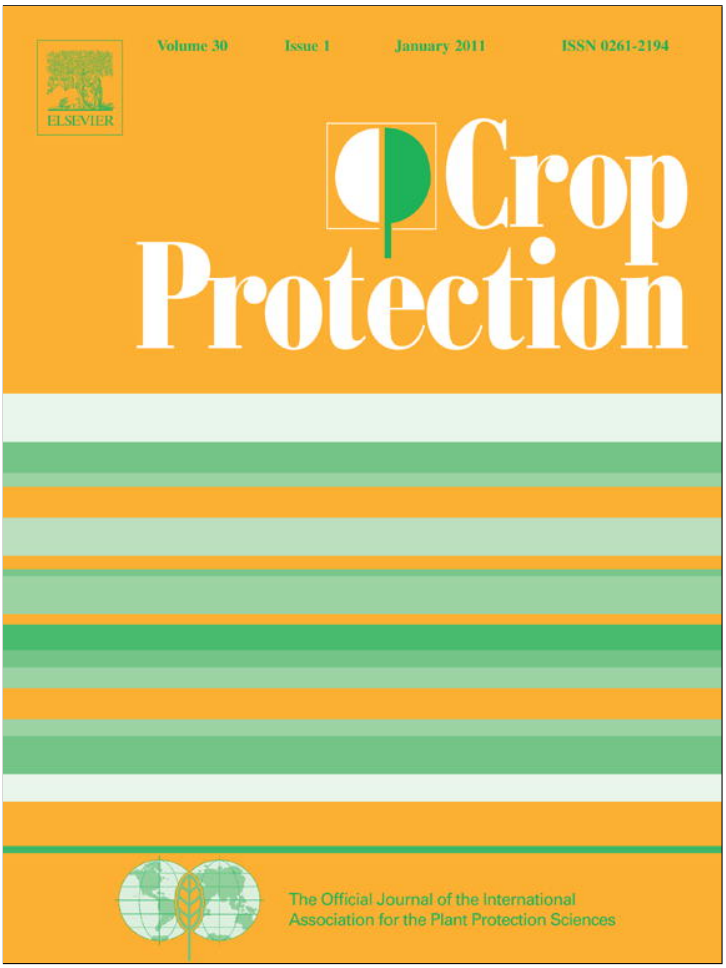

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Evaluation of corn plant as potential banker plant for supporting predatory gall midge, *Feltiella acarisuga* (Diptera: Cecidomyiidae) against *Tetranychus urticae* (Acari: Tetranychidae) in greenhouse vegetable production

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ABSTRACT

The twospotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), is one of the most important and highly polyphagous pests of vegetables and other crops worldwide. Experiments were conducted in the laboratory and greenhouse to evaluate corn (*Zea mays* L.) as a banker plant for the predatory gall midge, *Feltiella acarisuga* (Vallot) (Diptera: Cecidomyiidae) to potentially control *T. urticae*. Choice and no-choice experiments were carried out to determine the host plant preference of an alternative prey, *Oligonychus pratensis* (Banks)(Acari: Tetranychidae) to corn and green bean (*Phaseolus vulgaris* L.). Results showed that *O. pratensis* adults strongly preferred corn as a host plant and posed no risk to green bean. *F. acarisuga* was found to fly at least 7.0 m to search for new preys on green bean plants, and over 176 *F. acarisuga* larvae per leaf were recorded at 14 d after dispersal. *F. acarisuga* proved to be an excellent predator of both *T. urticae* and *O. pratensis*. The predation by *F. acarisuga* to *T. urticae* and *O. pratensis* ranged from 43.7 to 67.9% and 59.2 to 90.3%, respectively, under laboratory conditions. In a non-cage study, 81.2% of *T. urticae* population was suppressed by *F. acarisuga* in reference to the control (cage treatment). The results showed that this banker plant system has potential for controlling *T. urticae* in greenhouse vegetable production.

1. Introduction

The United States is the largest producer of green beans (*Phaseolus vulgaris*. L), accounting for 60% of the world production (Abate, 2006). The twospotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), is one of the most important and highly polyphagous pests of vegetables and other crops, especially green beans (Capinera, 2001; Opit et al., 2004; Liburd et al., 2007). Infestations can result in leaf abscission, decreased plant vigor, and even plant death (Kranz et al., 1977; Fasulo and Denmark, 2000; Xiao and Fadamiro, 2010).

Control of twospotted spider mites has relied heavily on the application of chemicals, such as acaricides. Due to their high reproductive potential and short life cycle, twospotted spider mites have rapidly developed resistance to a broad spectrum of pesticides (Herron et al., 1998; Gorman et al., 2001). Chemical application has also been seriously challenged by the current trend in the development of sustainable and environmental friendly farming practices (Kogan, 1998; Dabbert et al., 2004; Osborne et al., 2005). As a result, integrated pest management (IPM) based on biological control has gained increasing popularity, especially in greenhouse vegetable production (McMurtry, 1983; Childers, 1994; Wood et al., 1994; Van Lenteren and Woets, 1998; Opit et al., 2004; Cakmak et al., 2009; Xiao and Fadamiro, 2010). As an innovative approach to the traditional biological control methods, banker plant systems uniquely combine the advantages of both augmentative and conservative biological control strategies, providing a sustainable control of targeted pests. The system generally has three basic components: banker host plant, alternative host or prey, and natural enemies (Osborne et al., 2005; Frank, 2010; Huang et al., 2011; Xiao et al., 2011) where the alternative host (prey) should have strong preference to the banker plant without risk to targeted crops. The natural enemy should be easily maintained on the banker plants, and have the ability to quickly disperse to parasitize or prey on the targeted pests (Frank, 2010; Xiao et al., 2011).

