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# Biology, Ecology, and Management of *Microtheca ochroloma* (Coleoptera: Chrysomelidae) in Organic Crucifer Production

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## Abstract

Organic vegetable production is a rapidly growing industry in the southeastern United States. The yellowmargined leaf beetle, *Microtheca ochroloma* Stål (Coleoptera: Chrysomelidae), has recently become an important pest of organic and low-input crucifer vegetable production where growers are not permitted to use synthetic insecticides. *Microtheca ochroloma* was first reported in the United States in Mobile, AL, in 1947. Currently, it has been reported in nine southeastern states, with the potential for expansion to northern states because of its ability to withstand cold weather. Both adults and larvae feed voraciously on crops in the family Brassicaceae (e.g., arugula, cabbage, collard, mustard, radish, and turnip) and can cause complete crop loss. Despite the growing market demand for organic leafy greens, many organic growers in regions where the pest is predominant have reduced crucifer production owing to the vulnerability of their crops to *M. ochroloma* and lack of effective, organically compliant management tools against the pest. Here, we discuss the biology, ecology, and management tactics currently available against this invasive pest.

**Key words**: Chrysomelidae, crucifer IPM, invasive, *Microtheca ochroloma*, organic vegetable pest management

Crucifer vegetable crops, in particular *Brassica* spp. (Brassicaceae), have an estimated market value of >US$1 billion in the United States (United States Department of Agriculture–National Agricultural Statistics Service [USDA-NASS 2000]). These vegetables, which include arugula (*Eruca sativa* Mill.), broccoli (*Brassica oleracea* L. var. *italic*), cabbage (*Brassica oleracea* L. var. *capitate*), cauliflower (*Brassica oleracea* L. var. *botrytis*), collard (*Brassica oleracea* L. var. *medullosa*), turnip (*Brassica rapa* L. var. *pekinesis*), and watercress (*Nasturtium officinale* W.T. Aiton), are grown throughout the United States, and they are an important part of the fresh market vegetable crops in the south, as they comprise key ingredients in traditional southern American cooking. Although these crops are traditionally produced using conventional production practices, organic crucifer vegetable production is an emerging industry in the southern United States. For instance, watercress, a semiaquatic high value crucifer crop (one of the main ingredients in V8 vegetable juice [Campbell Soup Company, Camden, NJ]), is often grown organically in many parts of the southern United States, and is a multimillion dollar industry in Alabama and Florida (Meuninck 2016). In fact, New Market, a small community in northern Alabama (Madison County) is commonly regarded as the “Watercress capital of the world” (Lang 2008).

Although crucifer crops are attacked by a wide variety of insect pests that include diamondback moth (*Plutella xylostella* L.), cabbage looper (*Trichoplusia ni* Hübner), imported cabbageworm (*Pieris rapae* L.), armyworms (*Spodoptera* spp.), cutworms (*Agrotis* spp.), harlequin bug (*Murgantia histrionica*), and flea beetles (*Phyllotreta* spp.), the yellowmargined leaf beetle, *Microtheca ochroloma* Stål (Coleoptera: Chrysomelidae), in certain geographic areas is considered one of the most devastating pests in organic crucifer production systems (Balusu and Fadamiro 2011a). In most growing seasons, *M. ochroloma* is the only insect pest capable of causing significant economic damage to organic crucifer crops in certain parts of the southeastern United States. Indigenous to South America, *M. ochroloma* was first recorded in the United States in Mobile, AL, in 1947 (Chamberlin and Tippins 1948), and is now a major pest of crucifer crops in many southern states, including Alabama, Florida, Louisiana, Mississippi, South Carolina, North Carolina, Georgia, Oklahoma, and Texas (Woodruff 1974, Ameen and Story 1997a, Drees 1997, Story et al. 1997, Guillebeau 2001, Bowers 2003). Also, it was reported by Gilbert et al. (2011) as occurring in Santa Clara County, CA, and recently was discovered in southern Illinois on an unidentified roadside crucifer (Marché 2013).

## Biology and Description of Life Stages

### Adult

Like many chrysomelids, adult *M. ochroloma* are oval in shape, about 5 mm long and 2.5 mm wide, with a black head and bronzy black to dark brown elytra (Fig. 1; Woodruff 1974). The beetle earns its common name from the conspicuous pale yellow border surrounding the elytra. However, this border color varies from typically pale yellow to brown or clay red (Fig. 1B; Oliver and Chapin 1983). Each elytron has four prominent longitudinal rows of punctures, which distinguishes *M. ochroloma* from other similar species. Adults also have a characteristically bilobed third tarsal segment (Woodruff 1974). Males are distinguished from females by their decurved posterior abdominal sternum (Oliver and Chapin 1983) and are typically smaller than females (Fig. 1C). Adult beetles are long-lived, with alongevity of ~105 d (Ameen and Story 1997a). Males and females can mate several times during their life time.

### Egg

The eggs (Fig. 2B) are bright orange, elongate, and 1.2 mm long by 0.5 mm wide. They are laid singly or in small clusters of about 15–60 eggs on the underside of the leaf, dry plant debris, or soil surface (Bowers 2003, Fasulo 2005). *Microtheca ochroloma* eggs closely resemble those of lady beetle eggs in color, shape, and size but differ in their cluster arrangement. Lady beetle eggs are upright and closely packed in a cluster, whereas *M. ochroloma* eggs are arranged more or less loosely and irregularly in a cluster. The number of eggs a *M. ochroloma* female can lay over a lifetime varies greatly, ranging from 10 to 1,497 (Ameen and Story 1997a). Eggs usually hatch within 16 d at 15 °C to 5 d at 30 °C (Manrique et al. 2012).

