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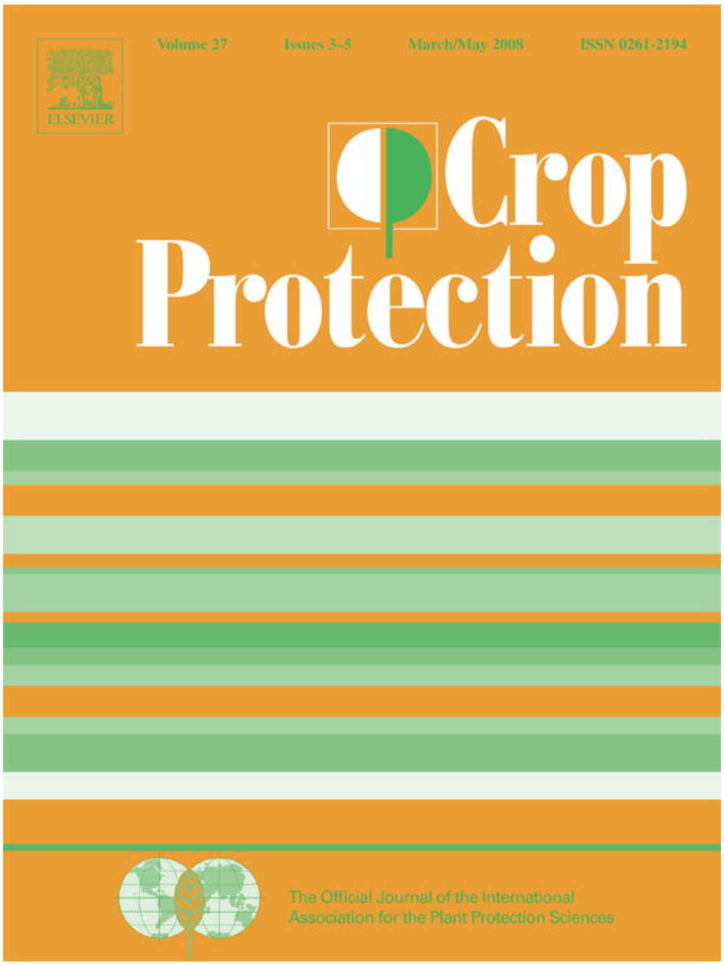

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Effect of kaolin particle film on *Thrips tabaci* (Thysanoptera: Thripidae), oviposition, feeding and development on onions: A lab and field case study

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Abstract

Laboratory studies were conducted to evaluate the effects of a kaolin-based particle film on biological characteristics of the onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), on onions. Oviposition rate was significantly reduced on kaolin-treated vs. water-treated onion leaves and plants, in choice and no-choice assays. Hatch rate was reduced when kaolin particle film was applied over eggs on onion leaves. The time required for development of larval stages was significantly increased and mortality was significantly higher on kaolin than on water-treated onion leaves. Feeding choice was influenced by the presence of the kaolin treatment and in choice assays both larvae and adults fed significantly less on kaolin-treated than on water-treated leaves. In a field study, significantly more adults were captured in the beginning of the season on control than on kaolin-treated plots, and at population peaks significantly more larvae and adults were harbored in control plots. The results indicate the potential of kaolin particle film against onion thrips in an integrated pest management program. However, because of the importance of a continuous coverage of plant material with kaolin particle film, better application methods and perhaps frequent applications will be required to cover newly expanding foliage.

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Keywords: Thrips tabaci; Onion thrips; Kaolin; Particle film; Pest management

1. Introduction

Onions are a high-value crop in the USA, providing $867.7 million from a harvested area of 65,960 ha in 2006 (NASS, 2007). Nevertheless, heavy reliance on chemicals for weed, disease and insect control has placed onions among the highest vegetable crops for pesticide usage (NASS, 2005). Onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), is a key onion pest and accounts for most of the insecticide usage in the New York onion crop where onions were grown on 5706 ha in 2006 (NASS, 2007). *Thrips tabaci* feeding damage results in leaf tissue silvering and photosynthesis reduction, leading to bulb size reduction and yield loss (Childers, 1997). Moreover, *T. tabaci* has been identified as the main vector of an emerging tospovirus, the Iris Yellow Spot Virus (IYSV), which is correlated to bulb size reduction in western states (Gent et al., 2004). Effective alternative methods to control onion thrips are further necessitated since resistance of *T. tabaci* to pyrethroids and organophosphate insecticides has been recently documented in NYS (Shelton et al., 2006) and Ontario, Canada (Allen et al., 2005).

