Research Article

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Repellency of a kaolin particle film to potato psyllid, *Bactericera cockerelli* (Hemiptera: Psyllidae), on tomato under laboratory and field conditions

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Abstract

BACKGROUND: The potato psyllid, *Bactericera cockerelli*, is a vector of *Candidatus* Liberibacter solanacearum, causing several diseases in solanaceous crops. Laboratory and field no-choice and choice experiments were conducted to evaluate the repellency of kaolin particle film on adults of *B. cockerelli* on tomato plants that had been sprayed with kaolin particle film on the upper surface only, on the lower surface only and on both leaf surfaces.

RESULTS: In no-choice tests in the laboratory, the numbers of adults on leaves were not different between the kaolin particle film and the water control, regardless of which leaf surface(s) were treated, but numbers of eggs were lower on the leaves treated with kaolin particle film than on those treated with water. In choice tests on plants treated with water/plants treated with kaolin particle film at ratios of 1 : 1, 6 : 3 or 8 : 1, fewer adults and eggs were found on the leaves treated with kaolin particle film than on leaves treated with water. Under field conditions, in caged no-choice or choice tests, fewer adults, eggs and nymphs were found on plants treated with kaolin particle film than on plants treated with water. In an uncaged test under field conditions, plants sprayed with kaolin particle film had fewer psyllids than those sprayed with water.

CONCLUSION: Even though potato psyllid adults could land on plants treated with kaolin particle film when no choice was given, fewer eggs were laid. When given a choice, the psyllids avoided plants treated with kaolin particle film under laboratory and field conditions. Kaolin particle film treatment may be a useful alternative for management of potato psyllids under field conditions.

Keywords: potato psyllid; potato; kaolin particle film; repellency; management

1 INTRODUCTION

The potato or tomato psyllid, *Bactericera cockerelli* (Sulc) (Hemiptera: Psyllidae), is one of the most important pests of vegetable crops in tropical and subtropical regions of the world. It is a polyphagous phloem-feeding insect and causes significant damage to solanaceous crops in the United States, Mexico, Central America and New Zealand.[1,2] In the United States, this insect has been found in most of the western and southern states.[3–6] *Bactericera cockerelli* has a wide host range of about 20 plant families, particularly in Solanaceae.[3,4] In recent years, *B. cockerelli* has been shown to be the vector of the bacterial pathogen *Candidatus* Liberibacter solanacearum (aka *Candidatus* Liberibacter psyllarosus) which has been linked with a new potato disease, zebra chip (ZC), that has caused millions of dollars in losses to the potato industry in Texas and in other places where this insect occurs.[1,5–8] In recent years, *B. cockerelli* has also increasingly become a pest on tomato, pepper and eggplant in the Lower Rio Grande Valley (LRGV) of Texas and in other regions.[5–10]

At present, application of chemical insecticides is the only effective means for management of *B. cockerelli* and its vectored diseases on potato and tomato. To ensure food safety and environmental sustainability, insecticides with low toxicity and alternative control methods and materials are needed. Nontraditional materials are becoming more important in pest control programmes. Yang *et al*.[11] recently showed that some mineral oils and plant extracts were effective in repelling *B. cockerelli* adults and

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deterring them from depositing eggs on tomato plants treated with the biopesticides.

Kaolin is a white, non-porous, non-swelling, non-abrasive, fine-grained, platy aluminosilicate mineral [$Al_4Si_4O_{10}(OH)_8$] that is chemically inert over a wide pH range. The use of kaolin particle film technologies has recently been introduced as a novel approach to suppressing arthropod pests. After being sprayed on the plant surface, the kaolin particle film creates a protective physical or mechanical barrier against plant pathogens and plant-feeding arthropods.[12] Kaolin particle film has been widely studied for the management of numerous pests: dipteran pests,[13,14] hemipterous/homopterous pests including whiteflies,[15] aphids,[16–18] thrips,[19,20] coleopteran pests, *Anthonomusgrandis* Boheman,[21] *Diaprepes abbreviates* (L.)[22] and lepidopterous pests including *Cydiapomonella* (L.),[23] *Spodopteraexigua* (Hübner),[24] *Plutella xylostella* L.[25] and *Lymantriadispar* (L.).[26]

Although kaolin particle film has been evaluated for management of other psyllid species, including *Cacopsylla pyri* (L.) and pistachio psyllid *Agonoscena targionii* (Lichtenstein),[27–30] its effects on *B. cockerelli* host plant choice and oviposition behaviour have not yet been investigated. Such encouraging effects on various insect pest species prompted the present study. Additionally, owing to the transmission of the ZC disease by this insect pest, repelling *B. cockerelli* adults before feeding or oviposition on host plants in the field could eliminate or reduce potato-psyllid-vectored disease infection. The objective of this study was to determine the repellent effects of kaolin particle film on *B. cockerelli* under both laboratory and field conditions. This study is part of an ongoing project on development and implementation of effective and environmentally sound management strategies against *B. cockerelli* in tomato and potato fields in Texas.

2 MATERIALS AND METHODS

2.1 Potato psyllids and tomato plants

Potato psyllids used in the study were obtained from a psyllid colony that had been maintained in a screen cage on tomato, *Solanum lycopersicum* L. (variety 'Florida Lanai'), plants for >2 years at the Texas AgriLife Research and Extension Center at Weslaco, Texas. The tomato was seeded first in seedling transplant trays with cone-shaped cells (3 × 3 × 4 cm) in a naturally lit greenhouse at 28–32 °C and in natural lighting conditions. One week after germination, the tomato seedlings were individually transplanted into 1 L plastic pots. The seedlings were fertilised weekly with 0.6 g L^{-1} water-soluble plant food (N:P:K = 15:30:15) (Chemisco, Division of United Industries Corp., St Louis, MO) and watered as needed. Four-week-old tomato plants were used in all experiments.

