Research Article

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Evaluation of organically acceptable insecticides as stand-alone treatments and in rotation for managing yellowmargined leaf beetle, *Microtheca ochroloma* (Coleoptera: Chrysomelidae), in organic crucifer production

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Abstract

BACKGROUND: Yellowmargined leaf beetle, *Microtheca ochroloma*, is the most damaging pest of organic crucifer crops in the southern United States. Experiments were conducted over four growing seasons (2007–2010) in Alabama to evaluate some botanical and microbial insecticides approved by the Organic Materials Review Institute (OMRI) against *M. ochroloma* in organically grown crucifer crops. Insecticides evaluated included PyGanic® (pyrethrum), Aza-Direct® (azadiractin), Entrust® (spinosad), Mycotrol O® (*Beauveria bassiana* strain GHA) and NOFLY® [*Isaria* (= *Paecilomyces*) *fumosoroseus* strain FE 9901]. Two experimental organic formulations, Tick-Ex (*Metarhizium anisopliae* strain F52) and MBI-203 (*Chromobacterium subtsugae*), and one non-OMRI-listed formulation, Novodor® (*Bacillus thuringiensis* subspecies *tenebrionis*), were also evaluated. The insecticides were applied as stand-alone treatments at recommended field rates on a weekly schedule. In 2010, some of the treatments were also evaluated in rotation/alternation with Entrust®. Insecticide efficacy was determined by comparing densities of *M. ochroloma* larvae and adults and crop damage ratings in treated versus untreated turnip plots.

RESULTS: Entrust® consistently performed well in suppressing *M. ochroloma* adults, larvae and crop damage. PyGanic® was the second best treatment. PyGanic® or NOFLY™ can be applied in rotation with Entrust® for effective management of *M. ochroloma*.

CONCLUSION: Entrust® applied weekly or in alternation with PyGanic® or NOFLY™ provided acceptable control of *M. ochroloma* in organic crucifer production.

Keywords: yellowmargined leaf beetle; *Microtheca ochroloma*; botanicals; microbials; OMRI

1 INTRODUCTION

Cruciferous vegetable production is an important industry in Alabama and other parts of the southern United States. Many farmers in the region grow various kinds of cruciferous crop (e.g. turnip, radish, mustard, napa cabbage, cabbage, collards, arugula and Japanese leafy vegetables such as mizuna and mibuna) as mixed cropping systems in the spring and fall, using organically acceptable practices.

The yellowmargined leaf beetle, *Microtheca ochroloma* Stål (Coleoptera: Chrysomelidae), is arguably the most damaging pest of organic cruciferous crop production in the region.[1–3] Indigenous to South America, this beetle was accidentally introduced into the United States from South America. Inspectors of the Bureau of Entomology and Plant Quarantine detected the first specimen of *M. ochroloma* in North America in 1945 at the port of New Orleans on grapes from Argentina.[4] The first field population of the beetle was later recorded in Mobile, Alabama, in 1947.[1] The beetle was subsequently reported in Mississippi, Louisiana, Florida and Texas and is now widely distributed in the southern United States, with major field infestations reported in Alabama, Florida, Louisiana, Mississippi, South Carolina, North Carolina and Texas.[4–8]

Both adult and larval stages of *M. ochroloma* often feed in groups on foliage of cruciferous crops with potential for major economic loss. When feeding on its host plants, *M. ochroloma* makes small, irregularly shaped holes in the leaves and feeds upon the leaf margins. *Microtheca ochroloma* is rarely a major problem in conventional vegetable production systems owing to its susceptibility to synthetic foliar insecticides.[3] However, it poses a major threat to organic vegetable production because organic farmers cannot use synthetic insecticides. *Microtheca ochroloma* is the predominant and often the only key pest detected in local organic vegetable fields (personal observation) in Alabama.

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Currently, there are no published studies on the efficacy of organically acceptable management tactics against *M. ochroloma*. Pest management tactics and formulations approved by the Organic Materials Review Institute (OMRI), which could potentially be used to manage *M. ochroloma* in organic and low-input vegetable production systems, include botanical insecticides, microbials, insecticidal soaps and semiochemicals.