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This study aimed to develop a banker plant system for potentially better control of twospotted spider mites. The predatory gall midge, *Feltiella acarisuga* (Vallot) (Diptera: Cecidomyiidae), like predatory mites, has been shown to be an effective biological control agent against spider mites (Tetranychidae) (Chazeau et al., 1985; Oatman et al., 1985; Gagné, 1995; Pickett and Gilstrap, 1986; Wardlow and Tobin, 1990; Opit et al., 1997; Meesters et al., 1998; Gillespie et al., 1998, 2000; Mo and Liu, 2006, 2007; Cock et al., 2010). *F. acarisuga* feeds on any stage of *T. urticae* in a wide range of crops (Brødsgaard et al., 1999; Gillespie et al., 2000; Agamy and Gomaa, 2002). However, the use of *F. acarisuga* as a biological control agent has been limited by the difficulty in maintaining its population in greenhouses when target pests are absent. Brewer (1995) demonstrated that the spider mite, *Oligonychus pratensis* (Banks) (Acari: Tetranychidae), infested corn plants (*Zea mays* L.). Our studies suggest that *O. pratensis* did not feed on green bean and could be heavily preyed upon by *F. acarisuga* (Xiao et al., unpublished data). Therefore, we proposed that corn plant could be a potential banker plant to indirectly support *F. acarisuga* by hosting *O. pratensis*; *F. acarisuga* in turn could suppress *T. urticae* during greenhouse vegetable production.

The specific objectives of this study were to (1) evaluate the preference of *O. pratensis* to corn and green bean plants; (2) investigate the dispersal ability of *F. acarisuga* from corn plants to green bean plants infested by *T. urticae* in greenhouse conditions; and (3) determine the predation by *F. acarisuga* reared on corn banker plants on *T. urticae* in both laboratory and greenhouse environments.

2. Materials and methods

2.1. Arthropods and host plants

Tested arthropods: Stock colonies of Banks grass mites (*O. pratensis*), twospotted spider mites (*T. urticae*), and predatory gall midges (*F. acarisuga*) established originally from multiple locations were maintained for 2 years in air-conditioned rearing rooms and greenhouses at the University of Florida's Mid-Florida Research and Education Center (MREC) in Apopka, FL, U.S. *T. urticae* (pest) were reared on fully expanded leaves of green bean variety Cangreen and/or Dusky (~30 d after planting) (Kello GG seed Co. CA, U.S.). These plants were grown in 8-cm plastic pots filled with Fafard 2-Mix growing medium (Conrad Fafard, Inc., Agawam, MA, U.S.) and enclosed in screen cages. *O. pratensis* (alternative prey) were reared on corn variety plants (Variety: Yellow dent, Pioneer Hi-Bred, Co. IA. U.S.) in 15-cm diameter pots (50–100 cm tall) filled with the same Fafard 2-Mix. Predatory gall midges (*F. acarisuga*) were maintained on the corn plants with *O. pratensis*. Arthropods and plants in different greenhouses were monitored daily, and plants were watered as needed. In laboratory rooms, *F. acarisuga* was maintained on 10 fully expanded leaves of same corn variety that were infested with *O. pratensis* in the center tray of plastic transparent containers. Each container (30 × 40 × 20 cm) had holes on the top, which were covered by screen net to allow air flow. Each tray was isolated by water to prevent mite escape and also to maintain leaf freshness for up to two weeks.

Banker plants: Seeds of mentioned corn variety were sown into 8-cm diameter pots containing the Fafard 2-Mix growing medium. Uniform and pesticide-free plants were used for the experiments outlined below. All rearing and experiments were conducted under laboratory conditions or climate-controlled greenhouses [26 ± 3 °C, 70 ± 10% RH and a photoperiod of 14:10 (L:D)] from early summer to fall, 2010.

2.2. Host preference and survival of O. pratensis

2.2.1. Laboratory tests

A choice experiment was conducted to evaluate the host preference of *O. pratensis* adults to the same corn variety (V2-3, 30 d after planting) and two green bean varieties (Cangreen and Dusky) [the 2nd leaf stage (V2), 20 d, 30 cm tall]. A small Petri dish (8 cm diameter and 1.0 cm depth) was placed in the center of a larger one (15 cm in dia. and 1.5 cm in depth) and isolated by water to form an island to prevent mites from escaping. A piece of wet filter paper was placed on each small dish. One 2.5 cm (diameter) leaf disc of each host plant was placed on the wet filter paper with an equal distance between them to form a triangle. Ten adult females of *O. pratensis* ($n = 10$) were released onto the center of the filter paper in the small Petri dish. The number of *O. pratensis* on each leaf disc (treatment) was counted at 24, 48, 72, 96, and 120 h after the release of mites into the Petri dish. The position of different leaf discs in the small dish was determined randomly and rotated in each replication. Average daily number of eggs laid by *O. pratensis* was calculated by counting the total number of eggs at day 5 (120 h) divided by 5 (days). The experiment was a randomized complete block design and replicated sixteen times.

A no-choice experiment was also conducted to evaluate the suitability of the same corn and green bean varieties as host plants for *O. pratensis* in the same manner as the choice experiment, except that three leaf discs of the same host plant were placed on the filter paper of the small Petri dish. Each treatment (host plant) was replicated sixteen times.

A survival experiment was conducted in the same way as the no-choice test to determine survival percentage of adult and immature *O. pratensis* on the corn and two varieties of green bean plants. Ten 1st or 2nd instar immatures of *O. pratensis* (mixed populations) and 10 newly emerged adult females were introduced onto each leaf disc of the small Petri dish. The number of *O. pratensis* that survived on each leaf disc of different host plants was recorded until the spider mites died. Each treatment (host plant) was replicated sixteen times.

