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Murgantia histrionica (Hahn)

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***Murgantia histrionica* (Hahn)**[1]

1834	*Strachia histrionica* Hahn, Wanz. Ins. 2: 116, pl. 65, fig. 196 (Mexico).
1835	*Cimex histrionicus*: Burmeister, Handb. Ent., 2: 368.
1853	*Eurydema histrionica*: Herrich-Schaeffer, Wanz. Ins. 9: 93.
1862	*Murgantia histrionica*: Stål, Stett. Ent. Zeit. 23 (1–3): 106.
1868	*Strachia histrionicha* (sic): Glover, U. S. Dept. Agr. Rept., p. 71.
1872	*Murgantia histrionica*: Stål, K. Svens., Vet.-Akad. Handl., 10(4): 37.
1903	*Murgantia histrionica* form *nigricans* Cockerell, Bull. S. Cal. Acad. Sci., 2: 85. (Synonymized by Kirkaldy, 1909, Cat. Hem., 1: 106).

CONTENTS

[1] Synonymy adapted from David A. Rider (personal communication).

6.1 Introduction

Murgantia histrionica, the harlequin bug, is an important pest of crucifers. This attractive red to yellow and black species (see **Figure 6.1D**) is a native of Central America and Mexico and, apparently, the oldest invasive stink bug in the continental United States. It first was reported for the United States by Walsh (1866) from specimens collected in Washington Co., Texas, in 1864, a record accepted by several subsequent authors (e.g., Chittenden 1908, 1920; Paddock 1915, 1918; White and Brannon 1939). However, Paddock (1918) noted that the 1864 record was as a pest and that it probably "crossed the border several years previous to 1864." It, then, spread up the Mississippi River Valley and eastward through the remaining Gulf States and up the Atlantic Coast. It reached Missouri and Kansas by 1870 (Riley 1872, 1884), North Carolina by 1867 (Riley 1870; Chittenden 1908, 1920), Tennessee by 1870 (Chittenden 1908, 1920), and Delaware by 1876 (Riley 1884; Chittenden 1908, 1920). Subsequently, it was reported from Virginia and Maryland in 1880, Indiana in 1890, Ohio in 1891 (Chittenden 1908), New Jersey in 1892, and New York in 1894 (Chittenden 1908, 1920). Westward, it was recorded during the same period from Colorado, Arizona, Nevada, and California by Uhler (1876). Today, it ranges in the continental United States from New Hampshire and New York south to Florida and west to Minnesota, South Dakota, Nebraska, and California (Froeschner 1988) and, recently, has been reported from North Dakota (Rider 2012). Thus, in about 50 years, the bug essentially had reached its current distribution. Although it may appear to inhabit much of the southern and northern states, it primarily is a southern species (e.g., Osborn 1894, Hodson and Cook 1960), occurring south of latitude 40° N. (Hodson and Cook 1960). Hodson and Cook (1960) felt that its appearance in Minnesota was due to unusual wind currents; this may also explain its discovery in other northern states (e.g., North Dakota, South Dakota). It now has been introduced into Hawaii (Froeschner 1988).

The migration of *Murgantia histrionica* was monitored closely during the late 1800s and early 1900s because of its proven pest status (e.g., Walsh 1866; Uhler 1876; Smith 1897; Chittenden 1908, 1920; Paddock 1915, 1918; Stoner 1920; Thomas 1915; White and Brannon 1939). As a result, much biological information was published during this time including host plants, life history, descriptions of the immature stages, damage, and control.

6.2 Host Plants

Murgantia histrionica feeds on a wide variety of plants but prefers crucifers (e.g., Brussels sprouts, cabbage, collard, mustard, turnip, rutabaga, radish, bitter cress, broccoli, cauliflower, kale, kohlrabi, peppergrass, shepherd's purse). It also attacks many noncruciferous plants including corn, bean, cotton, potato and others (see McPherson 1982, McPherson and McPherson 2000). In fact, Radcliffe et al. (1991) reported that it can be a minor pest of potatoes.