The objective of the present study was to evaluate the efficacy of some OMRI-listed and experimental formulations of botanical and microbial insecticides for management of *M. ochroloma* in organically grown crucifer crops. The ultimate goal was to identify organically acceptable treatments effective against *M. ochroloma* for recommendation to organic vegetable growers in the southern United States. The materials evaluated at recommended field rates included OMRI-listed formulations such as PyGanic® 1.4 EC (4.68 L ha^{-1}; McLaughlin Gormley King Company, Minneapolis, MN), Aza-Direct® EC (2.34 L ha^{-1}; Gowan Company LLC, Yuma, AZ), Entrust® WP (0.14 kg ha^{-1}; Dow AgroSciences LLC, Indianapolis, IN), Mycotrol O® ES (2.34 L ha^{-1}; Laverlam International Corporation, Butte, MT) and NOFLY® WP (2.24 kg ha^{-1}; Natural Industries, Inc., Houston, TX). In addition, two experimental organic formulations, Tick-Ex EC (7.02 L ha^{-1}; Novozymes Biologicals, Inc., Salem, VA) and MBI-203 SC (4.6769 L ha^{-1}; Marrone Bio Innovations, Davis, CA), with potential for OMRI approval, were evaluated. One non-OMRI-listed formulation, Novodor® FC (9.35 L ha^{-1}, Valent BioScience Corporation, Libertyville, IL), was also evaluated.

PyGanic® 1.4 EC is an OMRI-listed formulation of pyrethrum derived from the flowers of *Chrysanthemum* spp.[9] Pyrethrum, which is well known for its quick knockdown effect, is the predominant botanical insecticide in use, perhaps accounting for 80% of the global botanical insecticide market.[10] It has been shown to be effective against several insect pests, including Colorado potato beetle, *Leptinotarsa decemlineata* (Say), and harlequin bug, *Murgantia histrionica* (Hahn).[11,12] Aza-Direct® EC is an OMRI-listed formulation of azadiractin, a tetranotriterpenoid derived from seed kernels of neem trees, *Azadiracta indica*.[13] It is well known as an insect growth regulator that affects feeding and molting in a wide variety of insects.[14] Entrust® WP is a natural insect control product formulated for organic crop production. The active ingredient, spinosad, is developed from a fermentation byproduct of the soilborne actinomycete bacterium *Saccharopolyspora spinosa*.[15,16] The efficacy of Entrust® or its active ingredient, spinosad, has been demonstrated against several chrysomelid beetles and lepidopteran pests.[11,17–19] Mycotrol O® ES is an organic formulation of the entomopathogenic fungus *Beauveria bassiana* strain GHA. It has been reported as effective against *L. decemlineata*.[20] NOFLY® WP is a microbial formulation that contains live blastospores of the naturally occurring fungus *Isaria* (= *Paecilomyces*) *fumosoroseus* strain FE 9901. It has been shown to be effective against whiteflies and other insects.[21] Tick-Ex EC is an experimental organic formulation of the entomopathogenic fungus *Metarhizium anisopliae* strain F52, which was shown to be effective against black vine weevil, *Otiorhynchus sulcatus* (Fabricius).[22] MBI-203 SC is an experimental formulation of the bacterium *Chromobacteria subtsugae*, which was reported to be toxic to *L. decemlineata*.[23] Novodor® is a biological insecticide containing the active protein crystal produced by *Bacillus thuringiensis* subspecies *tenebrionis* (*Btt*). It is effective against the larval stages of several chrysomelid beetles, including *L. decemlineata*.[24]

It was hypothesized that most of the above formulations would be effective against *M. ochroloma* because they were known to be effective against other Coleoptera. The formulations were evaluated in different sets (i.e. not all formulations were evaluated in all years) at multiple locations over four growing seasons (spring 2007, spring 2008, fall 2008 and fall 2010) in Alabama. In the first three seasons, the formulations were evaluated as stand-alone treatments. In fall 2010, some formulations were evaluated in rotation (alternation) with Entrust®, which was identified in the previous seasons as the most effective treatment.

2 MATERIALS AND METHODS

This study was conducted over four growing seasons – spring 2007, spring 2008, fall 2008 and fall 2010 – at three locations: Red Root organic vegetable farm (Banks, Alabama), Snow's Bent organic vegetable farm (Tuscaloosa, Alabama) and E. V. Smith Research Center (Shorter, Alabama). The study was not repeated in 2009 owing to an unusually low field population of *M. ochroloma* in Alabama, possibly because of some weather-related factors. The experiment was conducted in three (2007) or four (2008 and 2010) long (∼107 m = 350 ft) rows of turnip (*Brassica rapa* var. *rapa*) plants. Each treatment plot consisted of a single row of turnip plants of 10.68 m (35 ft) by 0.76 m (2.5 ft), with plants spaced at ∼0.12 m (0.4 ft) apart for a total of ∼90 plants per plot. Treatment plots were established within the same row and separated by 3.05 m (10 ft). Treatments were arranged in a randomized complete block design, with three replicates (i.e. three rows) in spring 2007 and four replicates (i.e. four rows) in the remaining three field seasons. Organic certified seeds of 'purple top white globe' turnip (Johnny's Selected Seed, Winslow, ME) were established in all the trials and maintained using standard organic crop production practices. All insecticide treatments were evaluated at the recommended field rates, and each trial included an untreated control.