A novel development of insect control is the utilization of aqueous formulations of particle films based on kaolin, a white, non-porous, non-swelling, non-abrasive aluminosilicate mineral ($Al_4Si_4O_{10}[OH]_8$) that easily disperses in water and is chemically inert over a wide pH range (Glenn et al., 1999). Kaolin particles can be coated with chrome complexes, stearic acid, organo-silicone oil or plant and mineral materials to become hydrophobic (Puterka et al., 2000). Hydrophobic and hydrophilic formulations of kaolin-based particle films, applied as liquid suspensions,

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have shown to prevent arthropod infestations or disease infections. After being sprayed on the plant surface, kaolin-based particle films create a powdery film, which serves as a physical barrier repelling arthropods and/or suppressing infestations by making the plant visually or tactually unrecognizable as a host. Furthermore, it hampers insect movement, feeding and other physical activities (Glenn et al., 1999). Such technology has effectively suppressed plant diseases and several plant-feeding and virus-vector arthropods such as *Bemisia argentifolii* Bellows and Perring (Homoptera: Aleurodidae) on melon (Liang and Liu, 2002); *Circulifer tenellus* (Baker) (Homoptera: Cicadelidae) on chili pepper (Creamer et al., 2005); *Aphis spireacola* Patch (Homoptera: Aphididae), *Cacopsylla pyricola* Foerster (Hemiptera: Psyllidae), *Tetranychus urticae* Koch (Acarina: Tetranychidae) and *Empoasca fabae* (Harris) (Homoptera: Cicadelidae) in pear and apple (Glenn et al., 1999); *Cydia pomonella* (Linnaeus) (Lepidoptera: Torticidae) in apple and pear (Unruh et al., 2000); and *Anthonomus grandis grandis* Boheman (Coleoptera: Curculionidae) in cotton (Liang and Liu, 2002). In addition to the potential of kaolin-based particle films in IPM, such technology has also provided some physiological benefits to apple and pear orchards (Thomas et al., 2004) and significantly reduced virus incidence on chili pepper (Creamer et al., 2005). Studies conducted on soybean, cotton, artichoke, melons and peach have shown that foliar applications of kaolin particle films reduce plant stress, which is important for optimum plant growth, yield and quality (Creamer et al., 2005). The nature of the film does not seem to affect plant photosynthesis or productivity (Glenn et al., 1999).

Although kaolin-based products are reportedly efficient against thrips (Puterka et al., 2000); the mechanisms of their action have not been demonstrated. The encouraging results against a variety of pests with different feeding habits led us to initiate a series of experiments to investigate the effect of kaolin clay particle film on the feeding behavior, oviposition and development of *T. tabaci* on onion. Furthermore, a 1-year field study was carried out to examine the efficacy of kaolin clay against *T. tabaci* on onions in an open-field situation.

2. Materials and methods

Experiments were conducted in an environmental chamber at 27 °C, 60% RH, and a photoperiod of 16:8 (L:D) h. The kaolin particle formulation used was Surround® WP (a hydrophilic particle film containing 95% kaolin combined with dry oil-based spreader sticker to increase adhesion to foliage), hereafter refer to as kaolin, supplied by Englehard Corporation (Iselin, NJ, USA).[1] A rate of 60 g/l with a surfactant (Bond, Loveland Industries Inc., Greeley, CO) recommended by the manufacturer was used. The *T. tabaci* used throughout the experiments were from a continuous culture maintained on onions at 27 °C, 60% RH, and a photoperiod of 16:8 (L:D) h. The plant material used was 4.5 cm long onion leaf sections from the third and fourth leaf of plants grown by yellow onion sets for 2–3 weeks at 25 °C, 16:8 (L:D) h, in an environmental growth chamber. Unless stated otherwise, plant material was dipped and slightly stirred into the kaolin particle suspension and allowed to dry for at least 1 h prior to experiments. The control plant material was similarly dipped in distilled water with surfactant and allowed to dry. To prevent *T. tabaci* from occupying the onion leaf interior and to prevent the loss of moisture from the onion leaf, both sides of the leaf section were sealed by briefly dipping them in warm paraffin wax.

2.1. *Effect of kaolin particle on oviposition*

2.1.1. *No-choice assay*

A single 1-week-old adult female *T. tabaci* was allowed to oviposit for 24 h on an onion leaf section covered either in kaolin particle film or distilled water (20 replicates).