### Larva

Larvae (Fig. 2C) vary in color from yellowish brown to almost black and are covered with fine hairs or setae. The head capsule is strongly sclerotized and brown or black in color. Larvae progress through four instars, with a small number (~5%) progressing through a fifth instar (Ameen and Story 1997a). Larval development lasts on an average from 23 d at 15 °C to 7 d at 30 °C (Manrique et al. 2012). Young larvae aggregate, becoming solitary as they progress to later instars.

### Pupa

Like egg laying, pupation usually occurs on the underside of leaves or on the soil surface beneath leaf litter or other debris. Before pupating, mature larvae spin a black web around themselves that turns brown as it dries. The web makes the pupae resemble debris or frass (Fig. 2D). This stage of web spinning is sometimes called a prepupal stage, and it lasts an average of 3 d. The pupal stage lasts on an average from 11 d at 15 °C to 4 d at 30 °C (Manrique et al. 2012).

## Ecology

In Alabama and other parts of the southern United States, crucifer vegetable crops are typically grown in spring and fall seasons which correlate with the activity period of *M. ochroloma*. The beetle is a cool season pest, typically active from late September until early December in Alabama. Adults overwinter and become active again from mid-March to early June. During the hot summer months, they aestivate (a heat- or drought-induced resting period) on wild mustard hosts/beneath stones/plant debris/in moist soil crevices before they migrate into crucifer fields in September of the following year (R. Balusu personal observation). Therefore, management strategies for preventing damage by *M. ochroloma* should target overwintering adults within the field, and beetles migrating from wild hosts into fields during the following growing season.

In Florida, crucifer crops are grown from October through April, and *M. ochroloma* is active throughout this period. There is no overwintering period, although beetles are much less active during colder months in Northern Florida. As in other parts of the southeastern United States, the beetles aestivate during the summer months, but the specific aestivation sites are unknown.

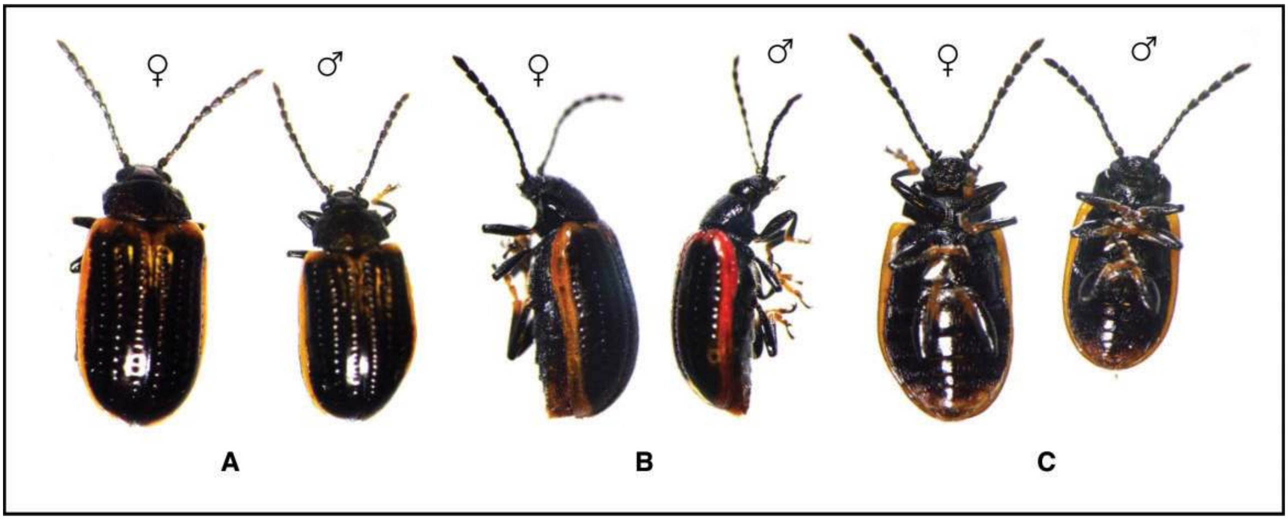

**Fig. 1.** *Microtheca ochroloma* adult female (left) and male (right) in dorsal (**A**), lateral (**B**), and ventral (**C**) views.