A listing of the treatments evaluated during each field season is provided in Table 1. The insecticides were evaluated as stand-alone treatments in the first three growing seasons. In the final season (fall 2010), treatments were modified to include only those that performed well in the previous seasons (i.e. PyGanic® and Entrust®) and two new materials (NOFLY™ and MBI-203), which were evaluated as stand-alone treatments. In addition, two insecticide rotation/alternation treatments were evaluated: Entrust® alternated with PyGanic® and Entrust® alternated with NOFLY™. In both alternated treatments, Entrust® was applied first, followed by application of the alternate insecticide (i.e. PyGanic® or NOFLY™) 1 week later, followed again by application of Entrust®.

In all seasons, foliar applications of treatments were made weekly with a pressurized, hand-operated knapsack sprayer (Solo®, Newport News, VA), which was calibrated to deliver 411.56 L ha^{-1} at 1810.02–2068.59 mmHg. A total of three weekly sprays were made per season, starting from the onset of beetle activity in the field. Plots were evaluated twice a week (every 3–4 days) by visually sampling five randomly selected plants per plot for *M. ochroloma* larvae and adults. The five plants were also rated for *M. ochroloma* feeding damage using a method modified after Maletta *et al*.[25] In this method, plants were rated on a scale of 1 to 6 as follows: 1 = very light defoliation with <10% of damage; 2 = light defoliation (10–30%); 3 = moderate defoliation (30–50%); 4 = heavy defoliation (50–70%); 5 = very heavy defoliation (70–90%); 6 = complete (total) defoliation (>90%). In addition, the plants were also observed for occurrence of other crucifer pests (i.e. caterpillars, leaf beetles, harlequin bugs and

Table 1. Insecticide treatments evaluated during each growing season

Season	Location	Treatments evaluated
Spring 2007	Banks, AL	PyGanic®, Aza-Direct®, Entrust®, Mycotrol O®
Spring 2008	Tuscaloosa, AL	PyGanic®, Entrust®, Mycotrol O®, Tick-Ex
Fall 2008	Banks, AL	PyGanic®, Aza-Direct®, Entrust®, Mycotrol O®, Novodor®
Fall 2010	Shorter, AL	PyGanic®, Entrust®, NOFLY™, MBI-203, Entrust® alternated with PyGanic®, Entrust® alternated with NOFLY™

aphids) and key non-target predatory insects (i.e. lady beetles and tiger beetles).

For each season, the mean number of *M. ochroloma* larvae and adults and the mean damage ratings were calculated for each treatment. Data were not normally distributed and thus were transformed by using the square-root ($\sqrt{x} + 0.5$) transformation method. Transformed data were analyzed for significant treatment effects using analysis of variance (ANOVA), with the replicates considered as blocks. Means were compared using the Tukey–Kramer HSD test (JMPIN v.7.0.1, 2007; SAS Institute, Cary, NC). Untransformed data were presented as means in the figures. Significant differences were established at the 95% confidence level ($P < 0.05$).

3 RESULTS

A high incidence of *M. ochroloma* was recorded in all the locations and growing seasons. In general, no significant block (replicate) effects were detected on any of the key variables, suggesting that the blocks were similar in *M. ochroloma* density and treatment efficacy. Other crucifer pests were either not recorded (i.e. caterpillars, leaf beetles and harlequin bugs) or recorded in very low numbers (i.e. aphids) in the experimental plots during the four seasons. Thus, it was not possible to assess the effect of the treatments on other crucifer pests. Beneficial insects (i.e. lady beetles and tiger beetles) were observed in low numbers in the experimental plots. Tiger beetles were observed feeding on larvae of *M. ochroloma*, but their effect was not quantified.

Very low numbers of *M. ochroloma* larvae were recorded in spring 2007 at the Banks location. This was possibly because the trial was commenced (on 18 May) several weeks after the onset of *M. ochroloma* activity. Thus, only the data collected on the number of adults and damage ratings were presented. No significant differences in adult counts were recorded among the treatments in the pretreatment samples collected on 18 May ($F_{4,68} = 1.02$, $P = 0.40$). However, significant differences in adult counts were recorded among the treatments on 21 May ($F_{4,68} = 88.44$, $P < 0.0001$), 25 May ($F_{4,68} = 86.77$, $P < 0.0001$), 29 May ($F_{4,68} = 36.43$, $P < 0.0001$), 1 June ($F_{4,68} = 20.49$, $P < 0.0001$) and 5 June ($F_{4,68} = 11.87$, $P < 0.0001$). On most of the sampling dates, significantly fewer *M. ochroloma* adults were recorded in Entrust®-treated plots compared with the untreated (control) plots or plots treated with the other insecticides (Fig. 1A). PyGanic® also resulted in significant suppression of *M. ochroloma* adults on most dates compared with Aza-Direct®, Mycotrol O® or the untreated control. Similar results were obtained for damage