2.1.2. *Choice assay*

Half of the onion leaf section was dipped either in kaolin particle film or distilled water before introducing a single adult female thrips to choose an oviposition site for 24 h (20 replicates). In both cases, the ovipositional output was recorded 4 d later under the microscope by counting the number of larvae and empty egg sacs left behind by successfully emerged larvae. The same choice assay was performed using whole 2.5-week-old onion plants grown in 30-ml plastic cups (WinCup, Phoenix, AZ, USA). Using a hand-held sprayer, the kaolin formulation or distilled water with surfactant was applied to the point of run-off and plants were allowed to dry for at least 1 h. One kaolin- and one water-treated plant were placed 5 cm apart in a cage consisting of a clear polysterene cylinder (30-cm tall × 10-cm diameter) with two screened ventilation holes (5-cm diameter). The bottom and top of the cylinder were protected with a plastic lid. Ten adult female thrips were collected in a 1.5-ml centrifuge tube and released in the center of the arena. After 24 h thrips were shaken off plants, and larval emergence was recorded 4 d later. The experiment was repeated 15 times, using different adult thrips. Numbers of larvae emerging in both choice and no-choice tests were subjected to one-way ANOVA after checking for normality. The statistical package Minitab 13.5 for Windows (Minitab Inc PA, 2001) was used for all analyses.

2.2. *Effect of kaolin particle on egg hatch*

Twenty-six adult female *T. tabaci* (≈8 d old) from the thrips cultures were individually allowed to oviposit on onion leaf sections for 24 h. Preliminary experiments showed that *T. tabaci* oviposit between 7–10 eggs/d, but,

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[1] Currently, Surround WP is being marketed by BASF.

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to avoid variation in numbers of eggs, 3 eggs on the same leaf section (6 eggs per leaf, 78 eggs per treatment) were treated either with kaolin particle film or with distilled water using a fine paintbrush. The treatments took place 3 d after oviposition when eggs were visible under the microscope as swellings under the leaf epidermis. Emergence was recorded by counting the number of larvae and empty sacs on the treated parts of the leaf section. The percentages of emerged larvae were arcsine transformed before one-way ANOVA was carried out.

2.3. *Effect of kaolin particle on feeding*

2.3.1. *No choice*

Three second-instar *T. tabaci* were confined on an onion leaf section treated either with kaolin particle film or distilled water (20 replicates). Feeding damage was recorded after 24 h. On kaolin-treated leaves, the particle film was washed off with a water-saturated cotton ball to allow the appearance of feeding marks.

2.3.2. *Choice*

Three second-instar *T. tabaci* were confined on an onion leaf section half-treated with kaolin particle film and half-treated with distilled water (20 replicates). Feeding damage was recorded after 24 h.

The same no-choice and choice assays were followed for single adult female thrips confined on water or kaolin-treated onion leaf sections (20 replicates).

Thrips feeding damage on onion leaves appears as silvery spots that coalesce into white blotches. The feeding area by larvae and adults was estimated using a clear acetate 2 mm^2 grid. The onion leaf was sliced open and placed on the acetate grid, and the leaf area was estimated and the percentage leaf damage expressed. Percentage leaf area damaged by larvae and adults was arcsine transformed and subjected to a one-way ANOVA. Untransformed data are presented.

2.4. *Effect of kaolin particle on development*

Three newly emerged *T. tabaci* larvae were confined on an onion leaf section treated either with kaolin particle film (25 replicates) or distilled water (20 replicates). Larvae were transferred with a fine paintbrush to new onion leaves every day and their development was recorded until adult emergence. The transition to second instar was verified by the cast skin and the prepupal stage was included in the pupal stage. Upon pupation, a saturated filter paper section was introduced into the experimental cage to provide humidity and a hiding place. Mortality was also recorded for each treatment. A one-way ANOVA was used to assess developmental times between treatments. This procedure was performed using the mean values from the insects on each leaf section as single data points. Mortality percentages were arcsine transformed before being subjected to one-way ANOVA.

2.5. *Effect of direct application of kaolin particle film*

In order to examine the effect of direct application on thrips, a 1.5-ml centrifuge tube was half-filled with kaolin clay aqueous formulation and five second-instar *T. tabaci* were introduced on the inside of the tube's cap (20 replicates). After sealing it, the tube was turned upside down for 10 s; thrips were recovered with a fine paintbrush and introduced on onion leaves for 24 h before assessing their mortality. As a control treatment, thrips were immersed in distilled water. The same procedure was repeated to assess adult mortality after direct application of kaolin particle film (20 replicates). In order to investigate treatment and age differences on survival, a log-linear analysis of frequency tables was carried out. Goodness of fit was tested by Pearson's chi-square test.