2.2.2. Greenhouse tests

In order to confirm the results obtained from laboratory tests, a greenhouse experiment was conducted. Seedlings of the same variety of corn with two fully expanded leaves (V2, 30 d after planting, 50 cm tall) and the two green bean varieties with two fully expanded leaves (early branching, 20 d after planting) were arranged randomly in the open air (without cage) of a greenhouse (~15.0 × 10.0 m). Each potted plant was placed on top of a tray filled with soapy water to prevent the mites from escaping. Twenty adult females of *O. pratensis* (10 adults per leaf) were released on each potted plant. Three types of host plants with four replicates (one potted plant as one replicate) for a total of 12 potted plants were used. The number of both adult females and their eggs laid on each plant was recorded at 24 h and 48 h after *O. pratensis* release.

2.3. Dispersal of F. acarisuga

Three greenhouse (~150 m2) experiments were performed to investigate the dispersal capability of *F. acarisuga* from potted corn banker plants ('Yellow dent', ~V10, each 100 cm tall) to 'Cangreen' bean seedlings (V2, 20 d after planting, 30 cm tall) or corn control plants (V2-3, 30 d after planting, 45 cm tall) as sentinel plants. In experiment 1, the dispersal capability was tested in three replicate greenhouses (15.0 × 10.0 m). Four potted corn seedlings with two fully expanded leaves (V2) infested by all stages of *O. pratensis* (20 adult females per leaf were initially introduced to the seedling one week before the experiment) and four potted bean seedlings with

two fully expanded leaves (V2) infested with all stages of *T. urticae* (initially 20 adult females per leaf) were used as sentinel plants. Two potted seedlings (one bean and one corn seedling) were randomly placed at one of the four corners of each greenhouse. Three large corn banker plants with *F. acarisuga* at late larval or pupal stage (over ~20 per leaf) were placed in the center of each greenhouse. The distance between the banker and sentinel plants was ~4.0 m. The numbers of *F. acarisuga* larvae on each leaf of the sentinel plants was recorded at 3, 5, and 7 days after introducing the banker plant. Based on the results from experiment 1, experiment 2 was designed to further determine the dispersal of *F. acarisuga* with a distance of 6.0 m. All other experimental parameters were identical to the first experiment.

Experiment 3 was conducted to examine the dispersal ability of *F. acarisuga* to an extended distance of 7.0 m. Banker plants consisted of four large potted corn plants, with the same infestation density as experiment 2, randomly located along one side of the greenhouse. Sentinel plants consisted of eight ($n = 8$) potted green bean plants heavily infested by *T. urticae* (>50 adults per leaf) and 8 potted corn plants with high densities of *O. pratensis* (>50 adults per leaf). These sentinel plants were randomly placed on the opposite side of the greenhouse. The experiment was performed in 2010. The number of *F. acarisuga* larvae on each leaf of the sentinel plants was recorded two weeks (14 d) after release.

2.4. Predation by F. acarisuga

2.4.1. Laboratory tests

A laboratory experiment was carried out to investigate predation ability of *F. acarisuga* on different stages (e.g., low density eggs, high density eggs, immature and adults) of two prey species. The experiments were similar to those described by Opit et al. (1997) and Xiao and Fadamiro (2010). A 2.5 cm diameter leaf disc of either corn ('Yellow dent' variety) infested with *O. pratensis* (alternative prey) or green beans (varieties 'Cangreen' and 'Dusky') infested with *T. urticae* (pest prey) was placed on moistened filter paper inside a small Petri dish (3.0 cm diameter × 0.5 cm depth). One 2nd instar larva of *F. acarisuga* (predator) was confined in each Petri dish for 48 h. The prey densities were set as 30–50 eggs (low density), 70–100 eggs (high density), 25 immature, and 20 adult females per leaf disc, respectively. Four small Petri dishes (3-cm diameter) were fixed in a larger Petri dish (15 cm