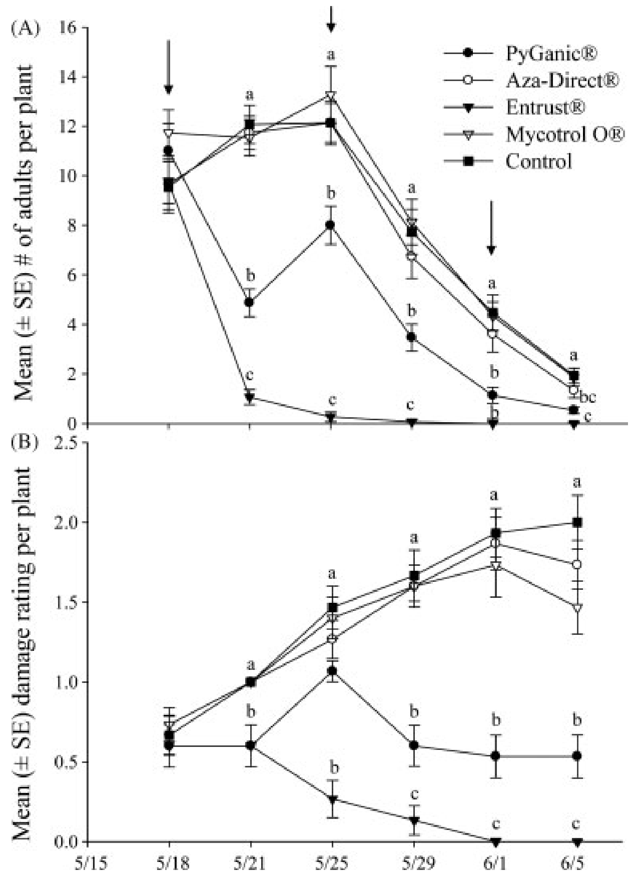

Figure 1. Mean (± SE) number of *M. ochroloma* adults (A) and damage ratings (B) of turnip plants in plots treated with different insecticide formulations during spring 2007 in Banks, Alabama. For each date, means having no letter in common are significantly different (ANOVA, Tukey–Kramer HSD, $P < 0.05$). Arrows indicate treatment dates.

ratings: Entrust® and PyGanic® produced significantly lower damage than the control or other treatments (Fig. 1B).

The results obtained in spring 2008 at the Tuscaloosa location were generally similar to those of spring 2007 in terms of treatment efficacy. Pretreatment sampling on 9 May showed no significant differences among the treatments in adult counts ($F_{4,92} = 1.75$, $P = 0.14$) (Fig. 2A), larval counts ($F_{4,92} = 0.24$, $P = 0.9149$) (Fig. 2B) and damage ratings ($F_{4,92} = 1.36$, $P = 0.25$) (Fig. 2C). However, significant differences in adult counts were recorded among the treatments on 13 May ($F_{4,92} = 9.07$, $P < 0.0001$), 16 May ($F_{4,92} = 4.78$, $P = 0.0015$), 20 May ($F_{4,92} = 3.71$, $P = 0.0075$) and 27 May ($F_{4,92} = 2.98$, $P = 0.0231$) (Fig. 2A). No significant difference in adult counts was recorded on 23 May ($F_{4,92} = 0.64$, $P = 0.6372$). Similarly, significant differences in larval counts were recorded among the treatments on 13 May ($F_{4,92} = 73.29$, $P < 0.0001$), 16 May ($F_{4,92} = 176.31$, $P < 0.0001$), 20 May ($F_{4,92} = 195.11$, $P < 0.0001$), 23 May ($F_{4,92} = 207.88$, $P < 0.0001$) and 27 May ($F_{4,92} = 54.56$, $P < 0.0001$) (Fig. 2B). Significant differences were also recorded among the treatments in mean damage ratings on 16 May ($F_{4,92} = 31.16$, $P < 0.0001$), 20 May ($F_{4,92} = 154.16$, $P < 0.0001$), 23 May ($F_{4,92} = 256.16$, $P < 0.0001$) and 27 May ($F_{4,92} = 980.94$, $P < 0.0001$) (Fig. 2C). In general, adult counts, larval counts and damage ratings were significantly lower in plots treated with Entrust® compared with the other treatments on most sampling dates. PyGanic® also resulted in