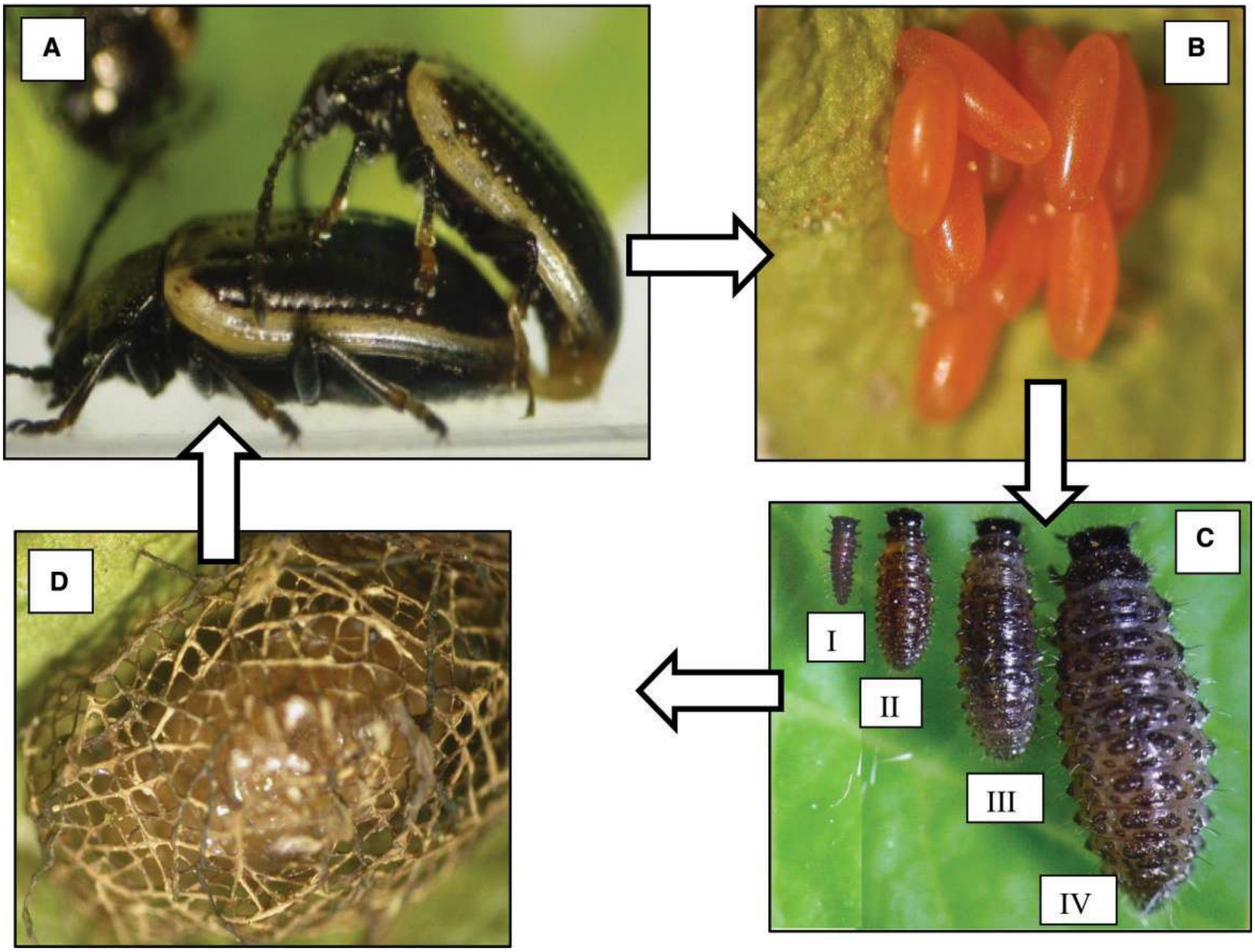

**Fig. 2.** *Microtheca ochroloma* life stages—adult (**A**), egg (**B**), first-, second-, third-, and fourth-instar larvae (**C**), and pupa (**D**).

## Feeding Behavior

Adults and larvae feed voraciously by chewing on foliage, causing severe defoliation (Fig. 3). After complete depletion of foliage, the beetles continue to feed on exposed tubers of turnips and radishes (Fig. 3D), which may result in entire crop loss.

Although all members of the Brassicaceae, both cultivated crops and wild Brassicaceae, may serve as hosts, *M. ochroloma* exhibits a definite host preference. In multiple-choice tests of whole plants in greenhouse cages, higher number of adults and larvae chose napa cabbage and turnip over cabbage and collards (Balusu and Fadamiro 2011a). Additionally, greater amounts of injury were seen on napa cabbage and turnip. Similarly, Ameen and Story (1997b) reported, based on leaf disk choice tests, that adult beetles preferred turnip, mustard, and radish over cabbage and collards, whereas larvae preferred turnip and mustard over radish, cabbage, and collards. Females laid more eggs on turnip than on collards and more eggs per day on turnip and mustard compared with collards (Ameen and Story 1997c).

Host plant preference in *M. ochroloma* is mediated at least in part by host plant volatiles. All members of the family Brassicaceae (formerly known as Cruciferae) have characteristic secondary plant metabolites called glucosinolates. Myrosinase, an enzyme stored in special cells in the tissue of crucifer plants (Rask et al. 2000), enhances the hydrolysis of nonvolatile glucosinolates to volatile biologically active isothiocyanates, thiocyanates, and nitriles (Vaughn and Berhow 2005). The composition of glucosinolates varies among Brassicacae plants (Sorensen 1991) and >120 different glucosinolates have been identified (Fahey et al 2001). Isothiocyanates are known to attract various specific crucifer-feeding insects (Visser 1986). *Microtheca ochroloma* was shown to use plant odors to locate their host plants and to discriminate between crucifer plant species (Balusu and Fadamiro 2011a). In four-choice olfactometer experiments, both sexes of *M. ochroloma* showed strong attraction to headspace volatiles of preferred host plants (turnip and napa cabbage) over less preferred host plants (cabbage and collards). Because glucosinolates are ubiquitous in Brassicaceae, the sensitivity of the beetle to specific glucosinolates or their cleavage products, isothiocyanates, may help them to recognize particular plant species of this family. For instance, Balusu (2011) demonstrated that specific isothiocyanate compounds, which were unique to preferred host plants, elicited significant biological activity in *M. ochroloma*.

Differing host quality may also play a role in host preference of *M. ochroloma*. For example, beetles reared on cabbage died after three generations, whereas they were able to produce at least four generations on turnip, mustard, radish, and collards (Ameen and Story 1997a). Females reared on turnip produced more eggs than those reared on collards. Interestingly, adults lived longer on radish compared with the other four host plants tested. Neither development time of individual life stages nor total development time were affected by host plants.

