupae, and the effects on longevity and fecundity of *T tabaci* adults under laboratory conditions.

2 MATERIALS AND METHODS

2.1 Insecticide

Pyriproxyfen 103 g liter^{-1} emulsifiable concentrate, (Knack 0.86 EC; Valent USA, Walnut Creek, CA) was used at two concentrations, 0.128 and 0.064 g AI liter^{-1}, which were determined based on recommended field rates at 30 and 60 g AI ha^{-1} in

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467 liters of water. Purified water (reverse osmosis) was used as controls. Pyriproxyfen dilutions and water were sprayed on cabbage leaf disks in clear plastic Petri dishes (5 cm in diameter, 1.5 cm in depth) using a Potter Spray Tower (Burkard Manufacturing Co Ltd, Rickmansworth, Hertfordshire, UK) at an air pressure of 0.70 kg cm^{-2}.

2.2 Thrips tabaci

Thrips tabaci were originally collected from onions, *Allium cepa* L (variety '1015Y') in a field at the Research Farm of Texas A&M University Agricultural Research and Extension Center at Weslaco, TX, USA. Because it is very difficult to maintain thrips on onions, cabbage plants (*Brassica oleracea* var *capitata* L) were used to maintain the thrips colony in an insectary at 20 (±2) °C, 50 (±5)% RH with a photoperiod of 16:8 h light:dark. Thrips from the first and second generations reared on cabbage were used in all treatments. Clean cabbage leaves detached from the plants at the 6 to 8-leaf stage were used as the hosts for thrips in all treatments. All four immature stadia and adults were separately treated.

The thrips has five developmental stadia: egg, first instar, second instar, pre-pupa, pupa and adult. Different stadia were determined based on size, shape and morphological characters as described by Miyazaki and Kudo.[25] To obtain different stadia, thrips adults (mixed sexes) were collected from the colony and were introduced onto individual cabbage leaf disks (15–20 cm^2 leaf area) in individual Petri dishes (5 cm diameter, 1.5 cm depth) with two pieces of filter paper at the bottom. A few drops of water were added on the filter paper daily to maintain adequate moisture. The leaf disks bearing eggs were examined daily for larval hatching, and the hatched larvae were monitored for development. All leaf disks were replaced with fresh leaf disks when the leaf disks began showing signs of deterioration. The adults were allowed to feed and oviposit on the leaf disks for 2 days, and they were then removed. Larvae, pre-pupae and pupae $\leq$1 day after each molt, and adults $\leq$1 day after emergence were used in all experiments.

2.3 Larval and pupal treatments

Pyriproxyfen dilutions or water were sprayed either on cabbage leaves (leaf disks), thrips, or both cabbage leaves and thrips. For the leaf-only treatments, both the upper and the lower surfaces of the cabbage leaf disks were sprayed with 1 ml of pyriproxyfen dilution or water. Two concentrations (0.064 and 0.128 g AI liter^{-1}) of pyriproxyfen were used. After air-drying for $\approx$1 h, different stadia of thrips were introduced onto the treated leaf disks. The Petri dishes were covered and sealed with parafilm to prevent thrips from escaping. Each treatment had 4–15 replications, and each replication had 12–36 individual thrips.

For the thrips treatments, 10–15 thrips were placed on a cabbage leaf disk in a Petri dish using a 000 brush. A water-saturated cotton strip (5 mm in diameter) was placed around the outer edge of the leaf disk to prevent first and second instars from escaping. Each leaf disk with thrips was sprayed with pyriproxyfen dilutions at 0.064 g AI liter^{-1} or water. After drying for a few min, the thrips were transferred to untreated leaf disks in Petri dishes. The thrips were monitored daily for development and mortality. Each treatment had four replications, and each replication had 41–43 individual thrips.

For the leaf–thrips treatments, both the upper and the lower leaf surfaces were sprayed. Clean cabbage leaf disks were placed in Petri dishes, and the upper leaf surface was sprayed with pyriproxyfen dilutions at 0.064 g AI liter^{-1} or water. After drying for 20 min, the leaf disks were turned over. Ten to 15 thrips were introduced on each leaf disk surrounded by a water-saturated cotton strip. Pyriproxyfen dilutions or water were sprayed on the leaf disk with thrips. After drying for $\approx$1 h, Petri dishes were sealed, and the thrips monitored as described above. Each treatment had four replications, and each replication had 39–46 individual thrips.