2.2 Laboratory repellency tests

Bioassays were conducted on the basis of the methods previously described by Liang and Liu.[15] The environmental conditions for all laboratory experiments were maintained at 23 ± 2 °C, 55 ± 5% RH and 14:10 h (L:D). The concentrations of kaolin particle film (Surround[WP]; Engelhard Corporation, Iselin, NJ) spray suspensions were prepared following the manufacturer's recommendations for field application (60 g L^{-1} or 56 kg 935 L^{-1} ha^{-1}). Deionised water was used as a control in all laboratory experiments. Kaolin particle film was prepared by adding the wettable powder to a 500 mL glass beaker with the appropriate amount of water and stirring on a magnetic stirring plate. The tomato plants used in the laboratory bioassays were at the 4–5-leaf stage. Only the first fully expanded leaf (approximately 25–30 cm^2) at the upper canopy was used.

2.2.1 *No-choice test*

This test had two treatments consisting of kaolin particle film or water. Ten tomato plants (leaves) were sprayed with kaolin particle film or water using a plastic handheld sprayer (ReStockIt, Hollywood, FL) on the upper leaf surface, lower leaf surface or both leaf surfaces until run-off. After air drying for ∼2 h, ten leaves of each treatment were placed on a wooden-wheel rotary table in a large cage (60 × 60 × 60 cm). Three hundred potato psyllid adults (unsexed and age unknown) were aspirated into a petri dish (9 cm in diameter and 2 cm in depth) that was placed in the centre of the rotary table. The adults were then allowed to fly to the exposed leaves. The numbers of adults on each leaf were counted by gently turning each leaf in the cage at 4, 24 and 48 h after release. After each count, all leaves were shaken to dislodge adults, forcing them to relocate to different leaves so as to avoid leaf-location bias in the cage. After the last count at 48 h, all leaves were excised from the plants, and the number of eggs on the upper and lower surfaces and the edge of each leaf were counted under a stereomicroscope. The number of potato psyllid adults that were repelled from the leaves or not on the leaves were used in the analysis. Each treatment was replicated 4 times.

2.2.2 *Choice tests*

Tomato plants used in this choice test were the same cultivar and were treated identically to those used in the no-choice test. In this choice test, potato psyllid adults were given a choice among the tomato leaves treated with kaolin particle film or with water (two material treatments), and the materials were applied on the upper leaf surface, the lower leaf surface or both the upper and lower leaf surfaces. All treated plants (leaves) were arranged as follows: (1) in the 1:1 choice test, ten plants, five treated with kaolin particle film and five with water, were randomly placed in a large cage; (2) in the 3:6 choice test, nine plants were arranged in a 3 × 3 square, and the three plants in the middle row were treated with water while the plants in the two flanking rows were treated with kaolin particle film; (3) in the 1:8 choice test, nine plants were again arranged in a 3 × 3 square, the one in the centre being treated with water and the other eight surrounding plants being treated with kaolin particle film. Potato psyllid adults at a 30 per leaf rate were introduced into each cage: 300 in the 1:1 choice test, and 270 in the other two tests. The numbers of adults on each leaf were counted by gently turning the leaf in the cages at 4, 24, 48 and 72 h after release for the 1:1 treatment, and at 4, 24 and 48 h for the 3:6 and 1:8 treatments. After each count at 4, 24 or 48 h, all leaves were shaken to dislodge adults, forcing them to relocate to avoid leaf-location bias in the cage. After examining the adults at 48 or 72 h, all leaves were excised from the plants, and the number of eggs on the upper and lower surfaces and on the edge of each leaf were counted using a stereomicroscope. Each treatment was replicated 4 times.

2.3 Field tests

Greenhouse-grown tomato plants in plastic pots (1 L) at the 14–15-leaf stage were transplanted into field cages, 25 cm apart, 1 day before the experiment. They were then sprayed with kaolin particle film or with water. The plants were drip irrigated as needed. The following three experiments were conducted.

2.3.1 Caged no-choice test

Four tomato plants were placed in each cage (1.25 m in length × 1.25 m in width × 1.00 cm in height). The plants were either treated with kaolin particle film or with water. The plants were air dried for 2 h. Potato psyllids were introduced at 180 adults per plant. The numbers of psyllid adults, eggs and nymphs were counted on a top leaf, a middle leaf and a bottom leaf of each plant at 1, 3, 10, 13 and 17 days after adult release (DAR).

2.3.2 Caged choice test

Eight tomato plants were placed in each cage (2.50 m in length × 1.25 m in width × 1.00 cm in height), and four were randomly chosen and treated with kaolin particle film and the other four with water; in these two tests, potato psyllid adults were introduced at 180 adults per plant 2 h after treatment. The numbers of psyllid adults, eggs and nymphs were counted on a top leaf, a middle leaf and a bottom leaf of each plant at 1, 3, 10, 13 and 17 DAR.

2.3.3 Uncaged test

Tomato plants were transplanted and sprayed as in the above two tests, but the plants were uncaged, and no potato psyllids were released; a natural infestation of potato psyllids was allowed to develop. The numbers of potato psyllid adults, eggs and nymphs were counted on a top leaf, a middle leaf and a bottom leaf of each plant at 1, 3, 10, 13, 17, 20, 24 and 27 DAR. Each experiment had three replications.

2.4 Data analysis

The numbers of potato psyllids (adults, eggs or nymphs) on tomato leaves in each test were subjected to analysis of variance (ANOVA) using the general linear model (PROC GLM; SAS Institute, Cary, NC, 2009), and means were separated using the least significant difference test (LSD).[31]

3 RESULTS

3.1 Laboratory repellency tests

3.1.1 No-choice test

There were no significant differences between treatments in the number of adults residing on individual leaves when kaolin particle film was applied on both leaf surfaces or on either the lower or the upper leaf surface ($F = 0.05-1.51$; df = 1, 18; $P > 0.05$) (Figs 1A, B and C). However, the number of eggs per leaf differed. More potato psyllid eggs were found on leaves treated with water than on those treated with kaolin particle film on the lower leaf surface ($F = 5.30$; df = 1, 18; $P = 0.0334$), the upper surface ($F = 3.46$; df = 1, 18; $P = 0.0495$) and both surfaces ($F = 6.61$; df = 1, 18; $P = 0.0192$) (Fig. 1D).