FIGURE 6.1 (See color insert.) *Murgantia histrionica* immatures, adults, and damage. A, egg cluster; B, second instars; C, fifth instars on cabbage; D, mating pair; E, damage on collards, Painter, Virginia. (Images A, C, and D: courtesy of Thomas P. Kuhar; B: courtesy of Sam E. Droege, USGS, Beltsville, Maryland; and E: courtesy of Anthony S. DiMeglio, Virginia Tech, Blacksburg).

6.3 Life History

The life cycle of *Murgantia histrionica* has been studied by several investigators (e.g., Riley 1872, 1884; Howard 1895; Sanderson 1903; Chittenden 1908, 1920; Smith 1909; Paddock 1915, 1918; Brett and Sullivan 1974). It is multivoltine, with estimates of the number of complete generations ranging from three to eight in the South (Howard 1895; Paddock 1915, 1918; Chittenden 1908, 1920) and two to five in the North (Howard 1895; Sanderson 1903; Chittenden 1908, 1920) with adults overwintering, usually under field litter and debris. However, the bugs can become active during the winter if temperatures are mild (Thomas 1915; Paddock 1915, 1918; White and Brannon 1939) with feeding, copulation, and oviposition possible (Brett and Sullivan 1974). Thus, it is possible to find all stages, including eggs, throughout the winter if temperatures are mild and hardy host plants are present. This activity, combined with overlapping generations during the year, undoubtedly is responsible for the confusion about the number of generations per year. However, it probably is bivoltine in the North and bi- or trivoltine in the South with an additional generation possible under favorable conditions. Recently, relatively speaking, Ludwig and Kok (1998a) reported that this bug is bivoltine with a partial third generation per year in southwestern Virginia, supporting an earlier report by White and Brannon (1939). Mild winter temperatures may play a major role in larger than normal populations the following season (Walker and Anderson 1933, Wallingford et al. 2011). Conversely, exposure to extreme cold temperatures (i.e., lower than 15 °C) can result in very high mortality of bug populations (DiMeglio et al. 2016).

Overwintered individuals emerge during spring, begin feeding and mating shortly thereafter. McClain (1981) found that adults preferred to colonize and oviposit within larger clusters of the host plant, at least with turnips, *Brassica napus* L., and felt that this preference enhanced nymphal survival.

English-Loeb and Collier (1987) examined nonmigratory movement of this bug on *Isomeris arborea* Nuttall in southern California. They examined the importance of age and sex of the bugs and abundance of the capsules and racemes of the host plant to movement of the adults within stands of the plants. They found that males left the release bushes more quickly than females but, subsequently, changed locations at a slower rate and less frequently than females. The authors found no sexual difference in distance moved between recaptures. Also, there was no age effect on time spent on the release bush, distance moved, or frequency of movement. Finally, females spent more time on the release bushes with more capsules and racemes.

This bug has been reared under confined conditions, and the eggs and various instars have been illustrated, photographed, and/or described (McPherson 1982) (see **Figure 6.1A-C**). Paddock (1918) reported that this insect has six instars rather than five as other authors have reported, but he undoubtedly was in error.

Precopulatory and copulatory behavior have been studied in this insect by Lanigan and Barrows (1977). The male approaches the female from the front or rear. If from the rear, he antennates the posterior part of her abdomen before moving to her head. In either the rear or front approach, he eventually begins to antennate her antennae. Subsequently, he moves posteriorly, antennating her side and then the posterior of her abdomen. If she is receptive, she will raise the tip of her abdomen approximately 30° and the male, with aedeagus extended, will rotate 180°, back into her, and insert his aedeagus. If a female is unreceptive during precopulation, she simply will walk away.

Zahn et al. (2008a) provided recent information on the rearing of this bug under controlled conditions and its reproductive behavior. Total developmental time from egg to adult at 26°C and 45% relative humidity was ≈48 days followed by a maturation period of ≈7 days. Females produced several egg masses of 12 eggs in two rows of six, thus agreeing with the reports of many earlier investigators (e.g., Smith 1897; Chittenden 1908, 1920; Smith 1909; White and Brannon 1939; Streams and Pimentel 1963; Brett and Sullivan 1974). They lived about ≈ 41 days, laying egg masses every 3 days. Males lived ≈ 25 days. Detailed information on interactions between virgin and previously mated male and females during courtship was provided.