2.4 Adult thrips treatments

Cabbage leaf disks were treated with two concentrations (0.064 and 0.128 g AI liter^{-1}) of pyriproxyfen or with water as described above. In the first experiment, 10–15 each of newly hatched female and male adults (<24 h old) were introduced onto a treated leaf disk in a Petri dish, and survivorship of the adults and numbers of larvae hatched were monitored daily. Each treatment had 12 replicates. A second experiment was designed to determine whether the effects of pyriproxyfen on the thrips adults were permanent or reversible. In one treatment, adult thrips continued feeding on treated leaves, and in the other, adult thrips were fed with treated cabbage leaf disks for 5 days, and were then transferred to untreated leaf disks. Each treatment had 12–16 replicates, and each replicate had 10–15 thrips. In both experiments, survivorship of male and female adults was monitored daily until they died. Numbers of thrips larvae on both the treated leaf disks and the untreated leaf disks were monitored daily for 7 days after the last female died.

2.5 Data analysis

The survival rate, developmental time of the larvae, pre-pupae and pupae, and the survival rate, longevity and fecundity (number of larvae hatched) of the adults were analyzed using the general linear model (PROC GLM). Means among treatments were separated using the Ryan–Elint–Gabriel–Welsch multiple range test (REGWQ) after a significant F test at $P = 0.05$.[26] Developmental times for the stages that did not successfully develop or molt to the next stage were not included in the analysis. Chi-squared (χ^2) goodness of fit was used to test the hypothesis that the survival rates of thrips adults among the treatments were not significantly different.[27]

3 RESULTS

3.1 Effects on larvae and pupae

Differences in survival were found among the leaf, the thrips and the leaf–thrips treatments with pyriproxyfen, depending on the developmental stage of thrips when they were treated (Fig 1). When first instars were treated, numbers of first instars that molted to second instars were not significantly different among the leaf, thrips and leaf–thrips treatments ($F = 0.31$; $df = 3, 23$; $P = 0.8154$). For those that became second instars, significantly fewer (36.5%) became pre-pupae and pupae when leaves were treated with the higher rate (0.128 g AI liter^{-1}) of pyriproxyfen than in other treatments ($F = 10.02$; $df = 3, 23$; $P = 0.0002$). None became pre-pupae on the leaves treated with the higher rate. For those that became pre-pupae, 51.6% and 55.3% pupated in the leaf and the leaf-thrips treatments, respectively, and all pre-pupae molted to pupae in the thrips treatment ($F = 76.54$; $df = 3, 23$; $P = <0.0001$). For those that