3.1.2 Choice tests

In the test of leaves treated with kaolin particle film and leaves treated with water at a 1 : 1 ratio, the numbers of adults found on the leaf surface varied depending on the leaf surface treated (Fig. 2). When kaolin particle film was applied on the upper leaf surface, more adults were found on the leaves treated with water than on leaves treated with kaolin particle film at all four sampling dates ($F = 3.96-26.80$; df = 1, 6; $P = 0.0042-0.0498$) (Fig. 2A). However, in the treatments where the lower leaf surface and both leaf surfaces were treated, the numbers of adults on the leaves treated with water were not different from the numbers of adults on those treated with kaolin particle film at 4, 24 and 48 h ($F = 0.46-4.03$; df = 1, 6; $P = 0.0571-0.5033$) but were significantly greater 72 h after release of adults ($F = 3.11-3.14$; df = 1, 6; $P = 0.0479-0.0384$) (Figs 2B and C). Significantly more eggs were oviposited on the water-treated leaves than on the leaves treated with kaolin particle film, regardless of which leaf surface(s) were treated ($F = 6.01-18.97$; df = 1, 6; $P = 0.0003-0.0227$) (Fig. 2D).

In the test of leaves treated with kaolin particle film and leaves treated with water at a 6 : 3 ratio, more adults were found on the leaves treated with water than on the leaves treated with kaolin particle film ($F = 4.82-69.06$; df = 1, 6; $P = 0.0035-0.0001$) (Figs 3A, B and C). Significantly more eggs were oviposited on the leaves treated with water than on the leaves treated with kaolin particle film, regardless of which leaf surface(s) were treated ($F = 10.16-60.54$; df = 1, 6; $P = 0.0031-0.0001$) (Fig. 3D).

In the test of leaves treated with kaolin particle film and leaves treated with water at a 8 : 1 ratio, more adults were found on the leaves treated with water than on the leaves treated with kaolin particle film ($F = 97.79-472.91$; df = 1, 6; $P < 0.0001$) (Figs 4A, B and C). Similarly, more eggs were found on the leaves treated with water than on the leaves treated with kaolin particle film, regardless of which leaf surface(s) were treated ($F = 43.13-189.02$; df = 1, 6; $P < 0.0001$) (Fig. 4D).

3.2 Field repellency tests

3.2.1 Caged no-choice test

More potato psyllid adults, eggs and nymphs were found on plants treated with water than on plants treated with kaolin particle film (Fig. 5). The number of adults varied during the period of experiment, and significantly more were found on the plants treated with water than on the plants treated with kaolin particle film on 3, 10, 13, 20 and 27 DAR ($F = 15.00-21.43$; df = 1, 6; $P = 0.0082-0.0036$), but not on 6, 17 and 24 DAR ($F = 0.75-1.40$; df = 1, 6; $P = 0.2528-0.4198$) (Fig. 5A). More eggs were found on water-treated plants than on plants treated with kaolin particle film starting from the first sampling date to day 17 ($F = 0.4.52-36.70$; df = 1, 6; $P = 0.0477-0.0009$), except on day 20 ($F = 1.31$; df = 1, 6; $P = 0.2582$) (Fig. 5B). No nymphs were found on the plants on the first three sampling dates, and significantly more nymphs were found on the plants treated with water than on the plants treated with kaolin particle film ($F = 8.27-10.20$; df = 1, 6; $P = 0.0413-0.0188$) (Fig. 5C). Overall, more potato psyllids were found on the plants treated with water than on the plants treated with kaolin particle film during the entire test period ($F = 4.04-23.29$; df = 1, 6; $P = 0.0418-0.0073$) (Fig. 5D). Over the eight sampling dates, 2.4-fold more adults, 3.4-fold more eggs, 2.5-fold more nymphs and 2.9-fold more total psyllids were found on the plants treated with water than on the plants treated with kaolin particle film (Table 1).

3.2.2 Caged choice test

More potato psyllid adults, eggs and nymphs were found on the plants treated with water than on the plants treated with kaolin particle film (Fig. 6). Significantly more adults, eggs and total psyllids were found on the plants treated with water than on the plants treated with kaolin particle film on all five sampling dates (adults: $F = 3.13-108.00$; df = 1, 6; $P = 0.0017-0.0001$; eggs: $F = 7.65-50.05$; df = 1, 6; $P = 0.0326-0.0004$; total psyllids: $F = 21.94-178.71$; df = 1, 6; $P = 0.0023-0.0001$) (Figs 6A, B and