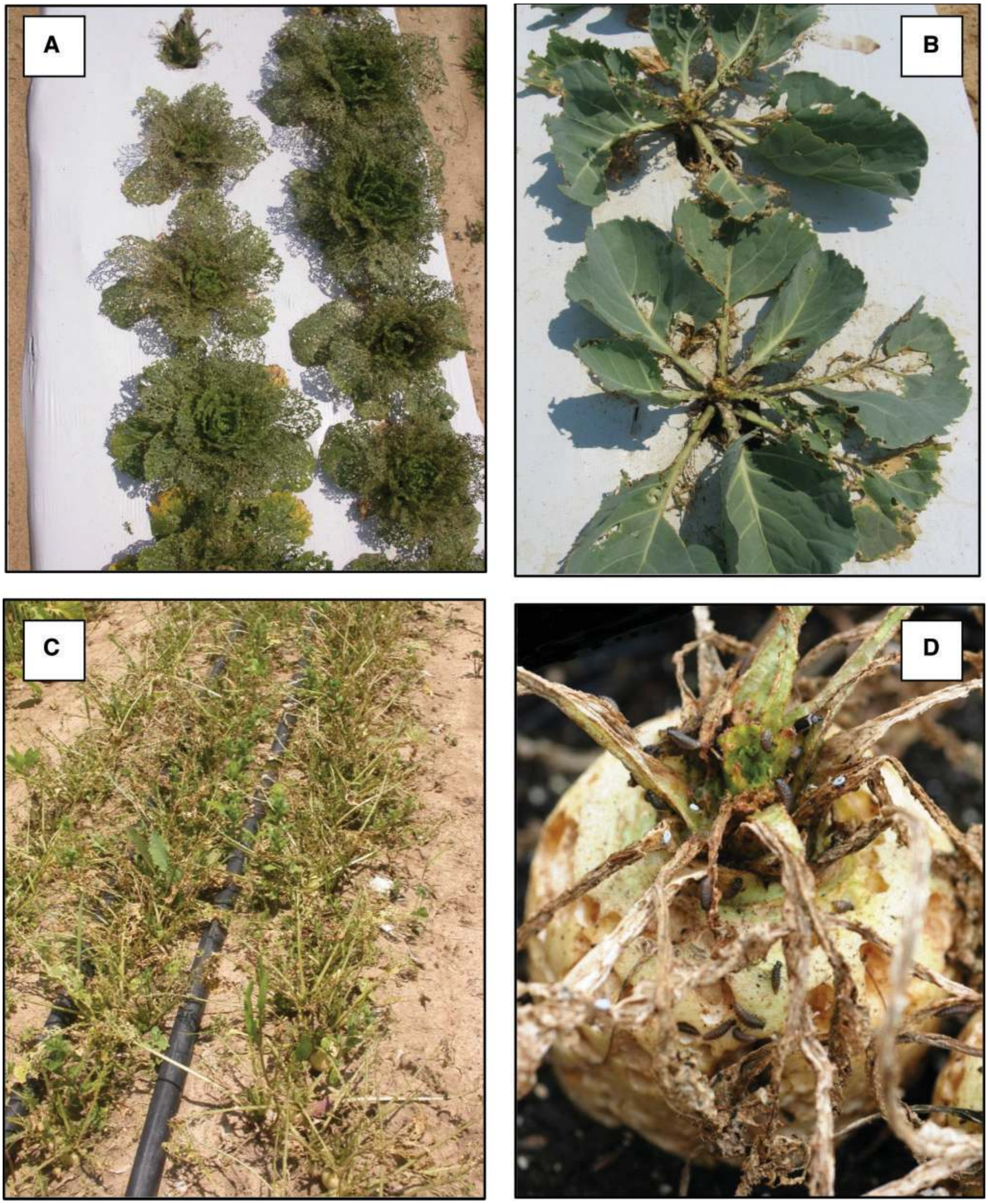

**Fig. 3.** *Microtheca ochroloma* feeding damage on napa cabbage (**A**), cabbage (**B**), turnip (**C**), and turnip root (**D**).

## Organic Management Tactics for *M. ochroloma*

### Cultural Control

**Sanitation**

Based on observations of the authors, there are several cultural practices that could prove useful in *M. ochroloma* management. Crucifer growers often leave unharvested plants and plant debris at the end of season that could serve as a food source and shelter during the winter. This improves the survival of overwintering beetle populations. Therefore, cultivation and clean-up of fields immediately after the harvest could help to minimize infestations the next season. As female *M. ochroloma* lay their eggs on the undersides of leaves, dry plant debris, or the soil surface (Bowers 2003, Fasulo 2005), keeping the soil or plastic mulch free from plant material and other debris during the crop season may reduce the amount of suitable egg-laying substrates and subsequently lower beetle populations.

*Alternate Host Management*. Proper weed management is another important cultural technique that could help with *M. ochroloma* management. Both wild mustard, *Sinapsis arvensis* (L.), and wild turnip, *Brassica rapa* ssp. *sylvestris* L., are common weeds in the southeastern United States, that could serve as off-season hosts or a source of reinfestation after insecticide applications. Unfortunately, no research has been conducted so far in this area with this pest, so these inferences are simply hypotheses.

### Intercropping

In intercropping, at least two different crops are grown next to each other at the same time in the same location (Powers and McSorley 2000). The rationale behind the use of intercropping in pest management is that the odors of nonhost plants confuse insects that search for hosts by smell, thereby disrupting their host-finding ability and reducing pest infestation. Intercropping crucifer host plants with nonhost plants, although effective against other crucifer insect pests such as *Phyllotreta crucifera* (Geoze) (Latheef et al. 1984), resulted in limited success in preventing *M. ochroloma* infestation (Bowers 2003). There were no differences in the number of adult beetles per plant in mizuna, *Brassica rapa* var. Kyona, intercropped with oak leaf lettuce, *Lactuca sativa* var. Berenice (noncrucifer vegetable crop), compared with control plots (monoculture of mizuna) regardless of the density of mizuna.