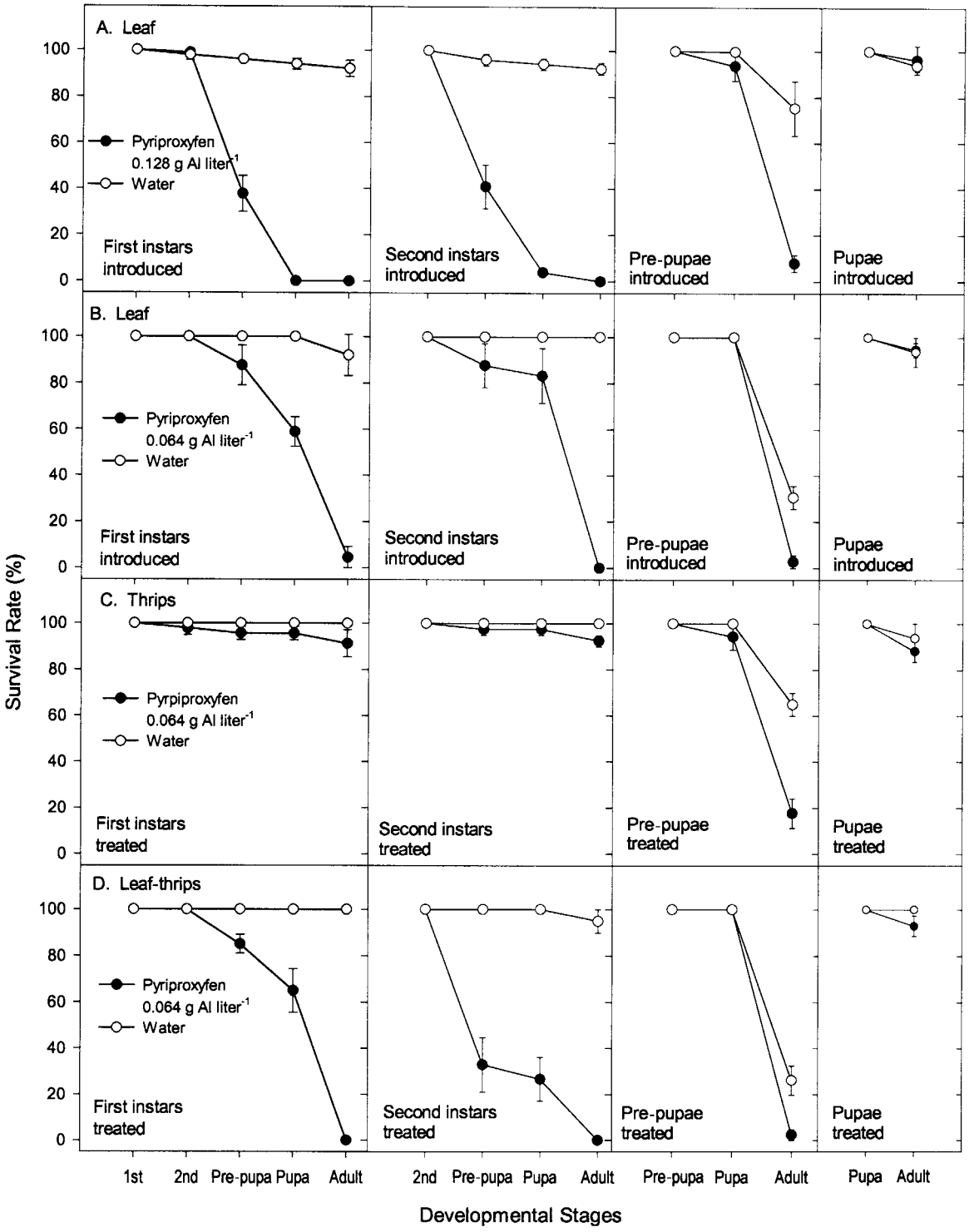

Figure 1. Effects of pyriproxyfen on survival of all developmental stadia of *Thrips tabaci* in the leaf-only, thrips-only and leaf–thrips treatments, Bar = SEM.

pupated, none became adults in the leaf–thrips treatment, and 7.6% pre-pupae emerged as adults in the leaf treatment at the lower rate of pyriproxyfen, whereas 95.5% pre-pupae successfully molted to adults in the water control ($F = 388.05$; $df = 3, 23$; $P = <0.0001$). When second instars were treated, fewer thrips became pre-pupae in the leaf treatment with the higher rate of pyriproxyfen and the leaf–thrips treatments than those in the leaf treatment with the lower rate of pyriproxyfen and the thrips treatments ($F = 8.60$; $df = 3, 23$; $P = 0.0005$). For those pre-pupae, 9.3% in the leaf treatment with higher rate treatment pupated, 100% in the leaf–thrips treatment, and 94.6% in the leaf treatment with the lower rate of pyriproxyfen ($F = 90.49$; $df = 3, 23$; $P = <0.0001$). Of those pupated, none emerged as adults except those in the thrips treatment where 94.9% emerged as adults ($F = 2980.25$; $df = 3, 23$; $P = <0.0001$). When pre-pupae were treated, 93.6–100% pupated. Of those pupated, 2.3–17.6% successfully molted to adults ($F = 2.16$; $df = 3, 23$; $P = 0.1309$). Relatively low survival rates were also found in the water control, with only 49.2% successfully molted to adults, which was far below the normal survival rates when other stages were treated (88.2–100%). There were no significant differences among all treatments when pupae were treated ($F = 1.01$ $df = 3, 23$; $P = 0.4123$).