Helmey-Hartman and Miller (2014) studied mate selection in relation to host availability and phenology. They found that both the natal host plant and the host plant where potential mates were encountered significantly affected mating success. Males and females reared on broccoli were more likely to mate than those reared on mustard, no matter the natal rearing environment or the host plant on which the opposite sex was found. Also, they found females preferred the odors of males that were the same as those the females had encountered during nymphal development. Communication is also aided by use of vibratory signals transmitted through the host plant (Cokl et al. 2004, 2007).

As with other stink bugs, the chemical ecology of *Murgantia histrionica* has been well studied (see Aldrich 1988, Aldrich et al. 1996). Zahn et al. (2008b) reported that mature males apparently produce an aggregation pheromone that is attractive to both males and females. More recently, Weber et al. (2014) showed that the two-component pheromone called murgantiol, (3S,6S,7R,10S)- and

(3S,6S,7R,10R)-10,11-epoxy-1-bisabolen-3-24 ol, is most attractive in the field to adults and nymphs in the naturally-occurring ratio of 1.4:1. Each of the two individual synthetic stereoisomers is highly attractive to male and female adults and nymphs, but they are more attractive in combination and when deployed with a host plant of *M. histrionica*.

Murgantia histrionica produces several warning secretions emitted from either the metathoracic or prothoracic gland when disturbed (Aldrich 1988, Aldrich et al. 1996). It also sequesters glucosinolates from its host plants and uses them in defense (Aliabadi et al. 2002). These black and orange bugs also sequester aglucones of glucosinolates (Aldrich et al. 1996); hence, the aposematic coloration.

This bug is attacked by several insect species. Eggs are attacked by hymenopteran parasitoids, primarily species of *Trissolcus*; nymphs by the assassin bug, *Arilus cristatus* (L.), and the nyssonid wasp *Bicyrtes quadrifasciata* (Say); and adults by the leaf-footed bug *Leptoglossus phyllopus* (L.) (unlikely record). It also is parasitized by the sarcophagid fly *Sarcodexia sternodontis* Townsend and the tachinid fly *Trichopoda pennipes* (F.) and preyed upon by the fire ant, *Solenopsis geminata* (F.) (McPherson 1982).

6.4 Damage

Adults and nymphs feed on the leaves and stems of the plants. If the damage is severe, the plants will wilt and turn brown. Small plants eventually will die; larger plants can survive but their growth may be stunted (White and Brannon 1939). Entire fields, if untreated, can be destroyed (Paddock 1915, 1918; Ludwig and Kok 2001). Although feeding may not kill the plants, it can leave white blotches at the feeding sites, making such plants as collard and kale unmarketable (Wallingford et al. 2011) (**Figures 6.1E and 6.2**).

Historically, prior to the introduction of broad-spectrum synthetic organic insecticides (e.g., dichlorodiphenyltrichloroethane [DDT]), the numbers of these bugs attacking crops seem almost unbelievable. A case in point is the report by Walker and Anderson (1933) of a severe outbreak that occurred in the summer of 1932 near Norfolk, VA. The outbreak was due to a mild winter during 1931–1932 resulting in a large population in the spring. This population reproduced on cruciferous crops in fields that had been abandoned or left standing for kale seeds. The feeding of large numbers of the resulting nymphs and the dry weather in August resulted in the nymphs migrating to new plants, "seriously damaging early fall cabbage and completely killing fields of young kale." They also fed on noncruciferous plants including corn, tomatoes, soybeans, and others. "Over 5,100 nymphs were collection on one corn plant and fully as many more fell to the ground and were not counted. This corn plant was at least a quarter of a mile from

FIGURE 6.2 Feeding injury of *Murgantia histrionica* on collards, Blacksburg, VA. (Courtesy of Anthony S. DiMeglio, Virginia Tech, Blacksburg).