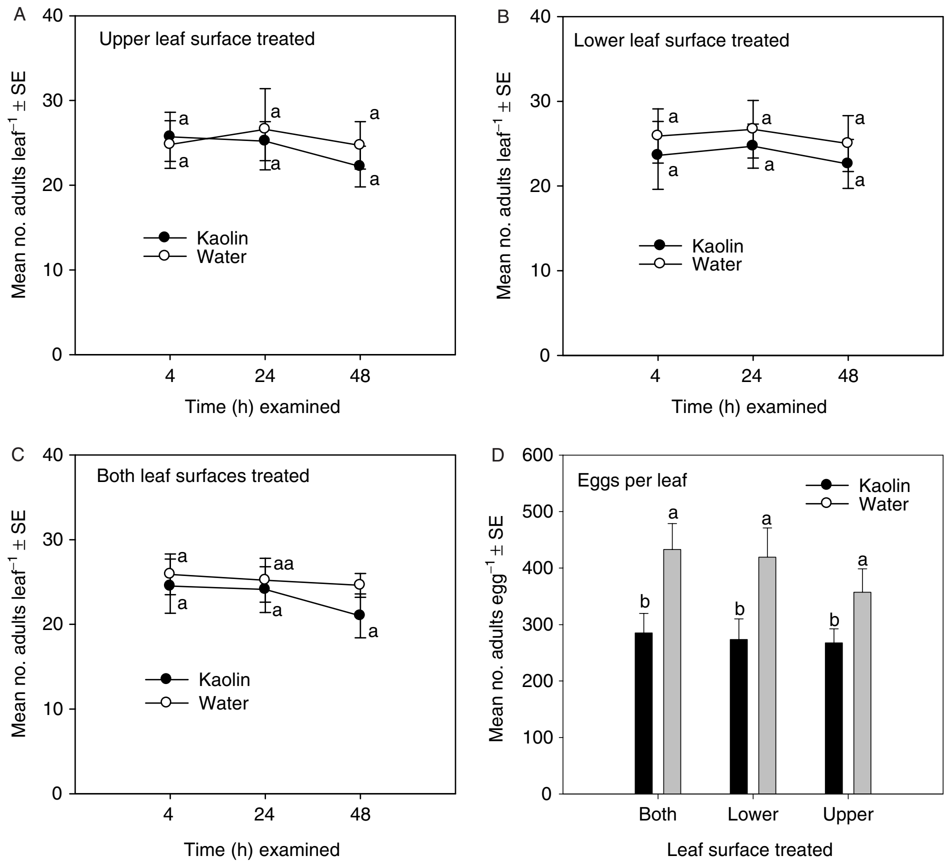

Figure 1. Repellency of kaolin particle film on potato psyllid on tomato in no-choice tests in the laboratory. A: both leaf surfaces were treated; B: only the lower leaf surface was treated; C: only the upper leaf surface was treated; D: eggs oviposited. The same letters between the treatments within each sampling time indicate that the two treatments are not significantly different at $P = 0.05$.

Table 1. Repellency of kaolin particle film to the potato psyllid in choice tests in the laboratory

Ratio of kaolin-particle-film-treated leaves to water-treated leaves (total leaves)	Number of leaves treated with kaolin	Number of leaves treated with water	Arrangement in row or column in the cage	Adults introduced	Leaf surface(s) treated
1 : 1 (ten leaves)	5	5	All leaves were randomly arranged	300	Upper
1 : 1 (ten leaves)	5	5		300	Lower
1 : 1 (ten leaves)	5	5		300	Both
1 : 2 (nine leaves)	6	3	3 × 3 square; the three leaves in the middle row were treated with water	270	Upper
1 : 2 (nine leaves)	6	3		270	Lower
1 : 2 (nine leaves)	6	3		270	Both
1 : 8 (nine leaves)	8	1	3 × 3 square; only the one in the centre was treated with water	270	Upper
1 : 8 (nine leaves)	8	1		270	Lower
1 : 8 (nine leaves)	8	1		270	Both

D). No nymphs were found on the plants on the first sampling date (day 3), and the number of nymphs was not significantly different between the water and the kaolin particle film treatments on the second sampling date (day 6) and the fourth date (day 13) ($F = 0.22$; df = 1, 6; $P = 0.6440$) (Fig. 6C). However, more nymphs were found on the plants treated with water than on the plants treated with kaolin particle film on the third and the last sampling dates ($F = 5.81$–30.23; df = 1, 6; $P = 0.0426$–0.0015). Over the five sampling dates, 3.6-fold more adults, 6.3-fold more eggs, 3.0-fold more nymphs and 5.0-fold more total psyllids were found on the plants treated with water than on the plants treated with kaolin particle film (Table 2).

3.2.3 *Uncaged test*

Under field conditions, the number of potato psyllids on tomato plants fluctuated greatly among the sampling dates, and generally more potato psyllids were found on the plants treated with water than on the plants treated with kaolin particle film (Fig. 7). After

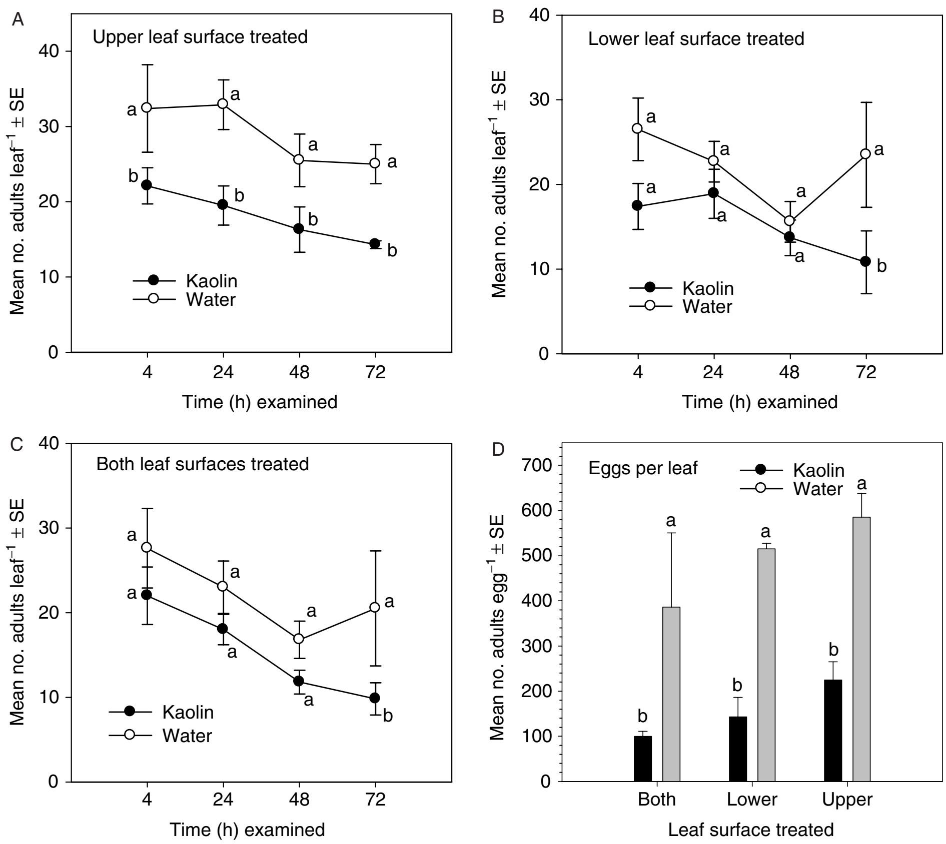

Figure 2. Repellency of kaolin particle film on potato psyllid on tomato in a 1 : 1 choice test – numbers of leaves treated with water : leaves treated with kaolin particle film (n = 10). A: both leaf surfaces were treated; B: only the lower leaf surface was treated; C: only the upper leaf surface was treated; D: eggs oviposited. The same letters between the treatments within each sampling time indicate that the two treatments are not significantly different at P = 0.05.