3.2 Development of larvae and pupae

The effects of pyriproxyfen on developmental time for each developmental stage of *T tabaci* varied depending on the treatment (Fig 2). When first instars were introduced on pyriproxyfen-treated leaves at the higher rate (Fig 2A), the first and second instars and pre-pupal stage developed significantly slower than those in the water control ($F = 6.01–78.07$; $df = 1, 102$; $P = 0.0162–0.0001$). Similarly, when second instars were introduced on the treated leaves, the second instars and pre-pupal stage developed significantly slower than those in the water control ($F = 11.06–70.92$; $df = 1, 128$; $P = 0.0013–0.0001$). It was interesting that when pre-pupae were introduced on the treated leaves, the pre-pupal stage developed slower and the pupal stage developed faster than those in the water control (pre-pupa: $F = 4.18$; $df = 1, 35$; $P = 0.0429$; pupa: $F = 7.15$; $df = 1, 35$; $P = 0.0113$), whereas there was no significant difference in development on the leaves treated with pyriproxyfen and water when pupae were introduced ($F = 1.68$; $df = 1, 103$; $P = 0.1975$). When first instars were introduced on pyriproxyfen-treated leaves at the lower rate (Fig 2B), there were no significant differences in development on pyriproxyfen- or water-treated leaves for the first instars and pupal stages ($F = 0.01–0.05$; $df = 1, 61$; $P = 0.8360–0.9474$), but the second instars and pre-pupal stage developed significantly slower than those in water control ($F = 11.57–34.79$; $df = 1, 61$; $P = 0.0015–0.0001$). When second instars were introduced, the development times of the second instars were not significantly different on pyriproxyfen- and water-treated leaves ($F = 0.42$; $df = 1, 54$; $P = 0.5219$), whereas the pre-pupal stage developed significantly on pyriproxyfen-treated leaves than those on water-treated leaves ($F = 11.00$; $df = 1, 54$; $P = 0.0017$). When pre-pupae were introduced, the development times on pyriproxyfen- and water-treated leaves were exactly the same in the pre-pupal stage ($F = 0.00$; $df = 1, 57$; $P = 1.000$), whereas the pupal stage developed significantly faster than those in water control ($F = 7.00$; $df = 1, 57$; $P = 0.0457$). Similarly, when pupae were treated at the lower rate of pyriproxyfen, the pupal stage developed faster than those in the water control ($F = 6.22$; $df = 1, 53$; $P = 0.0158$). When first-instar thrips were treated (Fig 2C), the first and second instars developed slower than those treated with water ($F = 7.11–16.71$; $df = 1, 60$; $P = 0.0098–0.0001$), the pre-pupal stage developed faster than those in water control ($F = 7.87$; $df = 1, 57$; $P = 0.0068$), and there was no difference for pupal development ($F = 0.51$; $df = 1, 60$; $P = 0.4780$). When second instars, pre-pupae and pupae were treated with pyriproxyfen or water, there were no significant differences in development in any stage ($F = 0.64–1.52$; $df = 1, 56$; $P = 0.2223–0.6713$). When both first-instar thrips and leaves were treated with pyriproxyfen (Fig 2D), the first and second instars and pre-pupal stage developed significantly slower than those in the water control ($F = 4.85–142.25$; $df = 1, 55$; $P = 0.0315–0.0001$). However, when both second-instar thrips and leaves were treated, no significant differences were found in development in the second instars and pre-pupa stage ($F = 0.53–2.66$; $df = 1, 35$; $P = 0.1120–0.4712$), and in pre-pupal and pupal stages when both pre-pupae and leaves were treated ($F = 1.43–1.47$; $df = 1, 5$; $P = 0.2291–0.2856$). In contrast, when both pupae and leaves were treated, the pupal stage developed significantly slower than those in the water control ($F = 7.08$; $df = 1, 56$; $P = 0.0101$).

3.3 Longevity of adults

Effects of pyriproxyfen on the longevities of adults of *T tabaci* differed significantly between the females and males among the two rates of pyriproxyfen and the water control, and also in the transferred and not-transferred treatments ($F = 4.30–7.86$; $df = 2, 36–145$; $P = 0.0163–0.0010$) (Fig 3). For females (Fig 3A), the longevities were not significantly different between those that continued feeding on the leaves treated with both rates of pyriproxyfen and those that were transferred to water-treated leaves after feeding on the treated leaves for 5 days ($F = 2.44–2.76$; $df = 1, 76–87$; $P = 0.1050–0.1188$). However, the females that continued feeding on treated leaves had significantly shorter lives than those that were subsequently transferred to water-treated leaves regardless the rates of pyriproxyfen applied ($F = 4.30$; $df = 2, 96$; $P = 0.0163$). Similarly, the longevities were not significantly different for those that continued feeding on