### Trap Cropping

Trap cropping is a type of cultural pest management tactic where a highly preferred plant species is used to attract the pest and reduce their likelihood of entering a cash crop (main crop). Trap crops have been shown to be an effective pest management strategy against a wide variety of insect pests in conventional and organic vegetable production systems (Ludwig and Kok 1998, Smith 2000, Badenes-Perez et al. 2005, Balusu et al. 2015). Designing a successful trap cropping strategy requires a thorough understanding of the target insect's host preference (relative attraction to the trap crop compared with the cash crop) and its dispersal behavior (mode of colonization and movement patterns within the field; Shelton and Badenes-Perez 2006). Trap cropping appears to be a potential pest management strategy for *M. ochroloma*, as the beetles display strong behavioral and ecological characteristics including: 1) display a strong preference for certain host plants as a food source or oviposition site (Ameen and Story 1997a–c; Balusu and Fadamiro 2011a); 2) migrate into the field rather than emerging from the field, which allows them to be amenable to perimeter trap crops before they come into contact with the main crop; 3) exhibit strong edge effect behavior—colonize on field margins first before moving into the center of the field as density increases; and 4) have limited mobility—so, less tendency to move after encountering a suitable host plant.

A recent study by the authors has indeed confirmed trap cropping as an effective strategy for managing *M. ochroloma* in crucifer production (Balusu et al. 2015). Turnip planted ∼2 wk before the cash crop as a perimeter trap crop on the border of mustard, napa cabbage, or cabbage plots was effective in attracting *M. ochroloma* away from the cash crop and delay beetle colonization, and subsequently reduce crop damage in organic crucifer production systems (Fig. 4; Balusu et al. 2015). The density of beetles in the cash crop plots bordered by turnip was 2–8× lower than the density in the cash crop plots without a trap crop (control plots), depending on the site, sampling date, or cash crop type. Furthermore, appropriately timed OMRI (organic material review institute)-approved insecticide applications to the trap crop proved adequate to prevent the spread of the beetle to the cash crop and reduced or eliminated the need for insecticide application on the cash crops. This is especially true for cash crops such as cabbage, broccoli, and cauliflower that are comparatively much less attractive to *M. ochroloma* than the turnip trap crop (Balusu et al 2015). However, in crops such as mustard and napa cabbage that are equally as or only slightly less attractive than turnip, application of insecticide only to the trap crop borders may not be adequate to reduce damage on the cash crop. In this case, early planted turnip may serve as a "sink" under low beetle pressure but become a source of the pest as beetle density increases later in the season. Therefore, trap cropping cannot be used as a stand-alone tactic to manage high beetle populations. It could, however, be one of a combination of tactics used as part of a comprehensive IPM strategy to manage *M. ochroloma* (Balusu et al. 2015). Thus, trap cropping offers an environmentally sound and economically attractive means of managing *M. ochroloma* in organic crucifer production.

**Fig. 4.** Field demonstration of trap crop strategy against *M. ochroloma* using turnip as trap crop and cabbage as main crop at the Chilton Research and Extension Center, Clanton, AL.

### Mulch

In general, organic mulch such as straw creates a favorable microenvironment that supports ground predators and reduces the ability of a pest to locate its host plant. For instance, straw mulch has been shown to support a greater number of predators—mostly ground beetles, lady beetles, and green lacewings. However, Manrique et al. (2010) reported that straw mulch is not an effective management tool for *M. ochroloma* (Manrique et al. 2010). Populations of the beetle were significantly higher in mulched turnip plots than in nonmulched plots, which resulted in significantly more crop damage in the mulched plots. Moreover, female *M. ochroloma* prefers to lay their eggs in leaf litter and in other sheltered places. Also, larvae prefer sheltered places for pupation. Therefore, straw mulch may be creating an ideal environment for *M. ochroloma* for both egg laying and pupation, as well as for overall population growth.

## Mechanical and Physical Tactics

### Handpicking

Physical control methods such as handpicking (followed by destruction) can be effective in controlling *M. ochroloma* in small scale or backyard vegetable production. Both adult and larval stages of *M. ochroloma* will stop moving and drop off the plant when disturbed (E. M. Rhodes personal observation). Therefore, the beetles could be easily collected into a container of soapy water by lightly shaking the plant over the container and then be disposed off.

### Row Covers

Row covers are pest exclusion screens made of lightweight, breathable fabric that are used to create a physical barrier over the plants to prevent colonization by pest insects. It is a well-established pest management practice in vegetable crops in the northern states against a wide range of insect pests including cucumber beetle, flea beetles, and Colorado potato beetle (Kuepper 2003, Diver and Hinman 2008, Parker et al. 2012). However, the use of this tactic against *M. ochroloma* in the southern region may be challenging owing to increased heat and humidity under the cover, which could create a suitable environment for disease development.

## Monitoring

Monitoring is a key part of any IPM strategy. Currently, in-situ counts are the most widely used monitoring method for *M. ochroloma*. During sampling, plants should be checked carefully, as both adults and larvae prefer the undersides of leaves and other sheltered areas. Sampling one or two plants out of every 10 provided good results in research trials (Manrique et al. 2010, Balusu et al. 2015). The economic threshold for *M. ochroloma* has not been determined, although a nominal threshold of one adult per plant has been used for research purposes (Balusu et al. 2015). However, this does not take into account the larval population, which is also highly destructive. Plant kairomone-based lures and traps are being developed as a monitoring tool for *M. ochroloma*. Field studies conducted in Alabama and Florida demonstrated that traps baited with a novel synthetic attractant identified from host plants captured significantly more beetles than unbaited traps (R. R. Balusu and H. Y. Fadamiro, unpublished data).

## Biological Control

Biological control is currently not a major strategy used in the management of *M. ochroloma*. Very few of its natural enemies are known (Figs. 5–7), and most have not been well studied. There are no known parasitoids of *M. ochroloma* in the United States. Parasitism by *Trichogramma* spp. has not been observed despite collecting and rearing thousands of eggs from numerous field sites. No foreign exploration has been undertaken in South America where the beetle is native.