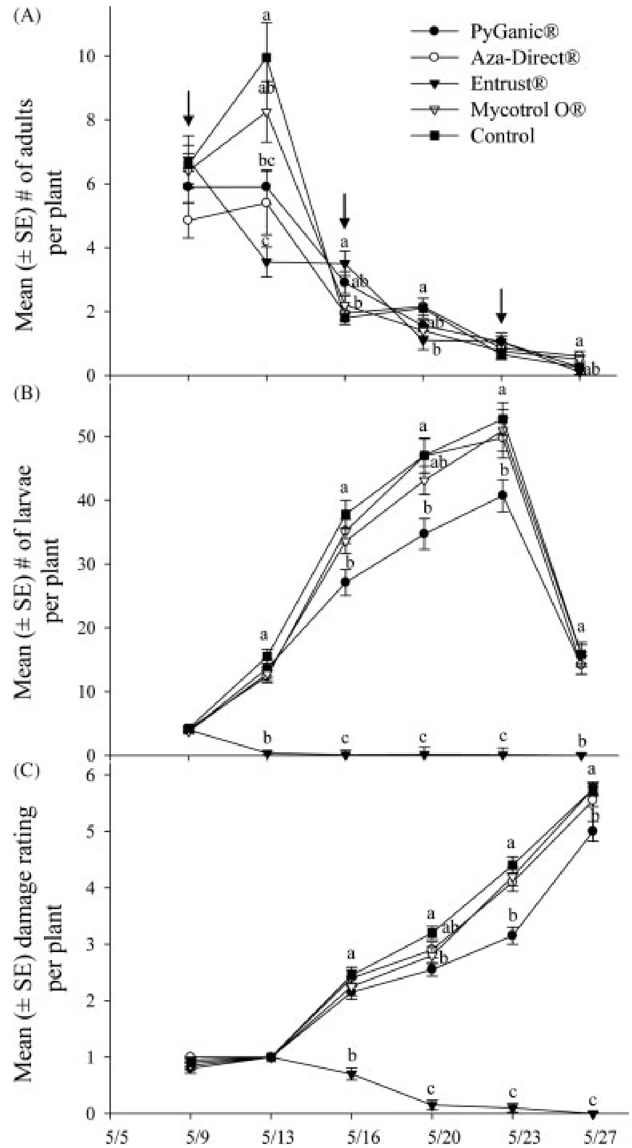

Figure 2. Mean (± SE) number of *M. ochroloma* adults (A) and larvae (B) and damage ratings (C) of turnip plants in plots treated with different insecticide formulations during spring 2008 in Tuscaloosa, Alabama. For each date, means having no letter in common are significantly different (ANOVA, Tukey–Kramer HSD, $P < 0.05$). Arrows indicate treatment dates.