Table 2. Numbers of potato psyllid on tomato plants after applications of kaolin particle film and water under field conditions in south Texas (Weslaco, Texas; Spring 2010)

	Mean number per plant ± SE[a]					
	Caged no choice		Caged choice		Uncaged (field)	
Stage	Water	Kaolin particle film	Water	Kaolin particle film	Water	Kaolin particle film
Adults	7.1 ± 1.7a	2.9 ± 0.6b	6.4 ± 0.7a	1.8 ± 0.3b	1.8 ± 0.4a	0.2 ± 0.1b
Eggs	81.3 ± 10.3a	24.0 ± 4.2	153.3 ± 13.8a	24.2 ± 2.8b	19.9 ± 4.4a	3.8 ± 1.5b
Nymphs	62.7 ± 11.6a	24.7 ± 5.3	49.7 ± 11.0a	16.3 ± 4.6b	13.0 ± 3.7a	2.3 ± 1.0b
Total	151.1 ± 17.1a	51.6 ± 6.5b	209.3 ± 15.0a	42.2 ± 5.3b	34.8 ± 5.0a	6.2 ± 1.8b

[a] Means in the same subrow between water and kaolin particle film treatments followed by the same letter do not different significantly at P = 0.05 (LSD; SAS Institute, 2009).

the first sampling date, significantly more adults were found on the plants treated with water than on the plants treated with kaolin particle film on the next three sampling dates and the last sampling date (F = 3.86–16.35; df = 1, 6; P = 0.0476–0.0068) (Fig. 7A). There were no differences between the two treatments at 17, 20 and 24 days after treatment (F = 1.00–3.00; df = 1, 6; P = 0.1340–0.3559). The numbers of eggs on the plants treated with water and with kaolin particle film were not significantly different on the first two and the last two sampling dates (F = 0.89–1.89; df = 1, 6; P = 0.2186–0.3826), but more eggs were found on the plants treated with water than on the plants treated with kaolin particle film on the other four sampling dates (F = 3.97–6.73; df = 1, 6; P = 0.0451–0.0242) (Fig. 7B). No nymphs were found on the plants on the first three sampling dates, and the numbers of nymphs were not significantly different between the water and the kaolin particle film treatments on the next three sampling dates (F = 1.11–3.88; df = 1, 6; P = 0.0963–0.3325) (Fig. 7C); more nymphs were found on the plants treated with water than on the plants treated with kaolin particle film on the last two sampling dates (F = 4.25–11.34; df = 1, 6; P = 0.0317–0.0214). The total numbers of potato psyllids were greater on the leaves treated with water than on

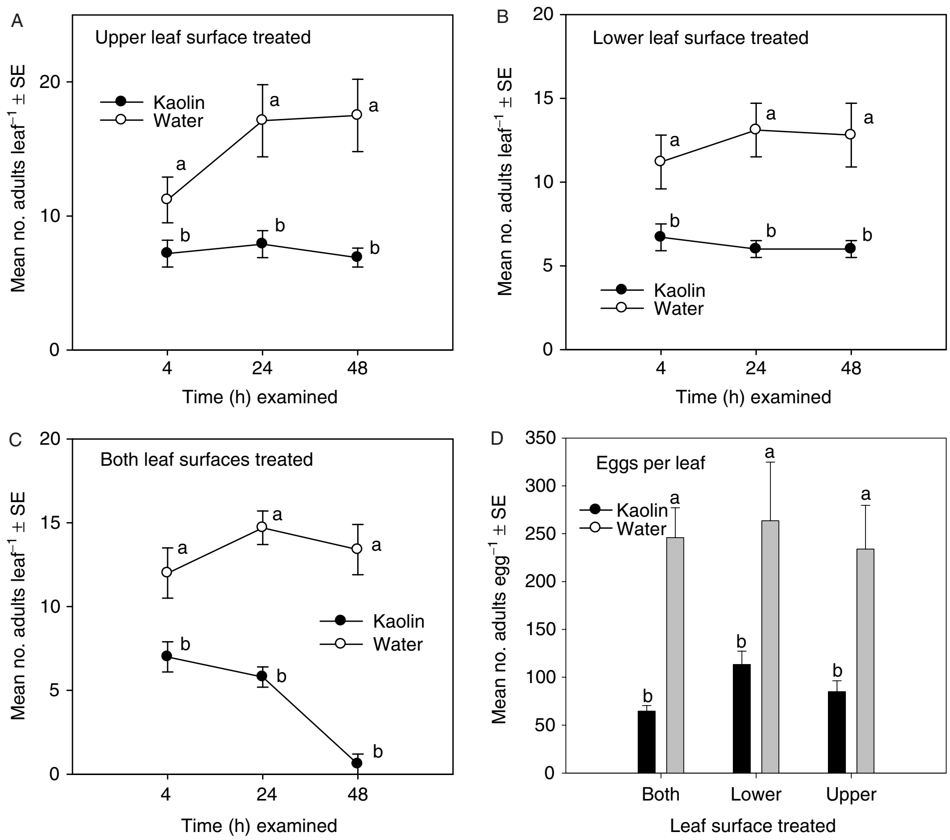

Figure 3. Repellency of kaolin particle film on potato psyllid on tomato in a 6 : 3 choice test – numbers of leaves treated with water : leaves treated with kaolin particle film ($n = 9$). A: both leaf surfaces were treated; B: only the lower leaf surface was treated; C: only the upper leaf surface was treated; D: eggs oviposited. The same letters between the treatments within each sampling time indicate that the two treatments are not significantly different at $P = 0.05$.

the leaves treated with kaolin particle film ($F = 4.46$–11.96; df = 1, 6; $P = 0.0492$–0.0135), except on the first two sampling dates ($F = 1.00$–1.22; df = 1, 6; $P = 0.3119$–0.3559) (Fig. 7D). Overall, 9.5-fold more adults, 5.2-fold more eggs, 5.7-fold more nymphs and 5.6-fold more total psyllids were found on the plants treated with water than on the plants treated with kaolin particle film (Table 2).