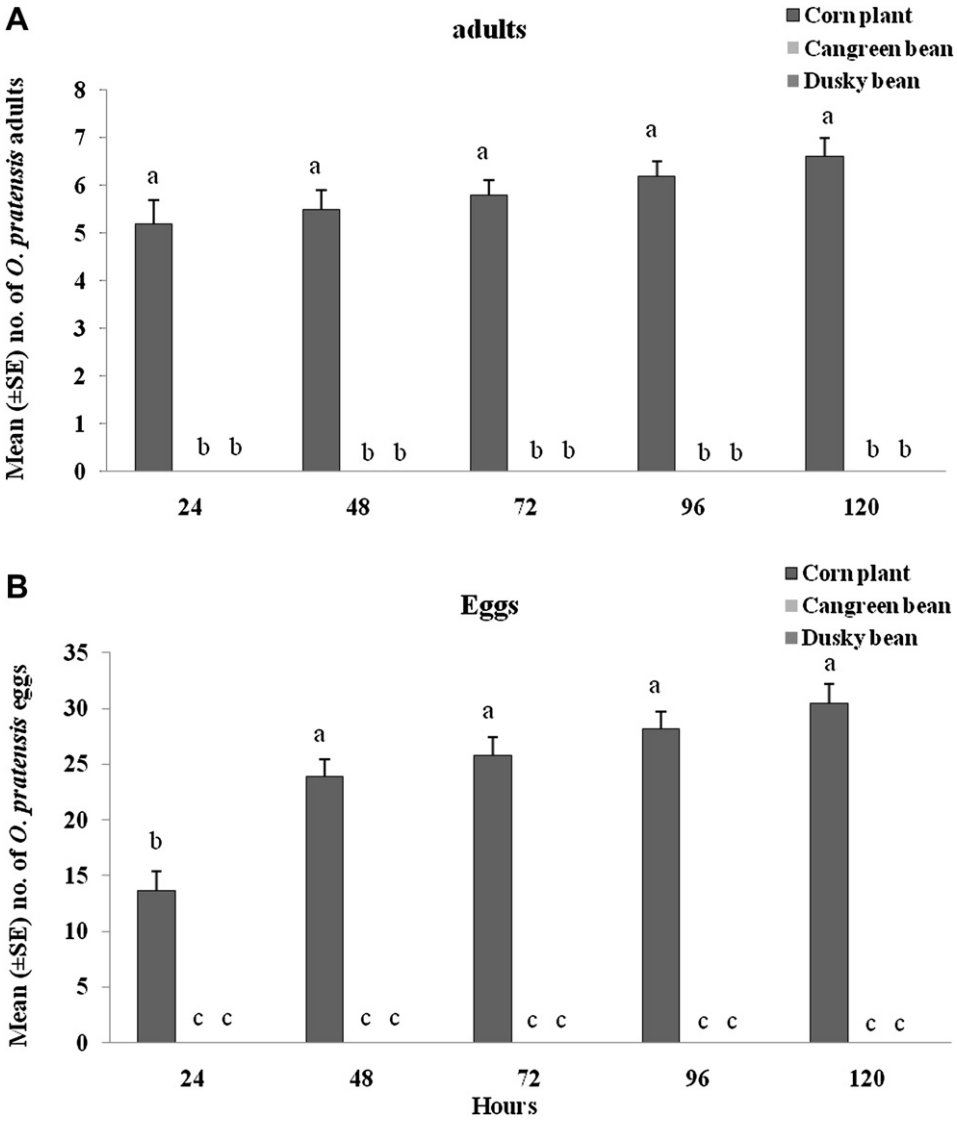

Fig. 1. The mean (±SE) of *O. pratensis* adults (A) and eggs (B) recorded on corn and two varieties of green bean plants over time in laboratory choice experiments. Means with the same letter are not significantly different ($P > 0.05$; Tukey–Kramer HSD test).

diameter × 1.5 cm), filled with the appropriate amount of water to isolate each small Petri dish to prevent arthropod escape. The large Petri dishes were sealed with Parafilm to prevent leaf disc from desiccation. Each large Petri dish represented four replications, egg treatments were replicated twenty ($n = 20$) times and immature and adult treatments were replicated fifteen ($n = 15$) times. The controls consisted of leaf discs with the same densities of prey stages (eggs, immature, or adults) without *F. acarisuga*. The number of dead prey or prey killed by the predator was recorded at 48 h after release of the predators.

2.4.2. Greenhouse test

A greenhouse experiment was conducted to evaluate any decline in predation ability after *F. acarisuga* was reared on banker plants. The experiment consisted of three treatments with five replications: 1) non-cage (open) (*F. acarisuga* adults could fly freely to potted plants in any direction); 2) open cage (with one side open to allow *F. acarisuga* to fly freely to potted plants only from the open side) to determine if the midge could find hosts; and 3) closed cage (*F. acarisuga* was not able to access the plants, as a control). Each cage contained one potted plant (as one experimental unit). A total of 15 potted plants of 'Cangreen' green bean at the 4th leaf stage (V4, 30 d after planting, 40 cm tall) were randomly assigned into the three treatments and the experiment was arranged in a randomized complete block design in one side of a greenhouse. These potted plants were placed on top of trays filled with soapy water to prevent mites from escaping. Forty adult females (10 adults each leaf) of *T. urticae* were released onto each plant for development and reproduction. Four corn banker plants (same variety and stages as mentioned in dispersal experiment) with similar late larval densities of *F. acarisuga* were placed on the other side of the greenhouse. The distance between bean and corn plants was 4–7 m. *F. acarisuga* adults were allowed to freely fly to the tested plants except for closed cages. The plants were checked daily and no other pests or natural enemies were allowed to access to the greenhouse. The numbers of all stages of *T. urticae* (except eggs) and *F. acarisuga* larvae were recorded using an amplifier (20×).

2.5. Data analysis

The data obtained from the host preference and dispersal experiments were normalized using the square-root