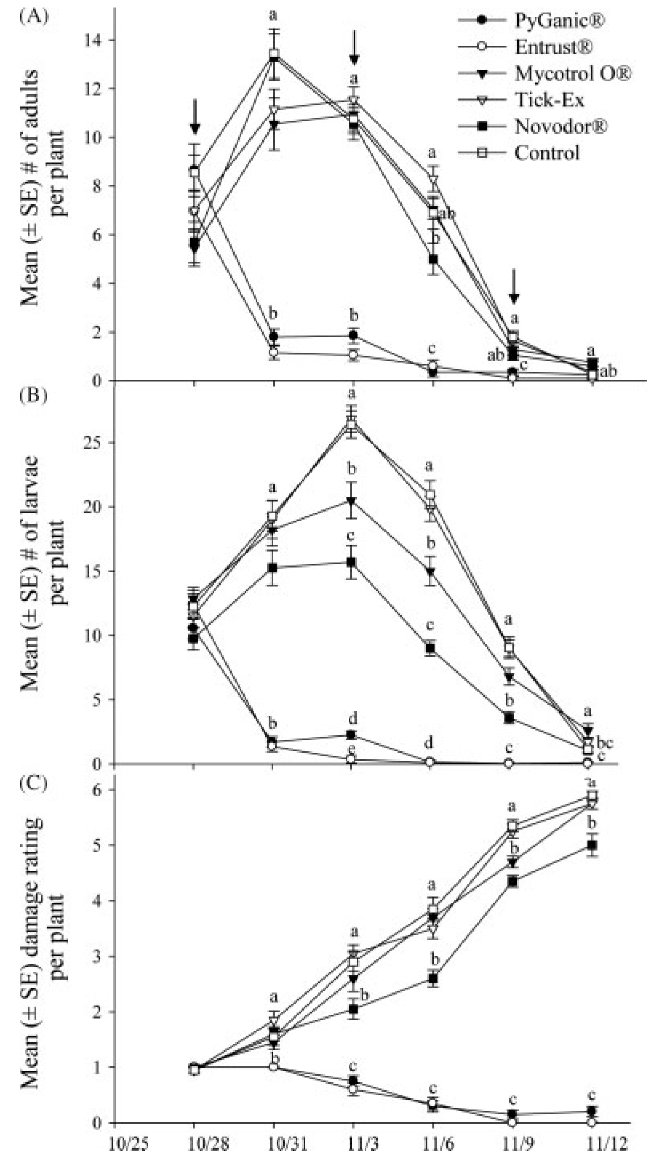

Figure 3. Mean (± SE) number of *M. ochroloma* adults (A) and larvae (B) and damage ratings (C) of turnip plants in plots treated with different insecticide formulations during fall 2008 in Bank, Alabama. For each date, means having no letter in common are significantly different (ANOVA, Tukey–Kramer HSD, $P < 0.05$). Arrows indicate treatment dates.

lower larval counts on some dates compared with the other treatments (Fig. 2).

In fall 2008 at the Banks location, pretreatment data collected on 28 October showed a fairly uniform distribution of *M. ochroloma* adults ($F_{5,111} = 2.30$, $P = 0.0493$) (Fig. 3A) and larvae ($F_{5,111} = 1.36$, $P = 0.2444$) (Fig. 3B) in all experimental plots. Very low damage ratings were also recorded in all the plots ($F_{5,111} = 0.60$, $P = 0.6972$) (Fig. 3C). Significant differences in adult counts were recorded among the treatments on 31 October ($F_{5,111} = 78.16$, $P < 0.0001$), 3 November ($F_{5,111} = 115.00$, $P < 0.0001$), 6 November ($F_{5,111} = 78.25$, $P < 0.0001$), 9 November ($F_{5,111} = 12.47$, $P < 0.0001$) and 12 November ($F_{5,111} = 3.67$, $P = 0.0042$) (Fig. 3A). Also, significant differences in larval counts were recorded among the treatments on 31 October ($F_{5,111} = 101.08$, $P < 0.0001$), 3 November ($F_{5,111} = 233.17$, $P < 0.0001$), 6 November ($F_{5,111} = 297.89$, $P < 0.0001$), 9 November ($F_{5,111} = 101.82$, $P < 0.0001$) and 12 November ($F_{5,111} = 13.51$, $P < 0.0001$) (Fig. 3B). Similarly, damage ratings were significantly different among the treatments on 31 October ($F_{5,111} = 8.30$, $P < 0.0001$), 3 November ($F_{5,111} = 46.04$, $P < 0.0001$), 6 November ($F_{5,111} = 134.57$, $P < 0.0001$), 9 November ($F_{5,111} = 973.45$, $P < 0.0001$) and 12 November ($F_{5,111} = 883.21$, $P = 0.0042$) (Fig. 3C). In general, the lowest adult counts, larval counts and damage ratings were recorded in plots treated with Entrust® or PyGanic®. Novodor® and Mycotrol O® also produced lower larval counts compared with the control.

Promising materials identified in the previous seasons, and two new treatments, were evaluated as stand-alone treatments and in rotation with Entrust® during fall of 2010 at the Shorter location. Pretreatment data collected on 1 November showed that adult counts ($F_{6,130} = 0.60$, $P = 0.7276$) (Fig. 4A), larval counts ($F_{6,130} = 1.94$, $P = 0.0789$) (Fig. 4B) and damage ratings ($F_{6,130} = 1.42$, $P = 0.2117$) (Fig. 4C) were similar in all