4 DISCUSSION

In this study, kaolin particle film repelled potato psyllid populations by reducing oviposition in no-choice experiments, and reducing adult infestation and oviposition in choice experiments under laboratory conditions. However, the differences between the treated and untreated controls in choice experiments varied greatly depending on the ratio of untreated leaves and treated leaves available to the potato psyllids; more treated leaves or fewer untreated leaves resulted in more potato psyllids on the untreated leaves.

Repellency of kaolin particle film to various insects has been reported in the literature. Barker *et al.*[32] found that, when *Myzus persicae* (Sulzer) were given a choice between kaolin-particle-film-treated and untreated (or water-solvent-treated) leaf areas, both adults and nymphs exhibited a significant preference for non-kaolin-particle-film-treated host plants. Rejection of kaolin-particle-film-treated plant material occurred very rapidly (<20 min). Erler and Cetin[29] also found that the presence of kaolin particle film significantly reduced the number of psyllid adults and also oviposition.

In this study, it was observed that kaolin particle film significantly inhibited oviposition, with significantly fewer eggs laid on leaves treated with kaolin particle film. However, because the potato psyllid prefers to feed and oviposit on the lower leaf surface,[9,10] it can be difficult to prevent oviposition once the adults move to the lower leaf surface. The present field data show that kaolin particle film was highly effective in the control of potato psyllid by preventing egg laying and subsequent population density.

It was observed that the adults landed on the treated leaves, and appeared to try to escape from treated leaves by moving around and testing the leaf surface, although their mouthparts could penetrate through the kaolin particle film barrier on the surface into leaf tissue. This is in agreement with results in the literature.[33] These results indicate that the activity of the kaolin particle film may be related to interference with tactile perception of the host plants.[34,35]

Although the modes of action of kaolin particles on insects and mites are not fully understood, the effects appear to be caused by the colour (white), which repels the insects from landing,[15] and disruption of feeding and oviposition.[5,12,15] Several authors have reported that kaolin particle film creates a physical barrier on plants and a hostile and unfamiliar environment, so that phytophagous insects do not recognise the plants as their host, and therefore their movement, feeding and oviposition are limited on the treated

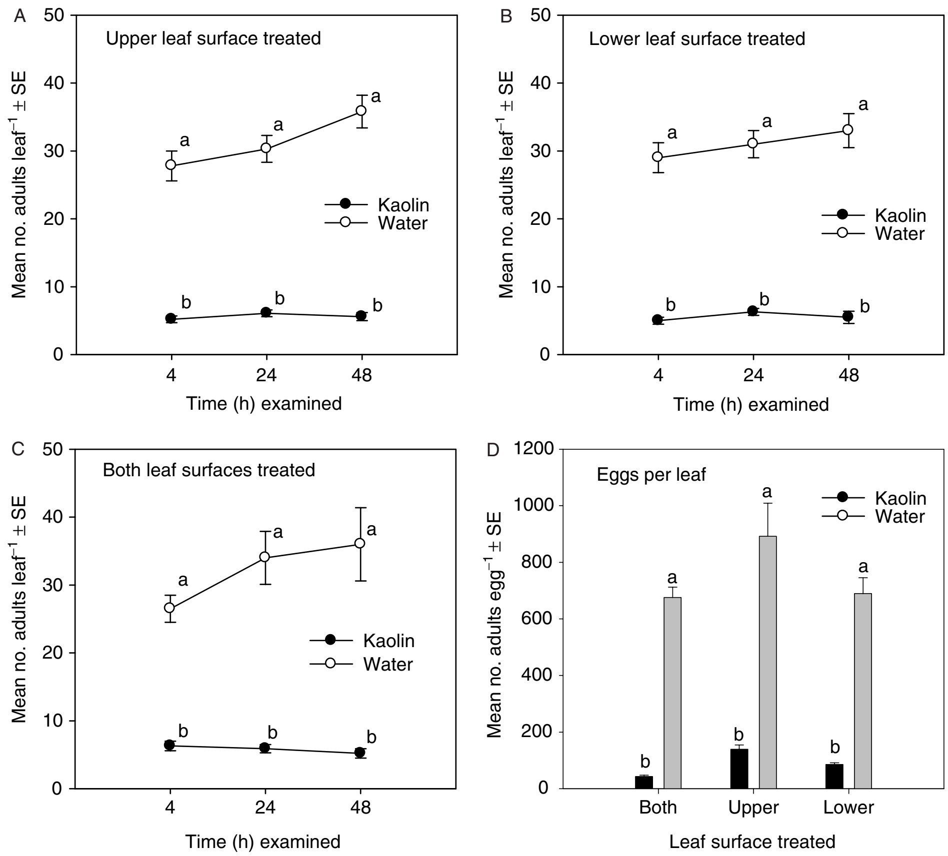

Figure 4. Repellency of kaolin particle film on potato psyllid on tomato in a 8 : 1 choice test – numbers of leaves treated with water : leaves treated with kaolin particle film ($n = 9$). A: both leaf surfaces were treated; B: only the lower leaf surface was treated; C: only the upper leaf surface was treated; D: eggs oviposited. The same letters between the treatments within each sampling time indicate that the two treatments are not significantly different at $P = 0.05$.

plants.[12,16,35] In addition, the mechanical barrier can impede insect movement and feeding.[25,36]

Other advantages of kaolin particle film include the fact that pests are unlikely to develop resistance to it,[5] it has no phytotoxic effects, it lasts longer than most insecticides on the plants when it does not rain or there is no excessive dew formation[37] and it is non-toxic to humans and relatively safe to natural enemies.[38,39] Additionally, it is washable and forms a suspension in water, it can be easily applied using conventional spray equipment and it may eventually reduce the number of applications of conventional insecticides.