2.6. *Field efficacy study*

Trials were conducted in a commercial onion field (cv. Millenium) in the muck region of Potter in Yates County, NY. Muck soil is rich in organic matter with high water-holding capacity, is porous and easy to cultivate and suitable for vegetable (onions, carrots, potatoes) growing. The experimental plots were 9.15 m × 10.7 m wide and consisted of six beds, 1.15 m apart, each with four rows 38 cm apart. The experimental design was a randomized complete block with two treatments each replicated four times. A buffer zone of 10 m separated the experimental plots.

The treatments were (a) a kaolin-based particle film application, Surround® WP at the manufacturer's recommended rate of 60 g/l of water with a surfactant; and (b) no kaolin clay film application, serving as control. No insecticides were applied to any of the plots. Surround® WP was applied as an aqueous suspension using a CO_2 powered backpack sprayer at a pressure calibrated to deliver 45.8 l/ha at a pressure of 2.8 kg/cm^2, using a boom sprayer with four Teejet TX-V56 hollow cone nozzles 38 cm apart. Regular agitation of the kaolin liquid suspension prevented clumping of the material and blocking of the nozzles. Each application consisted of two passes over the onions' rows ($\approx$30 cm over the onion plants) to ensure uniform coverage of the plants. The first kaolin clay application took place on 24 May 2006, 5 weeks after planting and when plants were at the second leaf stage. Heavy rain during the initial weeks of the study washed off the kaolin particle film, so applications were repeated on a weekly basis (1 June, 6 June, 13 June) and on a biweekly basis for the rest of the season (30 June, 19 July, 31 July and 9 August). Incidences of *Botrytis* leaf blight were controlled by applying two fungicide treatments (Penncozeb™ 75DF, Cerexagri-Nisso, King of Prussia, PA, USA) at a rate of 0.35 kg/m^2 on 13 and 30 June. Uniform weed control was obtained by hand weeding when necessary.

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2.6.1. Plant counts

Ten onion plants were randomly collected from each plot on a weekly basis (from 1 June to 17 August when plants were senescent), sealed in plastic bags and transferred into an ice cooler. In the laboratory, 200 ml of 65% ethyl alcohol was added to the plastic bag and plants were agitated for 2 m to dislodge and kill thrips. After plant parts were removed, the solution was sieved through a fine mesh of 180 μm and *T. tabaci* adults and larvae were counted under the microscope. Data for adults and larvae were square-root transformed before two-way ANOVA was performed. Treatment effects at population peaks and after treatment dates were individually detected by one-way ANOVA, after square-root transformations.

2.6.2. Yield data

Using commercial practices, onions were hand-topped in the field and bulbs were harvested from an undisturbed row from each experimental plot on 31 August. Onion plants were hand topped in the field and bulbs were collected. The entire row of onions was weighed and mean weights between treatments were compared by one-way ANOVA. Furthermore, onions were graded according to USDA standards, into jumbo (>77 mm), medium (57–77 mm) and small (<57 mm). Onions smaller than 30 mm were discarded, as was the normal practice.

3. Results

3.1. Effect of kaolin particle on oviposition

Choice pattern and treatment affected the number of eggs laid on onion leaves by female *T. tabaci* ($F = 36.5$, df = 1, 76, $P \leqslant 0.001$; $F = 196.0$, df = 1, 76, $P \leqslant 0.001$, respectively) and their interaction was not significant ($F = 0.02$, df = 1, 76, $P > 0.05$). In the no-choice assay, a mean of 2.4 ± 0.4 eggs were laid on onion leaves treated with kaolin particle film, whereas 7.5 ± 0.4 eggs were laid on the water-treated leaf part (Fig. 1). In the choice assay, adult thrips tended to oviposit significantly more eggs on the water-treated part of the leaf (5.3 ± 0.4) than on the kaolin-treated leaf part (0.2 ± 0.1) ($F = 144.5$, df = 1, 38, $P \leqslant 0.001$) (Fig. 1). The same pattern was observed in the whole plant choice assay, with significantly more eggs being laid on water-treated than on kaolin-treated plants ($F = 20.1$, df = 1, 28, $P \leqslant 0.001$).