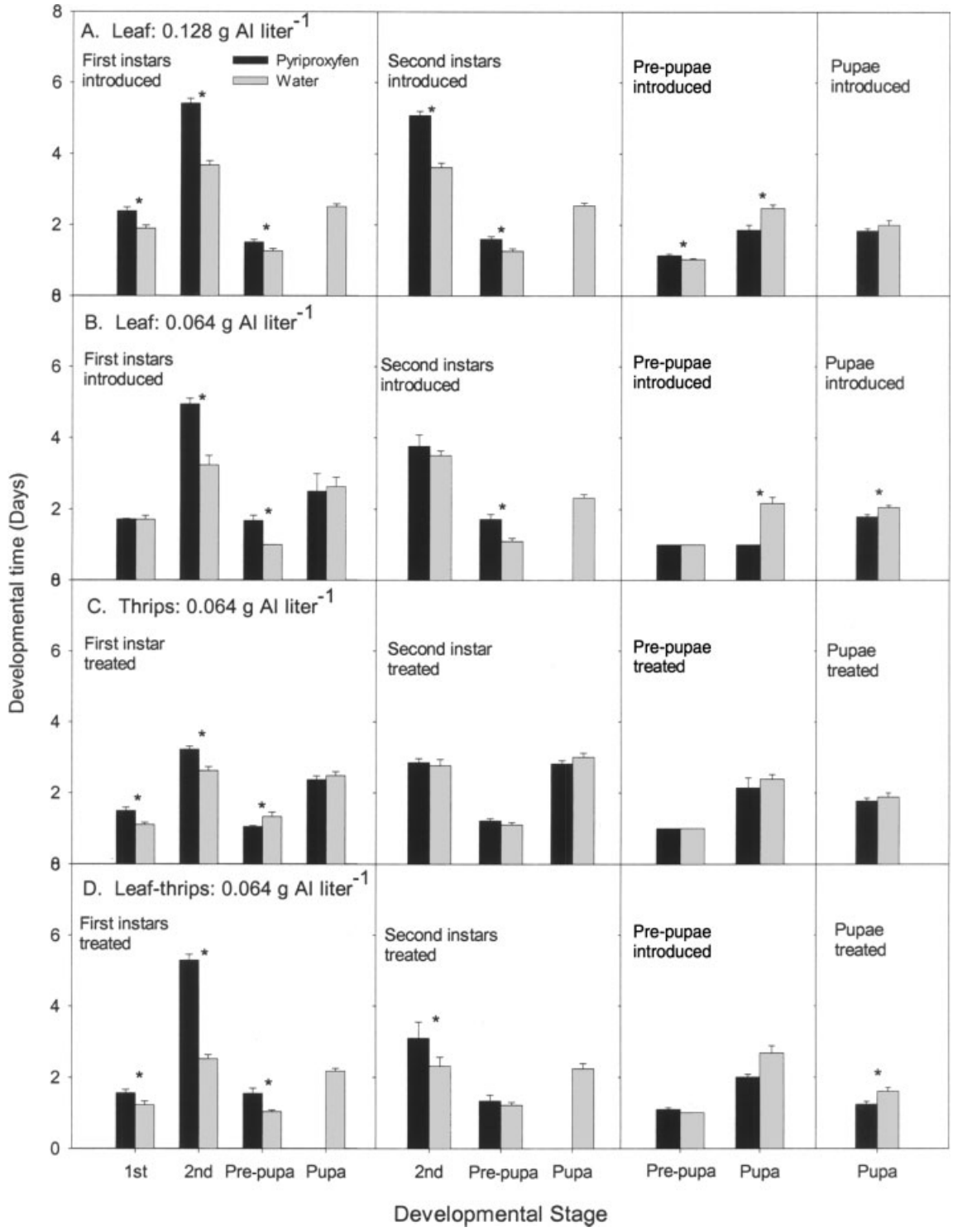

Figure 2. Effects of pyriproxyfen on development of each developmental stage of *Thrips tabaci* in the leaf-only, thrips-only and leaf–thrips treatments when the thrips were treated at different developmental stages. Bar = SEM ∗ over the paired-bars (pyriproxyfen-treated and water control) indicates the means differ significantly (REGWQ, $P = 0.05$).

the leaves treated with the higher rate of pyriproxyfen and those that were then transferred to water-treated leaves ($F = 0.29$; $df = 1, 35$; $P = 0.5954$) (Fig 3B). However, those that continued feeding on the leaves treated with the lower rate of pyriproxyfen had significantly shorten lives than those that were transferred to water-treated leaves ($F = 4.93$; $df = 1, 43$; $P = 0.0332$). Similar to the females, the males that continued feeding on pyriproxyfen-treated leaves had significantly shorter lives than those that were subsequently transferred to water-treated leaves, regardless of the rates of pyriproxyfen applied ($F = 2.29–7.86$; $df = 2, 36–57$; $P = 0.01156–0.0010$).

Generally, the longevities between the males and the females of *T tabaci* were not significantly different ($F = 0.02–2.76$; $df = 1, 39–51$; $P = 0.8936–0.1050$) whether they continued feeding on pyriproxyfen-treated leaves or were subsequently transferred to