Application of kaolin particle film provides many other benefits. Kaolin particle film protects some microbial pesticides after its application onto the plant surface.[40] Eigenbrode *et al.*[41] reported that application of kaolin particle film results in a direct enhancement of germination of entomopathogen *Pandora neoaphidis* of pea aphid, *Acyrthosiphon pisum* (Harris). Lapointe *et al.*[22] also observed that regularly applied sprays of kaolin particle film greatly enhanced the growth of citrus trees on a poorly drained Winder soil at Fort Pierce, Florida, and, after 3 years of applications every 3 or 4 weeks, kaolin-particle-film-treated trees had at least 5 times the mass, 6 times the canopy volume and ∼4 times the cross-sectional area of the tree stems at the graft union compared with untreated trees. These data suggest that the more vigorous trees resulting from kaolin particle film applications may be more resistant or tolerant to pest damage. Pasqualini *et al.*[27] observed that kaolin particle film impeded egg anchorage of pear psyllid, thus significantly reducing the number of eggs on leaves (by around 99%) and reducing the subsequent density of nymphs (by 99–100%). Kaolin particle film could prevent incident radiation, preserve heat, regulate temperature and enhance maturity.[42–44]

However, applications of kaolin particle film have been reported to promote the occurrence of some pests, including cotton aphid (*Aphis gossypii* Glover) infestations in cotton,[45] woolly apple aphid (*Eriosoma lanigerum* Hausmann) in apple orchards[14] and oviposition of *P. xylostella*.[25] Application of kaolin particle film could also affect predators and parasitoids of pests, depending on the crop systems and natural enemies. Negative effects of kaolin particle film on predator and parasitoids have been found in many orchards.[14,46,47] Sackett *et al.*[48] found that kaolin particle film affected the diversity of generalist arthropod predator assemblages and reduced the relative abundances of certain generalist predators, but not others. Iannotta *et al.*[49] found that kaolin particle film has a knockdown effect on many sampled taxa displaying a repellent effect particularly evident at the canopy level of fruit trees, and they suggest that refuge areas to non-target arthropods should be provided. The negative effects of kaolin particle film on natural enemies could be due to repellency, mechanical barrier or the lack of pest prey.

Kaolin particle film provides a physical or mechanical barrier against insect pests and shows considerable potential for effective control of insect pests in certain agricultural crops. Kaolin particle film can also be mixed with other biorational insecticides such

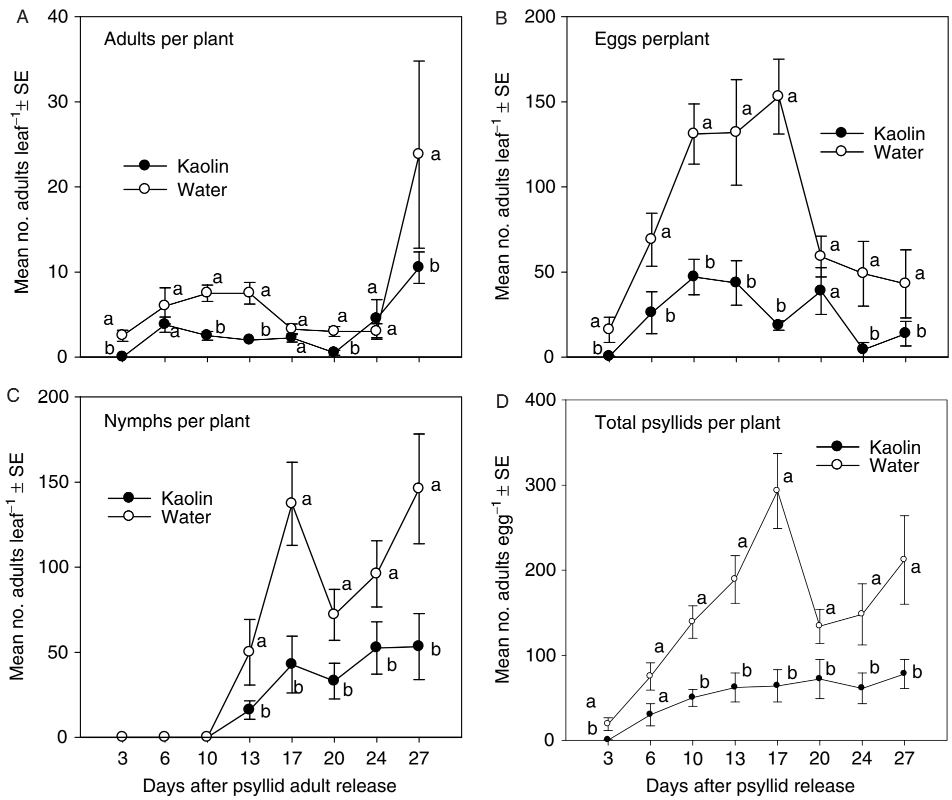

Figure 5. Repellency of kaolin particle film on potato psyllid on tomato under field conditions – potato psyllids had no choice between the two treatments in cages. The same letters between the treatments within each sampling time indicate that the two treatments are not significantly different at $P = 0.05$.