Montemayor and Cave (2009) identified three predators preying on various stages of *M. ochroloma* in the field in Florida: the spined soldier bug, *Podisus maculiventris* (Say) (Hemiptera: Pentatomidae), *Chrysoperla rufilabris* (Burmeister) (Neuroptera: Chrysopidae), and the convergent lady beetle, *Hippodamia convergens* (Say) (Coleoptera: Coccinellidae). Only *P. maculiventris* and *C. rufilabris* have been studied.

Nymphs and adults of *P. maculiventris* are predators of all stages of *M. ochroloma* (Fig. 5). Nymphs can consume on an average 741 eggs during their developmental period. Second instars can consume about six eggs per day, whereas third-, fourth-, and fifth instars can kill about 18, 50, and 84 eggs per day, respectively (Montemayor and Cave 2011). Montemayor and Cave (2012) evaluated three release rates of first-instar *P. maculiventris* nymphs in field cages harboring *M. ochroloma* larvae on six turnip plants. Two provisional recommendations for growers emerged from the study. If plants have ≥7 leaves per plant, then 10 first-instar *P. maculiventris* per six plants should be released. If plants have ≤6 leaves per plant, then 4 first-instar *P. maculiventris* per six plants should be released.

Niño and Cave (2015) investigated the predation rate and survivorship of *C. rufilabris* larvae with eggs and larvae of *M. ochroloma* as prey at four temperatures. The mean number of prey killed daily

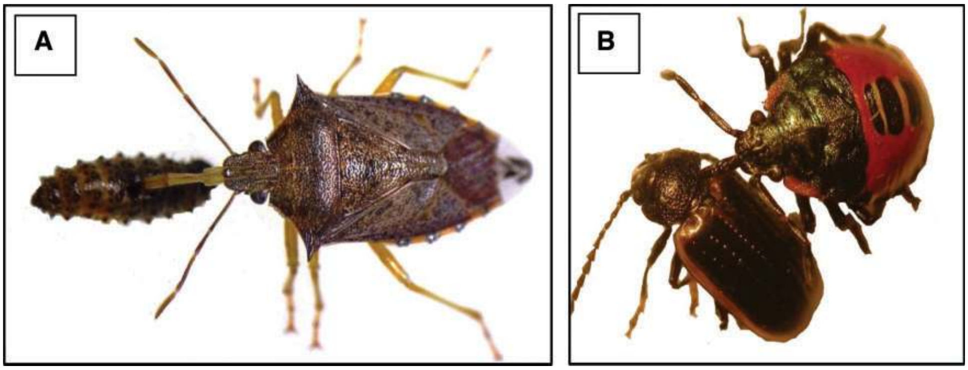

**Fig. 5.** Spined soldier bug adult, *P. maculiventris* (left), and Florida predatory stink bug nymph, *Euthyrhynchus floridanus* (right) (Hemiptera: Pentatomidae), feeding on larva and adult of *M. ochroloma*, respectively.