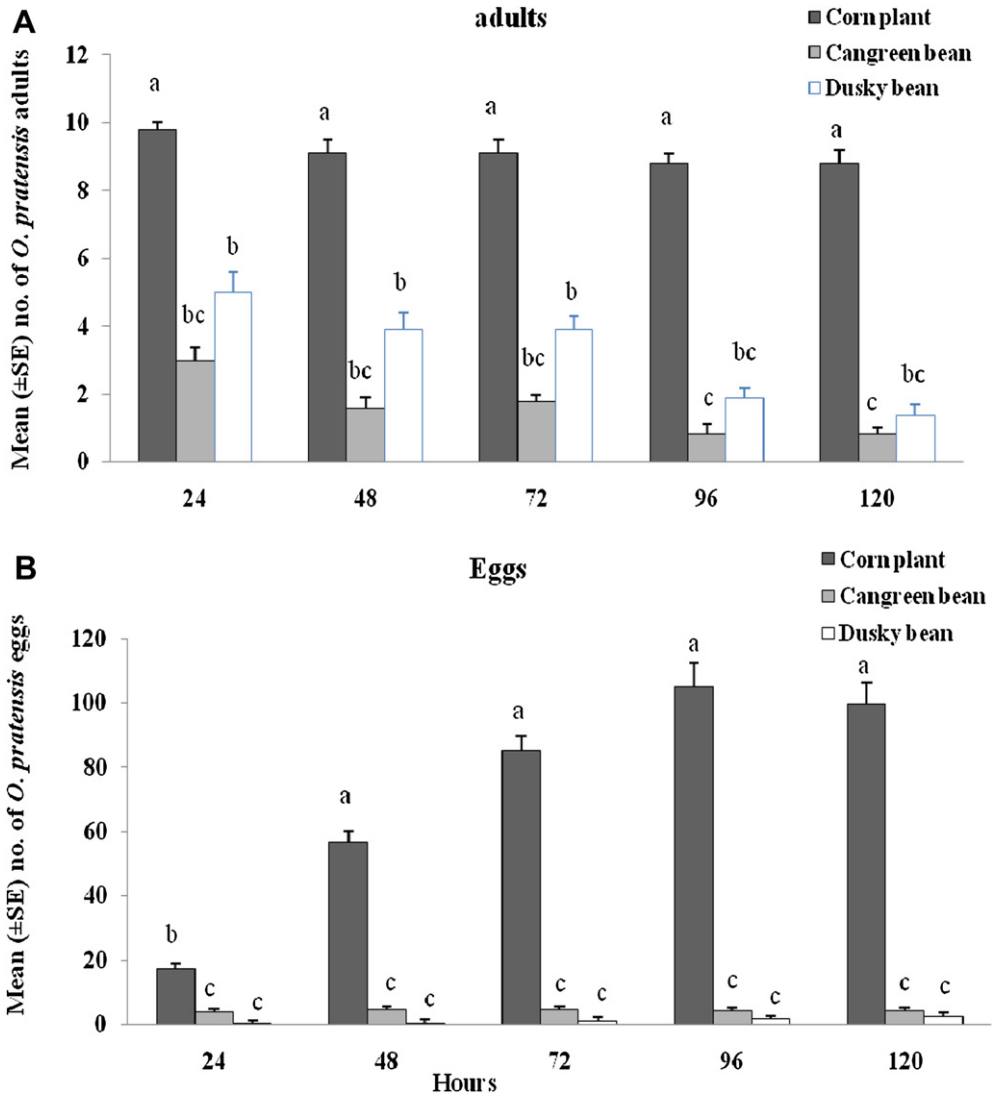

Fig. 2. The mean (±SE) of *O. pratensis* adults (A) and eggs (B) recorded on corn and two varieties of green bean plants over time in laboratory no-choice experiments. Means with the same letter are not significantly different ($P > 0.05$; Tukey–Kramer HSD test).

transformation ($\sqrt{x}+0.5$) if necessary. Data from percent predation were normalized using the arcsin square-root transformation ($\sqrt{x}+0.5$) if necessary. For laboratory host preference experiments, a repeated measure analysis of variance (ANOVA) was conducted with a compound symmetry variance-covariance structure. Factors were treatments (host species or varieties) and time period (repeated measure), and block (replications) was considered as a random effect. For all other experiments, either a one-way ANOVA was performed, followed by Tukey–Kramer honestly significant difference (HSD) comparison (Tukey, 1953), or a student's *t* test to determine significant differences between treatments ($P < 0.05$, JMP Version 8.01, SAS Institute, 2009).

3. Results

3.1. Host preference and survival of O. pratensis

Repeated measure ANOVA revealed that *O. pratensis* adults significantly preferred corn leaves in the laboratory choice experiments (host plants: $F = 3501.2$; df = 2, 225; $P < 0.0001$). Preference was not affected by time period ($F = 1.905$; df = 4, 225; $P < 0.1105$) and the by interaction between host plant and time period ($F = 1.905$; df = 8, 225; $P < 0.0603$) (Fig. 1a). Furthermore, adults laid significantly more eggs on corn leaf discs than on green bean leaf discs in the choice tests (host plant: $F = 2964.4$; df = 2, 225; $P < 0.0001$, time period: $F = 18.40$; df = 4, 225; $P < 0.0001$), and no interactions between host plant and time period was detected (host plant × time period: $F = 1.844$; df = 8, 225; $P < 0.070$) (Fig. 1b). Similar results were found in the no-choice test for adults per leaf disc (host plant: $F = 417.2$; df = 2, 225; $P < 0.0001$, time period: $F = 20.16$; df = 4, 225; $P < 0.0001$, host plant × time period: $F = 1.394$; df = 8, 225; $P < 0.201$) (Fig. 2a) and for eggs per leaf disc (host plant: $F = 1644.3$; df = 2, 225; $P < 0.0001$, time period: $F = 59.84$; df = 4, 225; $P < 0.0001$, host plant × time period: $F = 1.716$; df = 8, 225; $P < 0.0801$) (Fig. 2b). In addition, the average survival rate of *O. pratensis* on each corn leaf discs was significant higher (98.5%) compared to < 1.5% on green bean leaf discs in laboratory tests (adults: $F = 58.7$; df = 2, 45; $P = 0.0001$, immatures: $F = 191.5$; df = 2, 45; $P = 0.0001$) (Fig. 3).