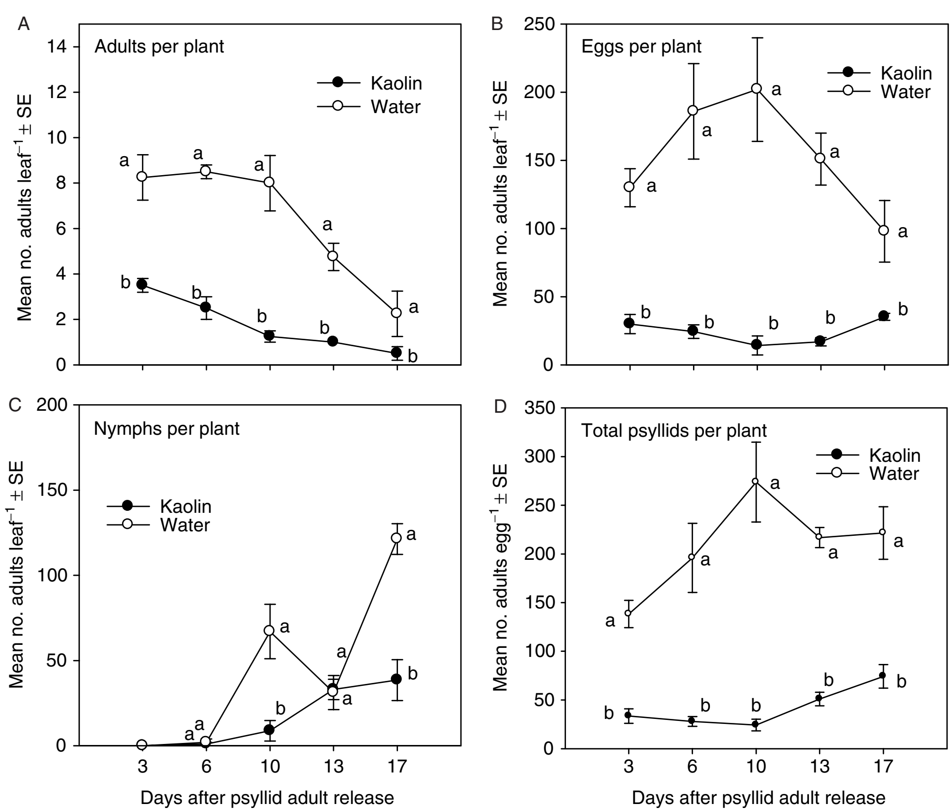

Figure 6. Repellency of kaolin particle film on potato psyllid on tomato under field conditions – potato psyllids were offered a free choice between plants treated with water or kaolin particle film in cages. The same letters between the two treatments at each sampling time indicate that the two treatments are not significantly different at $P = 0.05$.

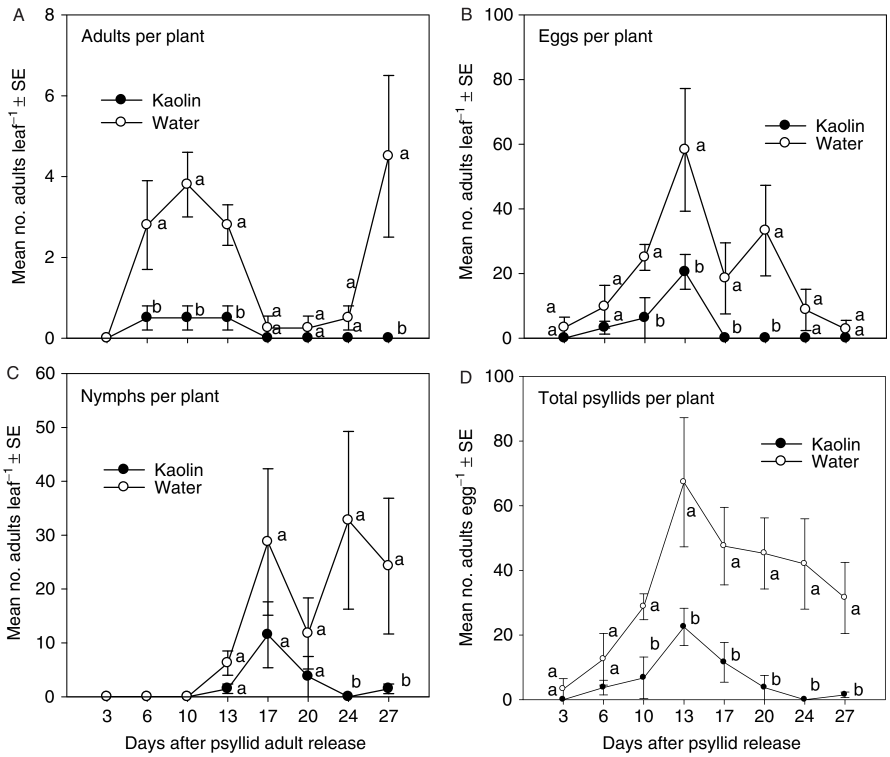

Figure 7. Repellency of kaolin particle film on potato psyllid on tomato under field conditions (plants were in an open field, not caged). The same letters between the two treatments at each sampling time indicate that the two treatments are not significantly different at $P = 0.05$.

as sunspray oil, botanical oils and essential oils to enhance their efficacy.[15,20] 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.

The present data indicate potential for kaolin particle film as a repellent for landing and a barrier to oviposition, and it may prove to be an economically viable and environmentally sound component of an integrated approach for control of potato psyllids and related pests. The potential limitations to the use of kaolin particle films under south Texas's climatic conditions include the ability of the formulation to adhere to leaves and to resist washout from rain and dew. This is less of a problem in California and western Mexico, where tomatoes are grown during the dry season. However, there is a concern that, because kaolin particle film acts like a dust with continuous covering on the leaf surface, it could disrupt the occurrence of other insects, including natural enemies, and possibly result in a resurgence of secondary pests.[33] Although it is not clear whether kaolin particle film can completely replace chemical insecticides in the management of potato psyllid on tomato and other crops, it may be a useful and less toxic alternative within a pest management strategy. The results from this study re-emphasise the need further to evaluate the efficacy of kaolin particle film in large-scale field studies for management of potato psyllid in south Texas and in other places where this insect pest occurs.

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