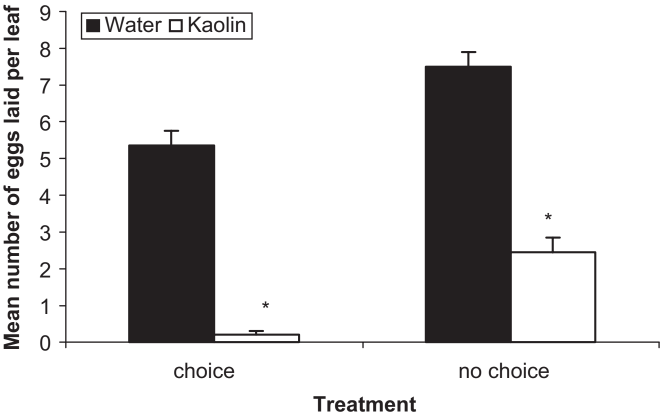

Fig. 1. Number (mean ± S.E.) of eggs laid on kaolin-treated and water-treated onion leaves in no-choice and choice experiments. Asterisks indicate significant differences with water-treated leaves.

3.2. Effect of kaolin particle on egg hatch

All of the eggs (100%) treated with water hatched, whereas 74% of the eggs treated with kaolin particle film were successful in hatching and this was significantly lower than the water control ($F = 23.3$, df = 1, 51, $P \leqslant 0.001$).

3.3. Effect of kaolin particle on feeding

After 24 h, all larvae and adults were recovered from the feeding choice and no-choice assays. Kaolin particle film affected both larval and adult feeding behavior and leaf area damaged (Figs. 2 and 3). In choice tests, larvae

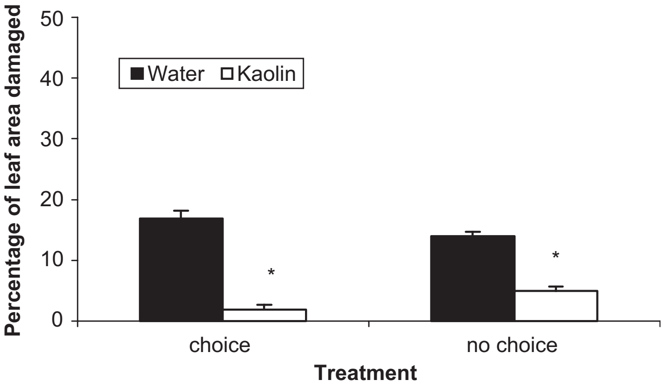

Fig. 2. Percentage (±S.E.) of area damaged by *Thrips tabaci* larvae feeding on kaolin-treated and water-treated onion leaves in no-choice and choice experiments. Asterisks indicate significant differences with water-treated leaves.

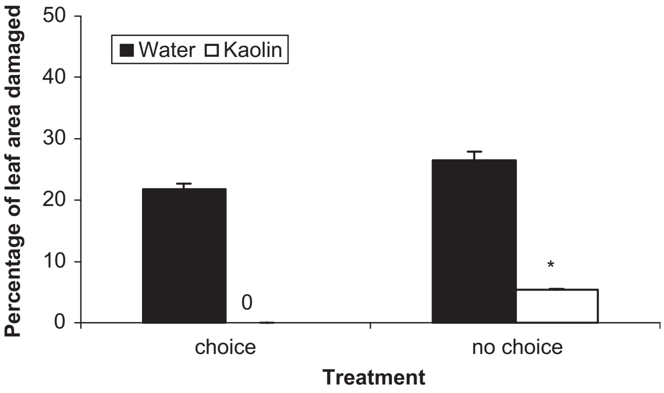

Fig. 3. Percentage (±S.E.) of area damaged by *Thrips tabaci* adults feeding on kaolin-treated and water-treated onion leaves in no-choice and choice experiments. Asterisks indicate significant differences with water-treated leaves.

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preferred the water-treated area to the kaolin-treated area ($F = 99.0$, df = 1, 38, $P \leqslant 0.001$), where only 1.9% of the leaf area was damaged (Fig. 2). In no-choice tests, more feeding marks were observed on water-treated than on kaolin-treated leaves ($F = 41.2$, df = 1, 38, $P \leqslant 0.001$). The percentage leaf area damaged on water-treated leaves was not different between choice and no-choice experiments ($F = 2.9$, df = 1, 38, $P = 0.1$), but it was significantly different on kaolin-treated leaves ($F = 9.2$, df = 1, 38, $P \leqslant 0.001$). Similar results were obtained for adult *T. tabaci* females. In choice tests, no feeding marks were observed on the kaolin-treated part of the onion leaf, whereas feeding marks covered 15.3% of the water-treated leaf area (Fig. 3). In no-choice tests, significantly more feeding marks were observed on water-treated than on kaolin-treated onion leaves ($F = 88.2$, df = 1, 38, $P \leqslant 0.001$). Similarly to the larval experiments, the percentage leaf area damaged on water-treated leaves was not different between choice and no-choice experiments ($F = 3.9$, df = 1, 38, $P = 0.1$).