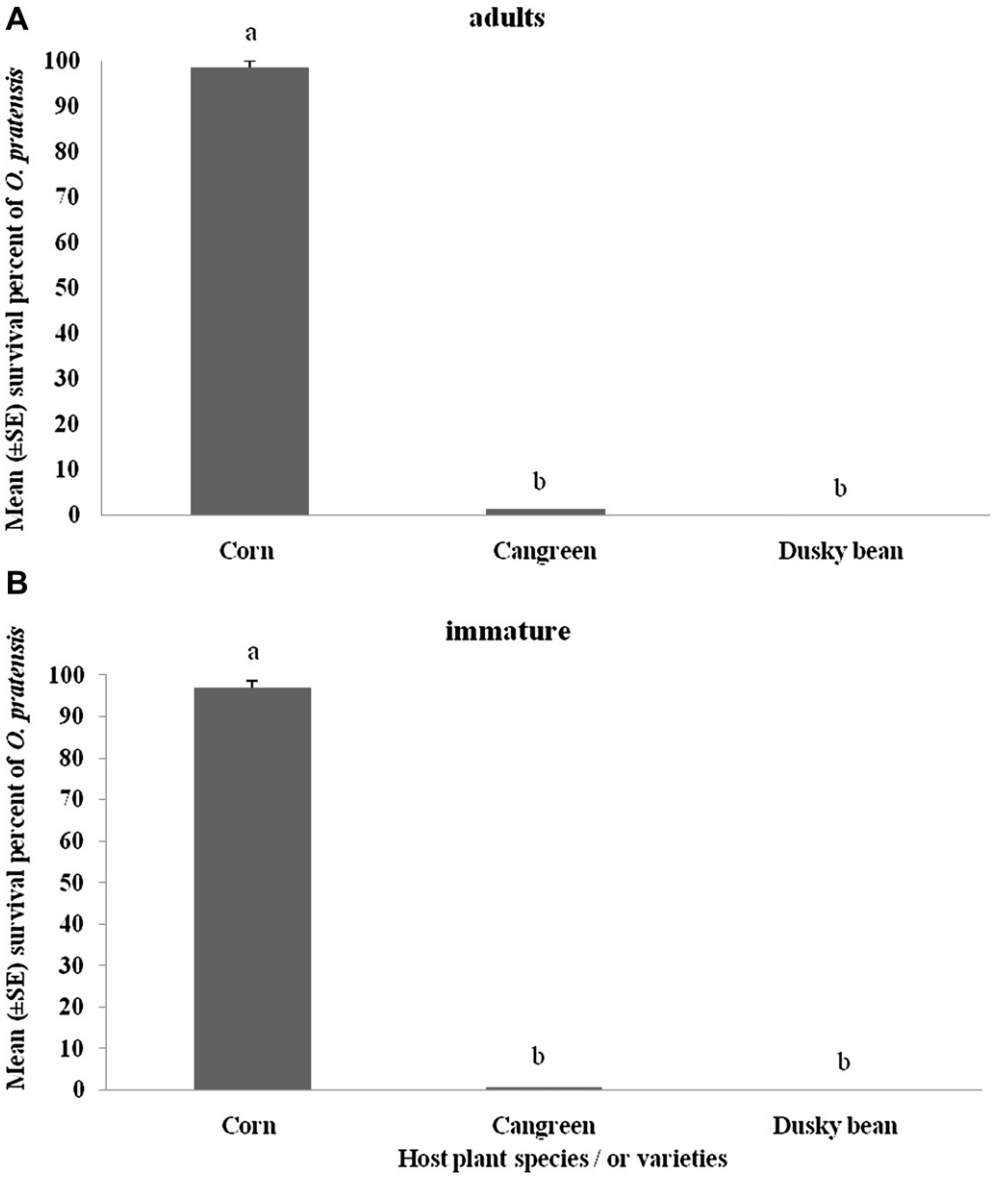

Fig. 3. The mean (±SE) survival percentage of *O. pratensis* adults (A) and immature (B) recorded on corn and two varieties of green bean plants one week after release in Petri dishes in the laboratory. Means with the same letter are not significantly different ($P > 0.05$; Tukey–Kramer HSD test).

The greenhouse test confirmed the laboratory results. Significantly more adults and eggs of *O. pratensis* were found on corn plants than on the two varieties of green bean at 24 h (adults: $F = 159.7$; df = 2, 9; $P = 0.0001$, eggs: $F = 491.6$; df = 2, 9; $P = 0.0001$) and 48 h (adults: $F = 1012.2$; df = 2, 9; $P = 0.0001$, eggs: $F = 845.9$; df = 2, 9; $P = 0.0001$) (Fig. 4).

3.2. Dispersal ability of F. acarisuga

Three separate dispersal experiments showed that *F. acarisuga* flew 4.0–7.0 m to search for new preys in the greenhouse (Table 1). The number of *F. acarisuga* on two sentinel plants varied from 7.3 to 9.5 larvae per leaf after 5–7 d of release. However, zero or few *F. acarisuga* larvae were found on sentinel plant after 3 d of release (data not shown). Data from experiments 1 and 2 were pooled and analyzed through one-way ANOVA, and results showed that there was no significant difference in larvae number of *F. acarisuga* between the two species of prey on different host plants ($F = 0.49$; df = 3, 28; $P = 0.83$). Furthermore, in the experiment with increased distance to 7.0 m (Exp. 3), the numbers of *F. acarisuga* larvae were found to be over 176 per leaf at 14 d after release of *F. acarisuga* on either green bean or control corn plants in the greenhouse ($t = 1.28$; df = 14; $P = 0.1096$) (Table 1).

3.3. Predation by F. acarisuga on target pest

F. acarisuga larvae were able to feed on all stages of both *O. pratensis* and *T. urticae*. Laboratory experiments showed that no significant differences were observed in the percent predation by *F. acarisuga* on either *O. pratensis* infesting corn plants or *T. urticae* infesting green bean plants [egg (high): $t_{egg2} = 1.94$, df = 38, $P = 0.063$; immature: $t_{imm} = 0.81$, df = 28, $P = 0.42$; adults: $t_{ad} = 1.95$, df = 28, $P = 0.06$] (Table 2). A 3.9- fold increase in *T. urticae* densities occurred in the non-cage trial compared to a 21.1-fold increase in the closed cage trial (control) ($F = 91.8$; df = 2, 57; $P < 0.0001$). In addition, the number of *F. acarisuga* reached 7.3–8.8 larvae per leaf of green bean plants due to their dispersal from corn banker plants ($F = 24.8$; df = 2, 57; $P < 0.0001$) (Table 3).