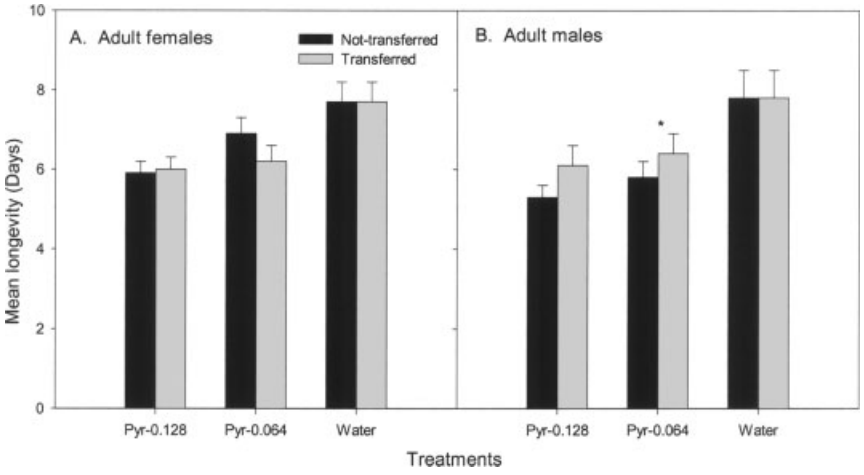

Figure 3. Effects of pyriproxyfen on longevity of male and female adults of *Thrips tabaci* between those that continued feeding on pyriproxyfen-treated cabbage leaves and those that were transferred on water-treated leaves after feeding on pyriproxyfen-treated leaves for 5 day. Bar = SEM ∗ over the paired-bars (pyriproxyfen-treated and water control) indicates the means differ significantly (REGWQ, $P = 0.05$).

water-treated leaves. However, the females that continued feeding on leaves treated with the lower rate of pyriproxyfen lived significantly longer than the males ($F = 7.43$; $df = 1, 79$; $P = 0.0079$).

3.4 Survival of adults

Mortality of both female and male adults of *T tabaci* in all treatments began a few days after they were introduced (Fig 4). Adult females treated with the higher rate of pyriproxyfen died significantly sooner than those treated with the lower rate; the difference began on day 7 and continued to day 11 when all females had died ($\chi^2 = 3.88–13.72 > \chi^2 = 3.84$; $df = 1$) (Fig 4A). The daily survival rates for the adult females that fed on leaves treated with the higher rate of pyriproxyfen in the first 6 day were not significantly different from those in water control, and lower survival rates were found from day 7 until all adult females died on day 12 ($\chi^2 = 7.76–27.6 > \chi^2 = 3.84$; $df = 1$). In contrast, the daily survival rates of the adult females treated with the lower rate of pyriproxyfen for the first 10 days were similar to those in water control, with significant differences on days 11, 12 and 13 ($\chi^2 = 8.46–10.98 > \chi^2 = 3.84$; $df = 1$). The survival rates of the male adults that fed on the leaves treated with both rates of pyriproxyfen were significantly lower than those in the water control from day 6, and continued until all males had died ($\chi^2 = 4.74–38.08 > \chi^2 = 3.84$; $df = 1$) (Fig 4B). All male adults that fed on the leaves treated with the lower rate of pyriproxyfen had died by day 9, whereas 100% of those fed on the leaves treated with the higher rate of pyriproxyfen had died by day 12. The daily survival rates between the two rates of pyriproxyfen were not significantly different ($\chi^2 = 0–2.30 < \chi^2 = 3.84$; $df = 1$) except for day 6 on which the thrips fed on the leaves treated with lower rate had lower survival rate than those fed on the leaves treated with the higher rate ($\chi^2 = 4.15 > \chi^2 = 3.84$; $df = 1$).

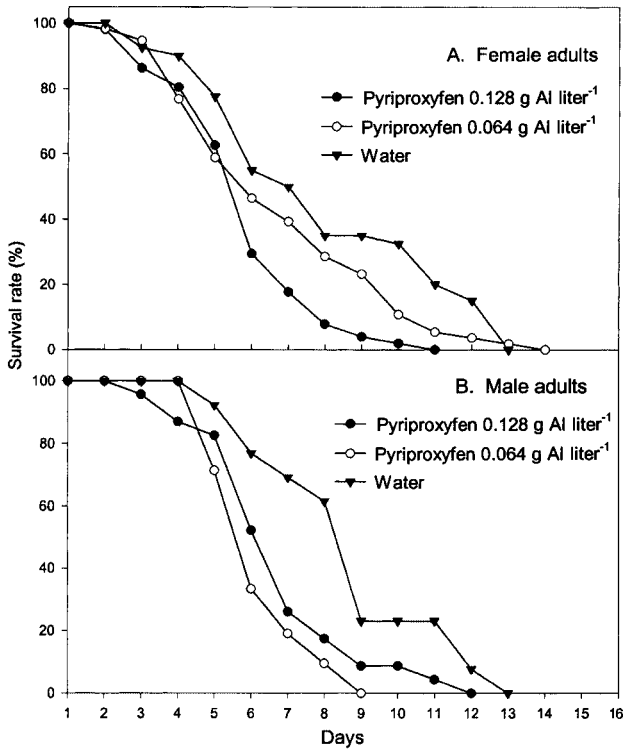

Figure 4. Effects of pyriproxyfen on survival of male and female adults of *Thrips tabaci* feeding on pyriproxyfen-treated cabbage leaves.