3.4. *Effect of kaolin particle on development*

Mortality was higher for larvae feeding on kaolin-treated onion leaves than on water-treated leaves ($F = 62.2$, df = 1, 44, $P \leqslant 0.001$), with 51.6±4.7 and 6.6±3.0% (±S.E.) of larvae dying before pupation, respectively. Kaolin treatment significantly increased the development time of first and second instars compared to the water-treated onion leaves, but did not affect the pupation time (Table 1).

Table 1
Mean development time (d±S.E.) of *Thrips tabaci* larvae reared on kaolin-treated and water-treated onion leaves in the laboratory

Treatment	Larva 1 (d±S.E.)	Larva 2 (d±S.E.)	Pupal stage (d±S.E.)
Kaolin	2.3±0.1b	3.5±0.2b	3.8±0.5a
Water	2.0±0a	2.45±0.1a	3.9±0.1a
	$F_{1,44} = 8.9$, $P \leqslant 0.001$	$F_{1,43} = 42.3$, $P \leqslant 0.001$	$F_{1,42} = 1.6$, $P = 0.2$

Mean values followed by the same letter are not significantly different ($p = 0.05$).

3.5. *Effect of direct application of kaolin particle film*

In all, 5% and 14% of larvae and adults, respectively, were dead after direct application of kaolin particle film, whereas no mortality was recorded in the water treatment. Pearson's chi-square test showed a good fitness for the log-linear analysis and revealed a significant effect of age ($\chi^2 = 4.2$, $P = 0.04$) and also of treatment on survival ($\chi^2 = 22.0$, $P \leqslant 0.001$).

3.6. *Field efficacy study*

3.6.1. *Plant counts*

Thrips numbers started increasing in mid-June (Figs. 4 and 5). The two-way ANOVA for adults and larvae revealed significant differences between treatments ($F = 49.3$, df = 1, 72, $P \leqslant 0.001$; $F = 88.2$, df = 1, 959, $P \leqslant 0.001$, respectively) and sampling dates ($F = 317.0$, df = 11, 72, $P \leqslant 0.001$; $F = 806.7$, df = 11, 72, $P \leqslant 0.001$, respectively), but also the interaction of both factors was significant. Although adult thrips numbers were low in the beginning of the season and no differences were detected between treatments during the initial sampling dates (Fig. 5), on the first adult peak point, i.e. 29 June, significantly more adults were found on control (1.3±0.2, mean±S.E.) than on kaolin-treated plants (0.5±0.1, mean±S.E.) ($F = 6.4$, df = 1, 78, $P \leqslant 0.001$). Similarly, on 20 July, when adult populations were increasing rapidly and a kaolin treatment preceded the sampling,

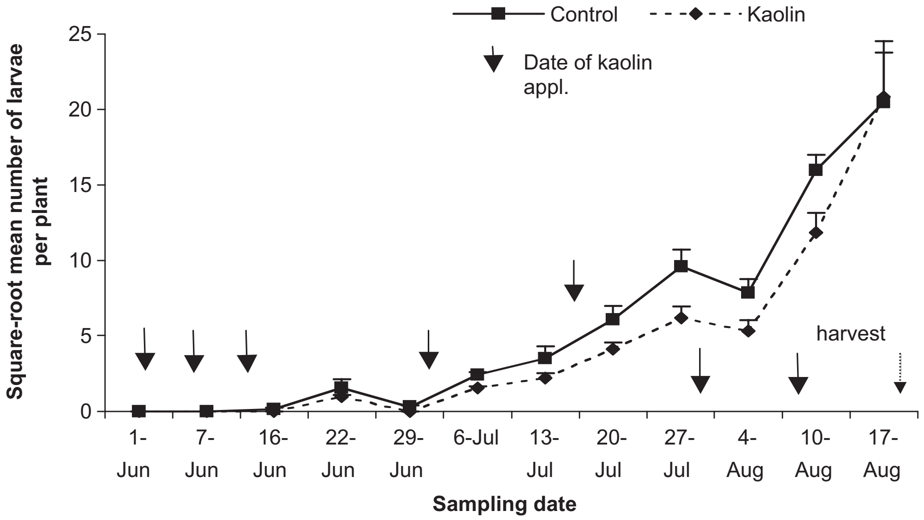

Fig. 4. Number of *Thrips tabaci* adults on kaolin-treated and control onion plants, during summer 2006. Arrows indicate kaolin application dates.