4. Discussion

The determination of the host preference of the alternative prey (non-pest) has become the critical step for evaluating a viable banker plant system (Huang et al., 2011; Xiao et al., 2011). In this study, *O. pratensis* proved to have a high preference for corn rather than green bean plants in both choice and non-choice tests (Figs. 1,

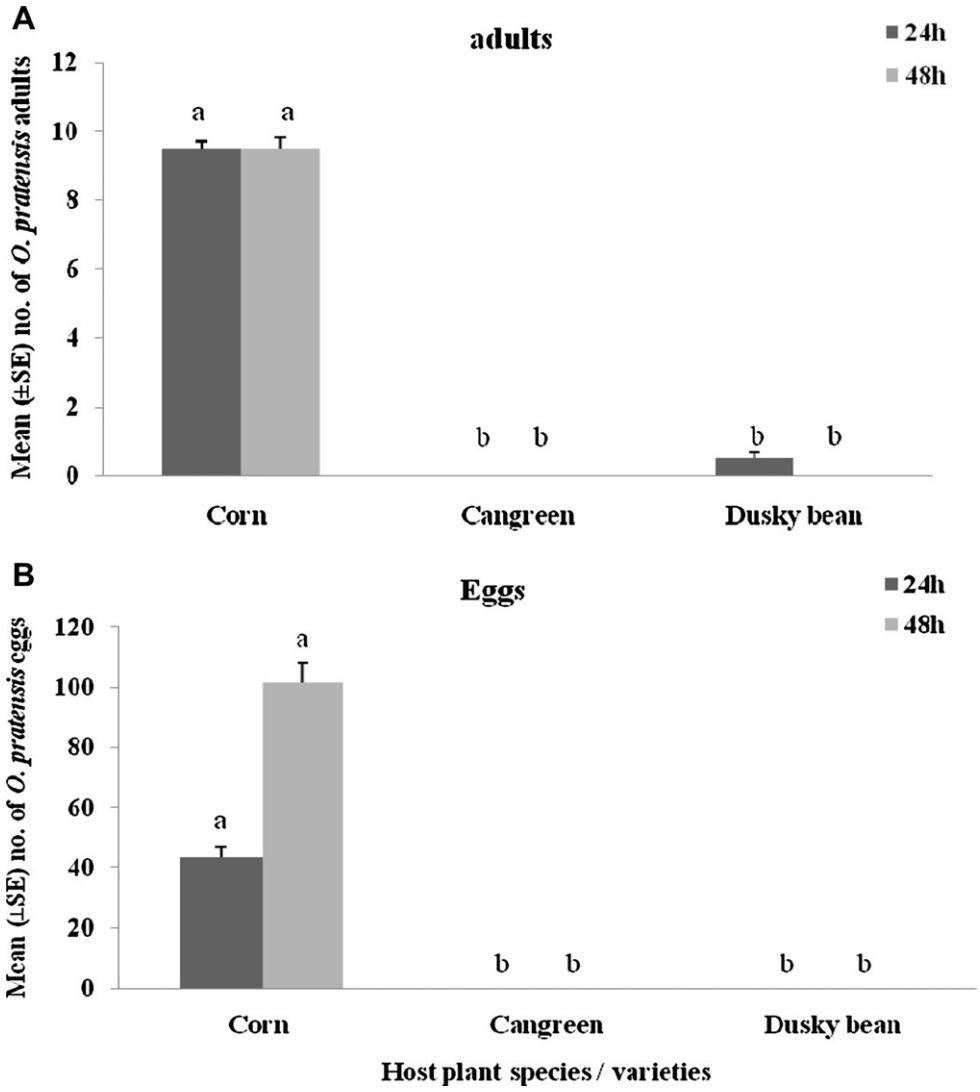

Fig. 4. The mean (±SE) number of *O. pratensis* adults (A) and eggs (B) recorded on corn and bean plants 24–48 h after they were released on three type of plants (one is corn, another is green bean with two varieties in the greenhouse). Means with the same letter are not significantly different ($P > 0.05$; Tukey–Kramer HSD test).

Table 1
Dispersal of *F. acarisuga* from corn banker plants to either green bean plants infested with *T. urticae* or corn plant infested by *O. pratensis* in a greenhouse trial.

Exp.	Banker plants	Sentinel host plant	Pest/alternative prey	Prey/leaf (no)	Distance (m)	days (d)	Mean (±SE) *F. acarisuga*/leaf (no)
1st	Corn→	Green bean	*T. urticae*	20	4.0	5–7	9.5 ± 0.9 a
	Corn→	Corn plant	*O. pratensis*	20	4.0	5–7	8.0 ± 3.7 a
2nd	Corn→	Green bean	*T. urticae*	20	6.0	5–7	7.6 ± 1.8 a
	Corn→	Corn plants	*O. pratensis*	20	6.0	5–7	7.3 ± 2.4 a
3rd	Corn→	Green bean	*T. urticae*	> 50	7.0	14	176.2 ± 13.2 a
	Corn→	Corn plants	*O. pratensis*	> 50	7.0	14	205.4 ± 14.9 a

Each experiment had three replications (greenhouses) and experiments were repeated three times. The data from experiments 1 and 2 were pooled for analysis. Means (±SE) within the same column in the same experiment 1 and 2 followed by same letters are not significantly different ($P < 0.05$; Tukey–Kramer HSD test). The data from experiments 3, means (±SE) within the same column followed by same letters are not significantly different ($P < 0.05$; student's *t* test).

Table 2
Percent predation of *F. acarisuga* larvae reared on corn banker plants to different stages of *T. urticae* on green bean or to *O. pratensis* on corn plants in a laboratory test.