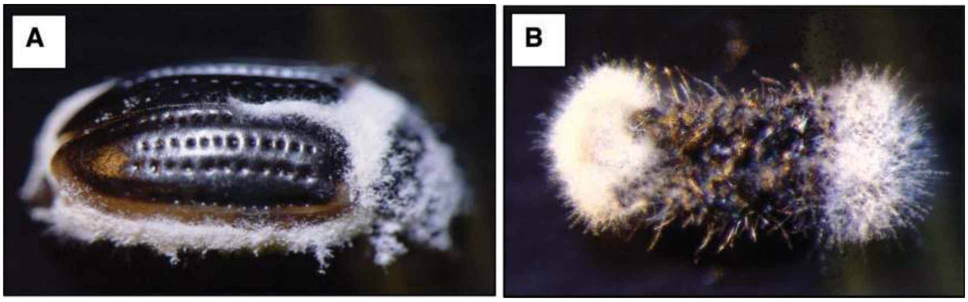

**Fig. 6.** Mycosis by entomopathogeic fungi *B. bassiana* on *M. ochroloma* adult (**A**) and larva (**B**).

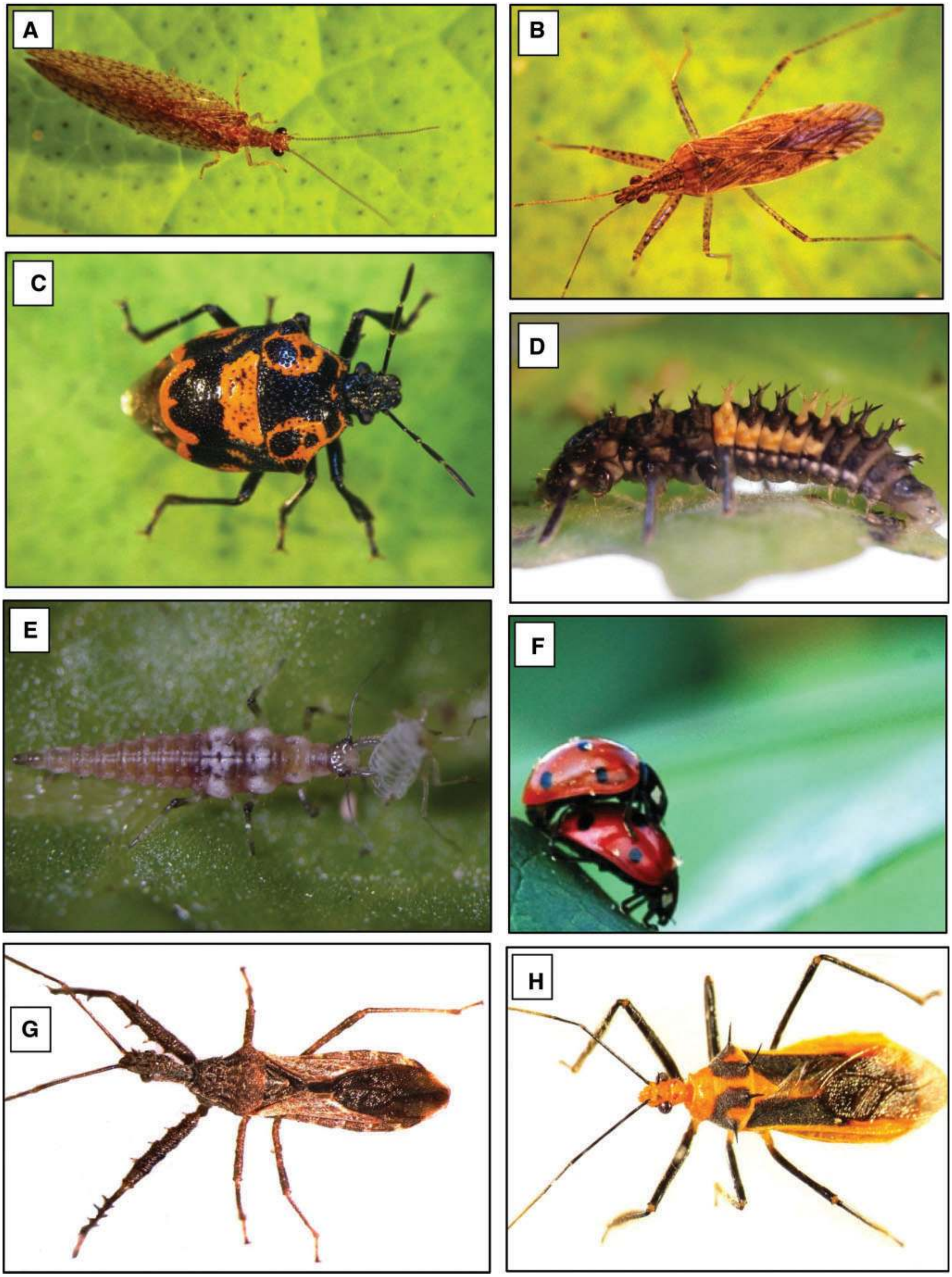

**Fig. 7.** Common predators of *M. ochroloma* in organic crucifer vegetable production in the southeastern United States. Brown lacewing Hemerobius posticus adult (**A**), Damsel bug Nabis americoferus (**B**), Anchor stinkbug Stiretrus anchorago (**C**), Lady beetle Coccinella septempunctata larva (**D**), Brown lacewing H. humulinus larva (**E**), Lady beetle C. septempunctata adult (**F**), Spined assassin bug Sinea diadema (**G**), and Milkweed assassin bug Zelus longipes (**H**).

increased from 8.4 eggs and 4.0 larvae at 15 °C to 18.6 eggs and 10.2 larvae at 25 °C. However, predator larvae killed 78% fewer eggs at 25 °C than at 15 °C owing to less time in the stage. Adult emergence from pupae was 100% for predators consuming *M. ochroloma* eggs, but only 13% for those that ate first-instar prey.

Niño Beltrán (2013) found that *C. rufilabris* killed more first-instar *M. ochroloma* than eggs on whole plants, but this difference may be owing to location of the prey on the plant. *Chrysoperla rufilabris* larvae spend more time on foliage where first-instar *M. ochroloma* are located, but the predator spends little time at the base of the plant near the soil surface where prey eggs are laid. Niño Beltrán (2013) also discovered that the predator prefers nymphs of the green peach aphid, *Myzus persicae* (Sulzer), over the immature stages of *M. ochroloma*. Given the poor survival of the predator when fed *M. ochroloma* first instars and the greater preference for aphids as food, Niño Beltrán (2013) concluded that this predator would not provide satisfactory control of this pest.

The only known pathogens that infect *M. ochroloma* are the entomopathogenic fungi *Isaria fumosorosea* Wize, *Beauveria bassiana* (Bals.-Criv.) Vuill. (Fig. 6), and *Metarhizium anisopliae* (Metchnikoff) Sorokin (Montemayor and Cave 2009; Balusu and Fadamiro 2011b, 2013), and the bacteria *Chromobacterium subtsugae* Martin, Gundersen-Rindal, Blackburn, and Buyer and *Bacillus thuringiensis* Berliner subspecies *tenebrionis* (Balusu and Fadamiro 2011b). Commercial formulations of these pathogens were tested in the laboratory and field, and the results of these tests are detailed in the next section. The larva is the most susceptible stage to *I. fumosorosea* (Montemayor et al. 2016) and exhibits reduced growth and unsuccessful molting due to infection.

Herbivory by adult *M. ochroloma* on bok choy leaves treated with *I. fumosorosea* at four concentrations was evaluated in two trials by Gámez Herrera *et al.* (2016). In the first trial, plants applied with 1.0 g/100 ml and 2.0 g/100 ml suffered significantly less foliar loss than the untreated control. In the second trial, a significant difference occurred only between the control and concentration 2.0 g/100 ml.