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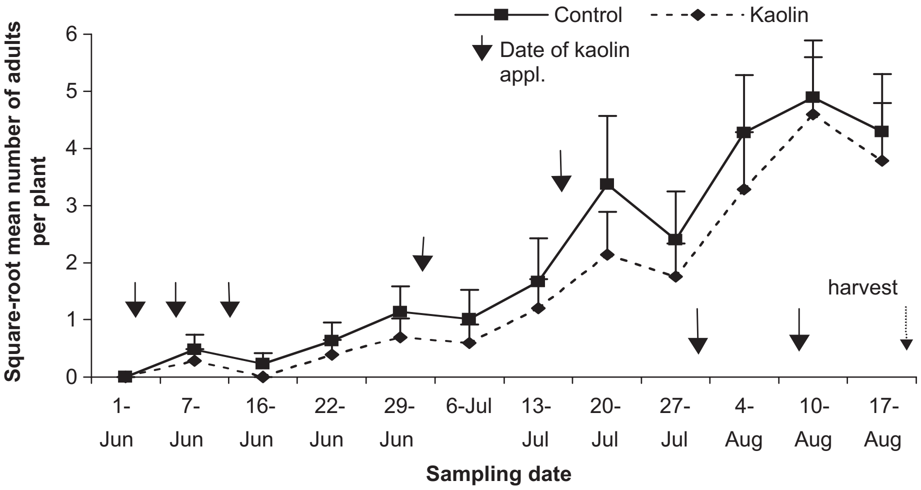

Fig. 5. Number of *Thrips tabaci* larvae on kaolin-treated and control onion plants, during summer 2006. Arrows indicate kaolin application dates.

Table 2
Analysis of variance for the effect of treatment on *Thrips tabaci* larvae on sampling dates following kaolin application in the field

Date	*F*-value	Df	*P*-value
6 July	11.5	1, 78	$\leqslant$0.001
20 July	13.9	1, 78	$\leqslant$0.001
4 August	30.4	1, 78	$\leqslant$0.001
10 August	23.5	1, 78	$\leqslant$0.001

fewer adults were captured on kaolin-treated plants (4.6±0.5, mean±S.E.) than on control plants (11.4±1.4, mean±S.E.) ($F = 19.3$, df = 1, 78, $P \leqslant 0.001$). At the first peak larval population on 27 July (Fig. 5), there were significantly more larvae on control plants (91.7±9.5, mean±S.E.) than on kaolin-treated onions (37.9±4.3, mean±S.E.) ($F = 31.6$, df = 1, 78, $P \leqslant 0.001$) and the same treatment effects were evident on sampling dates following kaolin applications on 6, 20 July and 4, 10 August (Table 2).

3.6.2. *Yield data*

Mean onion yield was not different between kaolin-treated and control plots (Table 3). More medium-sized onions were produced by both practices and jumbo onions were less than 5% in both kaolin and control plots.

4. Discussion

The laboratory results demonstrate that kaolin particle film had significant negative effects on oviposition, feeding and development of *T. tabaci*. Adult *T. tabaci*, when given the choice, avoided the kaolin-treated leaf part. When untreated leaves were unavailable (no-choice tests), adults oviposited on kaolin-treated leaves but in significantly lower rates, which suggests that any barrier effect conferred by kaolin reduced oviposition. *T. tabaci* oviposit eggs singly inside the tissue by making an incision in the plant surface, and, like most terebrantian thrips, before laying their eggs they investigate the substrate suitability with their terminal abdominal setae and ovipositor (Terry, 1997). The presence of kaolin particle film on the leaf surface interfered with the oviposition process. This was evident even in the choice assays, where *T. tabaci* ovipositional output was low, suggesting that when adults contacted kaolin it limited their oviposition potential.