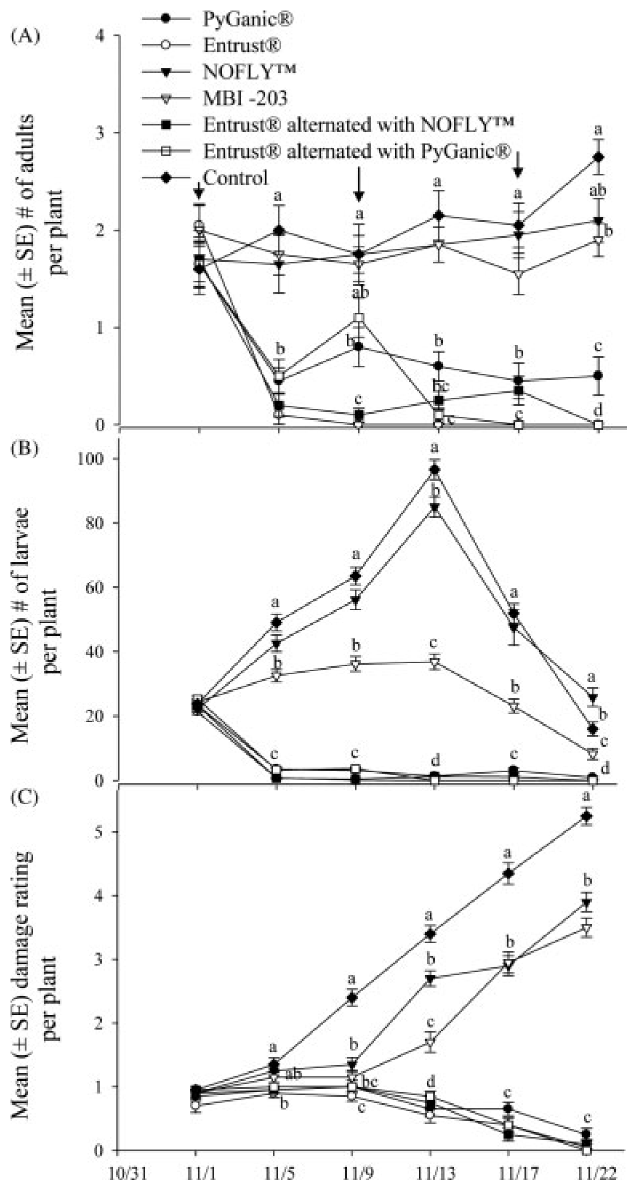

Figure 4. Mean (± SE) number of *M. ochroloma* adults (A) and larvae (B) and damage ratings (C) of turnip plants in plots treated with different insecticide formulations and rotations during fall 2010 in Shorter, Alabama. For each date, means having no letter in common are significantly different (ANOVA, Tukey–Kramer HSD, $P < 0.05$). Arrows indicate treatment dates.

the experimental plots. However, significant differences in adult counts were recorded among the treatments on 5 November ($F_{6,130} = 19.75$, $P < 0.0001$), 9 November ($F_{6,130} = 21.87$, $P < 0.0001$), 13 November ($F_{6,130} = 44.77$, $P < 0.0001$), 17 November ($F_{6,130} = 30.78$, $P < 0.0001$) and 22 November ($F_{6,130} = 87.07$, $P < 0.0001$) (Fig. 4A). Larval numbers were also significantly different among the treatments on 5 November ($F_{6,130} = 276.80$, $P < 0.0001$), 9 November ($F_{6,130} = 439.57$, $P < 0.0001$), 13 November ($F_{6,130} = 958.23$, $P < 0.0001$), 17 November ($F_{6,130} = 193.81$, $P < 0.0001$) and 22 November ($F_{6,130} = 76.55$, $P < 0.0001$) (Fig. 4B). Similarly, significant differences in damage ratings were recorded among the treatments on 5 November ($F_{6,130} = 4.91$, $P = 0.0001$), 9 November ($F_{6,130} = 25.90$, $P < 0.0001$), 13 November ($F_{6,130} = 62.69$, $P < 0.0001$), 17 November ($F_{6,130} = 122.60$, $P < 0.0001$) and 22 November ($F_{6,130} = 473.30$, $P < 0.0001$) (Fig. 4C). Compared with the control, the following four treatments resulted in significant suppression of *M. ochroloma* larvae and adults and damage on most sampling dates: Entrust® stand-alone, PyGanic® stand-alone, Entrust® alternated with PyGanic® and Entrust® alternated with NOFLY™. MBI-203 (experimental formulation) was effective only against the larvae. NOFLY™ stand-alone treatment was not effective against *M. ochroloma* larvae or adults (Fig. 4).

4 DISCUSSION

The goal of this study was to identify effective OMRI-approved insecticides for managing *M. ochroloma* in organic crucifer vegetable production systems. Data from the four field seasons in multiple locations confirmed that *M. ochloroma* is indeed a major constraint to organic crucifer production in Alabama. Of all the various insecticides tested, which included botanical and microbial formulations, weekly sprays of Entrust®, a formulation of spinosad for organic crop production, consistently performed well in suppressing *M. ochloroma* adults and larvae and crop damage. PyGanic®, a botanical insecticide with a quick knockdown effect, was the next best treatment. A few of the materials, such as Novodor® (*Bacillus thuringiensis* subspecies *tenebrionis*), Mycotrol O® (*Beauveria bassiana* strain GHA) and MBI-203 (an experimental formulation of *Chromobacterium subtsugae*) showed some efficacy in some seasons against *M. ochroloma* larvae but did not sufficiently suppress the adults or crop damage. The other tested materials, including Aza-Direct® (a botanical insecticide with azadirachtin as active ingredient), NOFLY™ (*Isaria fumosoroseus* strain FE 9901) and Tick-Ex (an experimental organic formulation of *Metarhizium anisopliae* strain F52), showed no efficacy against *M. ochroloma*, and ultimately did not suppress crop damage by the pest. Additionally, the results of the fall 2010 trials demonstrated that the application of Entrust®, in rotation or in alternation with PyGanic® or NOFLY™, was as effective as the Entrust® stand-alone treatment.