3.5 Fecundity of adults

Eggs of *T tabaci* are difficult to find because the adults deposit the eggs in leaf tissues. Therefore, numbers of larvae hatched from the cabbage leaf disks were used as an indicator of eggs oviposited by female adults, with the assumption that all larvae successfully hatched. When thrips adults were reared on treated leaves, the numbers of thrips larvae hatched from the leaves were significantly different compared with the water treatments, with 10.4-fold less larvae hatched from the leaves treated with the lower rate or a 90.4% reduction and 54-fold less larvae hatched from the leaves treated with the higher rate or a 98.2% reduction (Table 1).

Table 1. Reduction of thrips larvae hatched after application of pyriproxyfen on cabbage leaves

Treatment	No of larvae hatched/female (±SEM)[a] [% reduction]			
	On treated leaves only	Transferred to untreated leaves	*F*	*P*
Pyriproxyfen 0.128 g AI liter^{-1}	0.2 (±0.1) [98.2] bB	3.3 (±0.1) [72.2] bA	19.93	0.0003
Pyriproxyfen 0.064 g AI liter^{-1}	1.2 (±0.4) [90.4] bB	7.3 (±2.6) [39.0] abA	10.82	0.0046
Water	11.9 (±2.0) [0.0] aA	11.9 (±2.0) [0.0] aA	—	—
$F(df = 2, 620)$	41.89	4.76		
P	<0.0001	0.0219		

[a] Means in the same column followed by the same lower case letters and those in the same row followed by the same upper case letters do not differ significantly at $P = 0.05$ (REGWQ, SAS Institute 2000).

The numbers of larvae hatched from pyriproxyfen-treated leaves were not significantly different between the two rates applied (Table 1). Significantly more thrips larvae hatched after adults fed on treated leaves for 5 days and were then transferred to water-treated leaves than those that continued feeding on treated leaves regardless of treatment. The number of larvae hatched reduced by 72.2 and 39% on the leaves previously treated with the higher and lower rates of pyriproxyfen, respectively. The number of thrips larvae hatched from the leaves treated with the higher rate of pyriproxyfen was significantly fewer than those on water-treated leaves, whereas those treated with the lower rate of pyriproxyfen were not significantly different from the water treatment.

Numbers of *T tabaci* larvae hatched vary greatly during the larval hatching period (Fig 5). Thrips larvae on water-treated leaf disks started hatching on day 5. Numbers of larvae hatched increased rapidly on days 6 and 7, reached the highest peak on day 9, and then declined. After no larvae hatched for 1–2 days, more larvae hatched with a smaller peak on days 16 and 17, and no more thrips hatched after day 19. In contrast, only a few thrips larvae hatched from the leaf disks treated with pyriproxyfen at both rates, and most of these larvae hatched from day 6 to day 9 (Fig 5A). When *T tabaci* adults were transferred to water-treated leaves after feeding on treated leaves for 5 days significantly more larvae hatched (Fig 5B). Larvae began hatching on day 3 on untreated leaves. Consequently, numbers of larvae hatched increased gradually, reached the highest peak on day 11, and then declined.