Feeding by both *T. tabaci* larvae and adults was reduced in kaolin-treated leaves and both life stages avoided treated surfaces. Consumption of the water-treated area was similar in both choice and no-choice tests, but when clean leaves were unavailable kaolin-treated leaves were damaged, although to a lesser extent than control leaves. Feeding marks were observed in areas with thin kaolin deposits, suggesting that the uniformity of particle film coverage is essential to deter thrips feeding damage. Indeed, a complete and uniform film coating on plant surface is essential for kaolin particle film to be effective (Glenn et al., 1999), and the onion plant architecture with tight crowns and expanding and developing leaves evokes a challenging situation.

Kaolin treatments both delayed larval development and increased mortality compared to the water control. An increase in developmental time is likely due to difficulty in penetrating the particle film and feeding, as illustrated during the feeding tests. Our observations indicated that the kaolin particles on the thrips' body appear to have interfered with its feeding process, as larvae would spend more time cleaning themselves and less time feeding. Pupal stage was not affected by kaolin particle film, and larvae which pupated emerged successfully into adults.

The mortality rate after direct application with kaolin was low, but adults were affected more than larvae. The nonabrasive and soft nature of kaolin renders it ineffective as an insecticidal agent (Glenn et al., 1999), and the mortality observed in adult *T. tabaci* after direct

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Table 3
Onion bulb weights (kg) and sizes (mean ± S.E.) as affected by kaolin or control treatments.

Treatment	Size			
	Weight (kg ± S.E.)	Jumbo (>77 mm) *n* (%)	Medium (57–77 mm) *n* (%)	Small (<57 mm) *n* (%)
Kaolin	18.6 ± 2.0a	5.7 ± 3.2a (4.5%)	105.2 ± 13.9a (83%)	15.7 ± 2.1a (12.5%)
Control	15.9 ± 2.5a	4.5 ± 1.7a (3.8%)	92.5 ± 14.1a (77.7%)	22.0 ± 9.8a (18.5%)
	$F = 0.7$, df = 1, 7, $P = 0.4$	$F = 0.1$, df = 1, 7, $P = 0.7$	$F = 0.4$, df = 1, 7, $P = 0.5$	$F = 0.2$, df = 1, 7, $P = 0.7$

Mean values followed by the same letter are not significantly different ($p = 0.05$).

application could be explained by the possible coating of female body parts with kaolin which inhibited their feeding. Thrips' larval structure of the chitin surface connected to setae differs from that of adults (Moritz, 1997), and such a hydrophobic feature in larvae may interfere with the amount of kaolin clinging on their bodies and explain the low mortality 24 h after direct application.

The decreased numbers of *T. tabaci* adults and larvae in the kaolin-treated plots of the field study concur with the laboratory studies. Adults reached higher numbers in the control plots in the beginning of the season in plant counts, which could indicate a thrips response to the reflective properties of kaolin. Kaolin has been reported to have a white brightness quality (Glenn et al., 1999), and the black pecan aphid *Melanocallis caryaefoliae* (Davis) (Homoptera: Aphididae) and the boll weevil *Anthonomus gravis gravis* Boheman (Coleoptera: Curculionidae) have been reported to base their landing choice, between kaolin-treated and control plots, on light reflectance and color differences, respectively (Cottrell et al., 2002; Showler, 2002). Thrips locate suitable host plants through visual cues in the UV spectrum (Terry, 1997) and adults have been shown to respond to UV-reflective materials that reduce early season abundance (Stavisky et al., 2002; Reitz et al., 2003; van Toor et al., 2004). Such effect on onions and thrips after kaolin applications should be investigated. At peak population times kaolin-treated plots had a significant lower number of both life stages, which indicated the negative effect of kaolin on feeding and development of larvae, as was found in our laboratory studies. Also, in plant counts performed after kaolin applications, thrips numbers were significantly lower in kaolin-treated plots. Yield and bulb sizes were not affected by kaolin application, which indicates that plant physiological properties were not significantly altered by the coverage of photosynthetic surface.

Our results indicate the potential for kaolin as a deterrent to oviposition and feeding of onion thrips on onions. In the field, onion thrips numbers were significantly reduced after kaolin applications. As such, it may prove to be an important component of an integrated pest management program against *T. tabaci* in onions, limiting insecticide applications and reducing the risk of insecticide resistance, and offering an alternative control method for organic or small-scale growers. Kaolin-based products have been approved for organic use in fruit and vegetables crops (OMRI, 2007). However, because of the importance of a continuous coverage of plant material with kaolin particle film, multiple applications and better coverage than we experienced in the field will be required to cover newly expanding foliage. Furthermore, its use may be limited in areas where the film may be washed off by frequent rainfall or overhead irrigation.

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