## Chemical Control

Chemical control is the most widely used strategy by growers in protecting crucifer vegetables against *M. ochroloma*. Conventional growers have several chemical control options owing to *M. ochroloma*'s high susceptibility to a wide range of synthetic insecticides (Holmes and Kemble 2008). However, for organic crucifer growers, there are only a few OMRI-approved insecticides available. Numerous organically approved insecticide formulations, including microbials and botanicals, have been evaluated against *M. ochroloma* both in laboratory and field studies (Overall 2008; Balusu and Fadamiro 2011b, 2013; Montemayor et al. 2016). Balusu and Fadamiro (2011b) tested various insecticides and reported that weekly sprays of spinosad, which is based on natural metabolites derived from a soil actinomycete and approved for use in organic crop production under the trade name Entrust (Dow AgroSciences LLC, Indianapolis, IN), consistently suppressed *M. ochloroma* adults and larvae and reduced crop damage (Fig. 8). Pyrethrin (PyGanic; Valent BioScience Corporation, Libertyville, IL), a botanical insecticide with a quick knockdown effect, also provided efficacy. A few other pathogens including bacteria, *Bacillus thuringiensis* subspecies *tenebrionis* (Novodor; Valent BioScience Corporation, Libertyville, IL), *C. subtsugae* (Grandevo; Marrone Bio Innovations, Davis, CA), and the entomopathogenic fungi *B. bassiana* strain GHA (Mycotrol O; BioWorks, Inc. Victor, NY) showed some efficacy against *M. ochroloma* larvae but did not sufficiently suppress the adults or reduce crop damage. The other tested materials, including azadiractin (Aza-Direct; Gowan Company LLC, Yuma, AZ—a botanical insecticide derived from the neem plant), entomopathogenic fungi *I. fumosorosea* strain FE 9901(NOFLY; Natural Industries, Inc., Houston, TX), and *M. anisopliae* strain F52 (Tick-Ex; Novozymes Biologicals, Inc., Salem, VA—an experimental organic formulation), showed limited or no efficacy against *M. ochroloma* and ultimately did not reduce crop damage by the pest. Further field trials have shown that application of insecticides such as PyGanic and NOFLY, in rotation with Entrust were as effective as standalone application of Entrust. Therefore, the rotation would be prudent to preserve the efficacy of Entrust against *M. ochroloma* in organic vegetable production (Balusu and Fadamiro 2011b). Moreover, in a laboratory bioassay, Balusu and Fadamiro (2013) showed that the actual lethal concentration of the most effective insecticides, spinosad (Entrust) and pyrithrin (PyGanic), were only fractions (1/200 and 1/15, respectively) of the field-recommended rates. None of the entomopathogenic fungi (*B. bassiana* strain GHA, *M. anisopliae* strain F52, *I. fumosorosea* strain FE 9901, and *I. fumosorosea* Apopka strain 97) evaluated against *M. ochroloma* resulted in >50% larval or 14% adult mortalities under laboratory conditions (Balusu and Fadamiro 2013, Montemayor et al. 2016).

**Fig. 8.** *Microtheca ochroloma* damage on turnip plots treated with spinosad (Entrust) or *B. bassiana* (Mycotrol) versus untreated control plot.

## IPM Demonstrations and Emerging Recommendations

Several field demonstrations of trap cropping as a control strategy against *M. ochroloma* are ongoing in Alabama. These field demonstrations were initially laid out as strip test plots (nonrandomized) to determine the rapidity of *M. ochroloma* infestation at new locations that were never planted to crucifer crops. More recently, demonstration plots have been organized as replicated studies of trap crop and various organic insecticides plus conventional standards. These IPM demonstrations have led to the development of integrated recommendations closely aligned to commercial production systems. Demonstration locations are also used for field training of specialty crop producers and Extension educators who often misidentify the pest owing to its cryptic nature. Below are some specific IPM recommendations for managing *M. ochroloma* in crucifer production systems.

1. *Microtheca ochroloma* adults are relatively mobile; therefore, it is recommended to plant highly preferred and closely related brassica crops as far apart as possible to increase the time required by the beetle to locate brassica plants and thereby delay colonization.
2. Scout crucifer fields at least once per week to determine *M. ochroloma* densities especially at the beginning of the season.
3. Apply kaolin clay (Surround WP) early in the season before the beetle migrates into the field. Field trials demonstrated early application of Surround can deter *M. ochroloma* and delay its colonization (R.R. Balusu and H.Y. Fadamiro, unpublished data).

4. Action threshold: Research is ongoing to establish a field-based economic threshold for *M. ochroloma*. A nominal threshold of one adult per plant is currently recommended, as the pest is highly mobile and crop damage or contamination occurs very rapidly (Balusu et al. 2015).
5. Trap cropping with turnips and napa cabbage is very useful to protect less-favored brassica crops like cabbages. Large-scale field demonstrations (~1 acre plots) in Alabama have demonstrated the effectiveness of turnips as a perimeter trap crop. Timely treatment of the perimeter with alternative or chemical insecticides is critical to control *M. ochroloma* larvae without having to treat the main crop.
6. Conservation of biological control agents such as the spined soldier bug and lady beetle larvae can be a useful tactic for reducing *M. ochroloma* larvae (Montemayor and Cave 2011).
7. Apply insecticides only when the beetles are active, normally during dusk when temperatures are between 70–75°F. Thorough coverage, especially under the leaves where beetles congregate, is vital to increase the effectiveness of spray applications.
8. Because *M. ochroloma* infestations are usually observed to be clumped within a field, especially at the beginning of the season (owing to its unique aggregation behavior), it is recommended to treat only "hot spots" or areas of high infestations.

## Concluding Remarks

Limited numbers of tools are currently available to manage *M. ochroloma* in organic crucifer vegetable production. There are no biological control agents that can effectively regulate populations of *M. ochroloma* below economically damaging levels. Also, no parasitoids have been identified for *M. ochroloma* either in its native land or in the United States. Resistant cultivars that could discourage feeding damage by *M. ochroloma* are not commercially available. Although trap cropping has been demonstrated as a promising cultural control tactic for *M. ochroloma*, the need to dedicate a portion of the field to the trap crop, which otherwise could be used to grow other marketable crops (cash crops), may be a limitation. Furthermore, only very few organically acceptable insecticides are effective against *M. ochroloma* and their widespread use could result in the development of pest resistance. Thus, an integrated pest management strategy, which combines cultural control tactics such as trap cropping, pest monitoring, and targeted application of OMRI-approved insecticides, is the most effective and ecologically sustainable method of managing *M. ochroloma* populations in crucifer production systems.

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