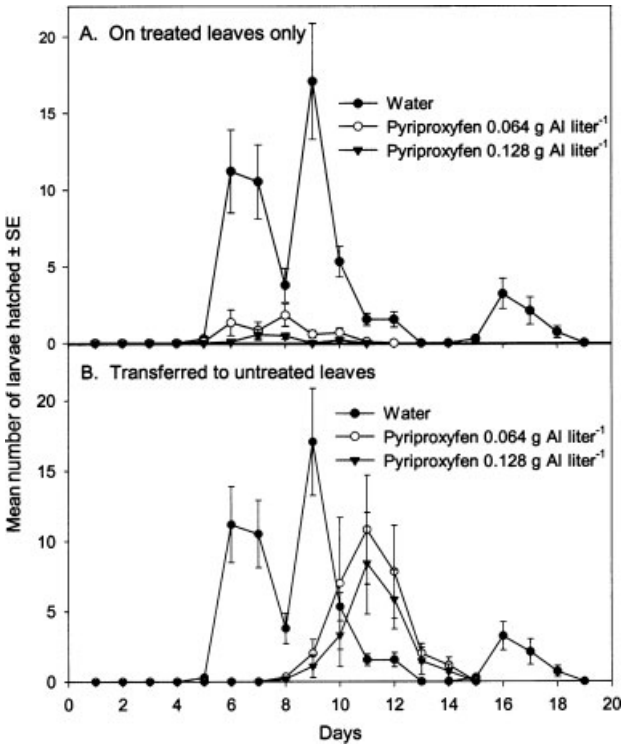

Figure 5. Effects of pyriproxyfen on fecundity of *Thrips tabaci* females feeding on pyriproxyfen-treated cabbage leaves or on untreated leaves after feeding on treated leaves for 5 days Bar = SEM.

4 DISCUSSION

Pyriproxyfen did not exhibit a significantly lethal effect on larvae, pre-pupae, pupae or adults of *T tabaci* through direct contact (Fig 1C). When first and second instars were treated and fed on water-treated cabbage leaves, almost all larvae successfully pupated and pupae became adults. Therefore, the primary effect of pyriproxyfen on *T tabaci* was through ingestion by feeding. However, the effect to larvae was dose-dependent. The larvae that had fed on the leaves treated with the lower rate of pyriproxyfen had a significantly higher survival rate than those that had fed on the leaves treated with the higher rate of pyriproxyfen. Although the first and second instars had high survival compared with the subsequent stage when fed on the leaves treated with the lower rate of pyriproxyfen, none successfully developed to adults, indicating that pyriproxyfen at the lower rate prevented adult formation during metamorphosis. It is interesting that almost all of the pre-pupae pupated after exposure to the various treatments, but high mortality occurred in the pupal stage, even in the water control. Even though the pre-pupae were carefully and gently handled the same way as other stages were, they might be extremely sensitive to mechanical contact. However, the exact cause for the high mortality in the pupal stage regardless of treatment is not clear, and is certainly worthy of further investigation.

Similar results for insect growth regulators on thrips have been reported in the literature for other thrips species. Nagai[21] found that pyriproxyfen had no effect on adults of *T palmi* when applied to leaves, but increased pupal mortality. In a laboratory test, an insect growth regulator, flufenoxuron, inhibited molting of first-instar larvae and the metamorphosis of second instars to pre-pupae, but did not affect survival and fecundity of females.[23] By contrast, Kubota[24] found that flufenoxuron, chlorfluazuron, diflubenzuron and teflubenzuron prevented pupation of *T palmi*.

Pyriproxyfen exhibited significant effects on the developmental time of *T tabaci*. The developmental times of the larval stages were prolonged when the larval stages were treated with pyriproxyfen, particularly at the higher rate. The developmental times of the pupae were significantly shorter for pyriproxyfen treatments than in the water control.

No supernumerary instars were observed, as is sometimes the case in insects with incomplete metamorphosis, such as aphids,[14] and results were similar to those found in insects with complete metamorphosis where development is stopped before pupa formation.[13,28,29] Embryonic effects of pyriproxyfen on many species of insects have been demonstrated.[10,11,18–20,28,29] Results from this study show that pyriproxyfen did not exhibit lethal effects on *T tabaci* adults that fed on pyriproxyfen-treated leaves, but reduced the number of larvae hatched. These effects could be caused by sterilizing eggs, reducing survival of viable eggs, or reducing fecundity of the adults. However, significantly more *T tabaci* larvae hatched from the females that had fed on pyriproxyfen-treated leaves for 5 days and then were transferred to water-treated leaves. This result indicates that the adult females were not permanently sterilized when they fed on pyriproxyfen-treated leaves. Similar results have been reported in the literature. Grout and Morse[28] found that the number of progeny produced by females of the citrus thrips, *Scirtothrips citri* (Moulton), were significantly reduced after application of several insect growth regulators. Because the viability of the eggs was not directly examined, it cannot be determined whether the mechanism for lower number of progeny was caused by lower fecundity, sterilization or lowered egg survival. It is possible that the effects of insect growth regulators on the fecundity of thrips can be unintentionally misinterpreted by not taking into consideration sterilized or unviable eggs.

In this study, it was demonstrated that pyriproxyfen could cause direct mortality, reduce longevity and inhibit progeny production of *T tabaci* under laboratory conditions. Further observations of the effects on the thrips population should be conducted on a larger scale under greenhouse or field conditions. Because it is compatible with some important predators, eg *Orius sauteri* (Poppius) and other *Orius* sp,[22] pyriproxyfen has the potential to play an important role in management of *T tabaci* and other thrips.

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