Life Stage	Banker plants	Sentinel host plant	Pest/alternative prey	Mean (±SE) number per leaf arena		
				Prey density (no.)	Prey killed (no.)	Predation (%)
Eggs (low)	Corn→	Green bean	*T. urticae*	41.5 ± 2.1	28.1 ± 3.1	67.9 ± 3.9 b
	Corn→	Corn plant	*O. pratensis*	35.1 ± 1.5	31.7 ± 2.1	90.3 ± 2.5 a
Eggs (high)	Corn→	Green bean	*T. urticae*	70.0 ± 2.9	43.9 ± 2.4	62.7 ± 1.6 a
	Corn→	Corn plant	*O. pratensis*	83.2 ± 6.6	59.1 ± 3.5	71.0 ± 3.8 a
Immature	Corn→	Green bean	*T. urticae*	25	16.8 ± 1.5	67.4 ± 5.7 a
	Corn→	Corn plant	*O. pratensis*	25	18.3 ± 1.2	73.4 ± 3.5 a
Adults	Corn→	Green bean	*T. urticae*	20	8.74 ± 2.1	43.7 ± 6.1 a
	Corn→	Corn plant	*O. pratensis*	20	11.8 ± 3.2	59.2 ± 4.8 a

Means (±SE) within the same column in the same life stage followed by same letters are not significantly different (student's *t* test, $P < 0.05$) for 48 h after *F. acarisuga* release. Eggs (Low): low density of prey eggs (30–50/leaf); Egg (high): high density of prey eggs (75–100/leaf).

2 and 4). Thus, the corn plant was identified as an ideal banker plant suitable for maintaining *O. pratensis* and indirectly supporting *F. acarisuga* which is then a highly effective predator of *T. urticae* (Table 3). This agrees with the results reported by Opit et al. (1997), Agamy and Gomaa (2002), and Mo and Liu (2006).

The dispersal ability of predators is another concern in the establishment of banker plant systems. Results from this study showed that *F. acarisuga* adults were able to fly or migrate from corn banker plants to sentinel plants (control corn and bean seedlings) in search of new hosts for feeding or for reproduction (Table 1). These results concurred with those reported by Heinz (1998), Osborne et al. (2005), and Langhof et al. (2005) that most natural enemies have strong flying dispersal ability. The dispersal of predators to find infested host plants is driven by visual and olfactory cues, such as secondary chemicals (semiochemicals) (Brown, 1984; Bowers, 1990; Rank et al., 1998; Choi et al., 2004; Xiao and Fadamiro, 2009). However, the driving force behind the dispersal ability of *F. acarisuga* is still unknown.

The predation ability or feeding efficiency is also critically important to a biological control agent. Our results indicated that *F. acarisuga* preyed heavily on both *O. pratensis* and *T. urticae*. The percent predation by *F. acarisuga* on *T. urticae* infesting green bean plants reached 43.9–67.9% in 48 h under laboratory conditions (Table 2). Such rapid predation is not surprising, since *F. acarisuga* is an excellent predator, successfully preying on all stages of spider mites in many crops (Sharaf, 1984; Oatman et al., 1985; Opit et al., 1997; Gillespie et al., 1998; Bylemans et al., 2003; Mo and Liu, 2006, 2007; Cock et al., 2010). As a consequence, 81.2% of the *T. urticae* population was suppressed by *F. acarisuga* on green bean plants in the greenhouse test (Table 3). The result is consistent with a previous study showing that *Feltiella* sp. naturally reduced spider mite numbers by 2–93%, with an overall seasonal reduction of 40% in eggplants (Sharaf, 1984). Therefore, *F. acarisuga* reared on corn banker plants should represent a potential strategy for controlling *T. urticae* within cropping systems, especially for greenhouse crops because *F. acarisuga* favors higher humidity greenhouse conditions which have a suitable microclimate for its development and foraging (Gillespie et al., 2000).

Table 3
Predation of *F. acarisuga* larvae reared on corn banker plants to *T. urticae*-infested green bean plants after *F. acarisuga* was dispersed in greenhouses.

Treatment	Initial prey	Mean (±SE) number per leaf after 14 d			
	Density/leaf	*T. urticae* (no.)	Predation (%)	Population increase (fold)	*F. acarisuga* (no.)
Non-cage	10	38.8 ± 7.7 b	81.2	3.9 ± 1.5 b	8.8 ± 1.4 a
Open cage	10	91.8 ± 8.4 b	55.7	9.2 ± 0.9 b	7.3 ± 0.9 a
Closed cage	10	207.4 ± 9.8 a	0.0	21.1 ± 1.8 a	0.0 ± 0.0 b

Means (±SE) within same column followed by different letters are significantly different ($P < 0.05$; Tukey–Kramer HSD test). Dispersal distance of the predator from banker plant to green bean plants was 4–7 m.

This study evaluated a corn banker plant system for sustaining *F. acarisuga* against *T. urticae* in greenhouse green bean production. Compared to the traditional biological control (Collier and Van Steenwyk, 2004; Pickett et al., 2004; Van Driesche and Heinz, 2004), this corn banker plant system would present several advantages. First, the corn plants are a highly specific host for *O. pratensis*; and introducing *O. pratensis* would pose no risk to green beans. The implementation of this banker plant system would potentially provide long-lasting control of *T. urticae* and probably other spider mites (Gillespie et al., 2000; Mo and Liu, 2007). Second, corn is easy to grow and the management in the greenhouses, without cheap purchasing seeds. Third, the corn banker plant system would be compatible with other pest control practices as reported by Xiao et al. (2011). For example, if a pesticide application is necessary, corn banker plants can be moved out of the greenhouses. After a safe interval, corn plants can be placed back in the greenhouses with its natural enemies. Nevertheless, this established banker plant system is new; further research to determine its full potential for better controlling *T. urticae* in commercial greenhouses is warranted.

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