The efficacy of Entrust® or its active ingredient (spinosad) has also been documented against some other beetles in the same family (Chrysomelidae) as *M. ochroloma*, including flea beetles, *Phyllotreta* spp. in cruciferous crops and *Epitrix tuberis* Gent. and *L. decemlineata* in potato.[11,17,18,26] Furthermore, a recent study in Alabama reported the efficacy of Entrust® against lepidopteran pests of cole crops.[19] The efficacy of Entrust® recorded in the present study and others listed above may be attributed to its broad-spectrum activity, multiple modes of entry and residual effect.[11,27–29] In addition, the active ingredient in Entrust® is both a contact and stomach poison.[27,28] The present results showed that weekly sprays of Entrust® were highly effective, suggesting that its residual effect in the field may be longer than 1 week, contrary to the report by McLeod *et al.*[29] which indicated that activity of Entrust® degraded within 1 week in the field. The present results also showed that the application of Entrust® in rotation/alternation with NOFLY™ (which was not effective as a stand-alone treatment) was as effective as weekly sprays of Entrust® alone, further suggesting that the residual activity of Entrust® is over 1 week and perhaps up to 2 weeks or more, given that Entrust® was applied at 2 week intervals in the rotation treatments.

PyGanic®, the botanical insecticide most commonly used by local organic growers, was the second best treatment, but not as effective as Entrust®. The rapid knockdown effect of its active ingredient, pyrethrum, may have contributed significantly to its efficacy against *M. ochroloma*, in particular the larvae. The extremely rapid colonizing behavior and highly destructive capacity of *M. ochroloma* are possibly important factors limiting field efficacy of relatively slow-acting formulations such as Aza-Direct® (azadiractin), Mycotrol O® (*Beauveria bassiana* strain GHA), Novodor® (*Btt*), NOFLY™ (*Isaria fumosoroseus* strain FE 9901) and Tick-Ex (experimental organic formulation of *Metarhizium anisopliae* strain F52). Aza-Direct®, a slow-acting botanical with antifeedent activity and effect on molting, was also shown to be ineffective against some other chrysomelid species, including flea beetles in cruciferous crops and *L. decemlineata*.[11,17] Similarly, the entomopathogenic fungal formulations Mycotrol O®, NOFLY™ and Tick-Ex were ineffective, possibly because of their slow activity and the unfavorable environmental conditions such as high temperatures and low humidity under the short turnip crop canopy. Interestingly, most of these formulations were effective against *M. ochroloma* in laboratory trials (Balusu RR, unpublished data); therefore, their inefficacy in the field trials may be related to unfavorable field conditions. Long *et al.*[30] observed an inverse relationship between *L. decemlineata* mortality induced by *B. bassiana* strain GHA and temperatures ranging from 15 to 30 °C. Lacey *et al.*[31] reported improved control of *L. decemlineata* larvae following row (canopy) closure and suggested that this coincided with higher humidity and increased protection from sunlight. Wraight and Ramos[32] showed that *B. bassiana* strain GHA as a stand-alone product was not effective against *L. decemlineata* larvae under field conditions.

5 CONCLUSIONS

In summary, this study has identified promising OMRI-acceptable biopesticides for managing *M. ochroloma* in organic crucifer vegetable production systems in the southern United States. Entrust® was the most effective insecticide, followed by PyGanic®. Furthermore, the present results also showed that some insecticides, such as PyGanic® and NOFLY™, can be applied in rotation with Entrust® for effective management of *M. ochroloma* and possibly other pests of organic crucifer production, and thus limit the potential for development of resistance to Entrust®. The present data, which showed that MBI-203 (experimental formulation of *Chromobacterium subtsugae*) was effective against *M. ochroloma* larvae, are also encouraging and suggest that this formulation may be used in rotation with Entrust® or PyGanic®. A proactive approach to reducing the potential for development of resistance to Entrust® in organic vegetable production is prudent, given that many pests have been reported to show resistance to its active ingredient, spinosad, in conventional production systems.[33] Rotation with other insecticides is a viable insecticide resistance management strategy because spinosad has not been reported to share cross-resistance mechanisms with any other group of insecticides.[34,35] Insecticide rotation may also help with conservation of natural enemies, given that spinosad is known to be toxic to parasitoids.[36–38] Further studies are necessary to determine the efficacy of biweekly sprays of Entrust® and PyGanic®, to identify other effective materials and tactics for rotation or integration with both insecticides and ultimately to develop an organically acceptable integrated pest management program for managing *M. ochroloma* and other pests in organic crucifer production.

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