the source of the infestation." "Later, a severe outbreak of the adults occurred. The host plants in some of the abandoned or neglected fields remained green longer than in others. In these fields, large numbers of the nymphs matured before their host plants died. Millions of these adults then flew into surrounding fields of kale, collards, cabbage, Chinese cabbage, broccoli, rutabagas, turnips, mustard, corn, tomatoes, and soy beans, and others collected on trees, shrubs, and grasses, and weeds of various kinds. Many of the jimson weeds, pigweeds, and ragweeds were so heavily loaded with these insects in the infested fields that the plants bent over with their weight, the under sides of the leaves often being completely covered with them. One man collected over five gallons of these bugs from tall weeds and soy beans in a kale field in less than five hours. The adults were flying over several young kale fields examined on different warm days in such great numbers that they appeared like a swarm of bees in flight. These adults completely destroyed a large number of fields of kale, collards, and cabbage, and seriously injured many others. One 40 acre field of young, vigorously growing kale was entirely killed out within three weeks after the adults began flying into it from an abandoned field. These insects were observed flying across a small lake in the face of a strong wind and landing in a field of collards on the other side, completely destroying it in a few days."

As devastating as the attacks by these bugs could be to cruciferous crops, Riley (1870) felt that even these insects had some positive qualities: "It is said that no criminal among the human race is so vile and depraved, that not one single redeeming feature can be discovered in his character. It is just so with this insect. Unlike the great majority of the extensive group (*Scutellera* Family, Order of Half-winged Bugs) to which it belongs, it has no unsavory bedbuggy smell, but on the contrary exhales a faint odor which is rather pleasant than otherwise. We have already referred to the beauty of its coloring. As offsets, therefore, to its greediness and its thievery, we have, first the fact of its being agreeable to the nose, and secondly the fact of its being agreeable to the eye. Are there not certain demons in the garb of angels, occasionally to be met with among the human species, in favor of whom no stronger arguments than the above can possibly be urged?"

6.5 Control

6.5.1 History

The pest status of this bug has changed dramatically over the years. In the late 1800s and early 1900s, it was considered a major pest because the controls available at that time were not sufficient. Control methods were discussed in several outstanding contributions, but only a few will be discussed here. But, note how similar they are to each other, several of which are still used today.[1]

6.5.1.1 B. J. Walsh and C. V. Riley

The earliest control recommendation for this bug was handpicking by Walsh (1866) who stated, "I have as yet, found no way to get clear of them, but to pick them off by hand." However, by 1884, Riley listed several additional methods, all cultural, including "hot water," and "trapping the bugs under turnip or cabbage leaves laid on the ground, between the rows." He also recommended "clean cultivation and burning of weeds and rubbish piles in winter." "We may also insist upon the point mentioned by Mr. Lintner, and often brought up by us in treating of other insects, of the great desirability of destroying, as far as possible, the early broods." "The gardener should keep a constant watch upon his cabbages, and upon the first appearance of the young bugs, should either commence careful handpicking at once or should begin the use of some one of the remedies just mentioned." He noted that "The ordinary poisonous applications have little effect upon this bug." Lastly, he mentioned the use of kerosene in passing, stating "Finally, though we have had no opportunity of testing its value in this particular case, we have little doubt but that the kerosene emulsion will here also prove most satisfactory, as it has been found so effectual against other destructive species of the same sub-order."

[1] See **Chapter 16** for current terminology used in control practices.

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By the end of the 1800s and early 1900s, control practices still were mainly cultural. As will become apparently as we progress through the early 1900s, the three primary control practices for stink bugs were clean culture, trap cropping, and handpicking, the first two of which are still recommended today. Use of insecticides as an effective control was not strongly recommended until the 1940s with the advent of DDT.

6.5.1.2 J. B. Smith

Smith (1897) recommended "clean culture and cleanliness about the farm." However, one should keep "a heap or two of loose rubbish to attract insects seeking winter quarters." Then, during the winter, the sites can be destroyed by burning. If the remaining land is kept as free of weeds as possible, particularly crucifers, then the insects will leave the area when they emerge in spring.

Smith also discussed trap crops, recommending mustard or radishes, with mustard being preferred by the insects. He noted that diluted insecticides had proven to be largely ineffective. In higher concentrations, the insecticides were effective against the bugs but usually also killed the plants. However, this was unimportant if the plants were not important to the farmer (i.e., trap crop). Pure kerosene was effective, but no diluted emulsion was effective. Therefore, insects feeding on mustards or radishes could be collected early in the day by brushing or jarring the plants upon which they were feeding, causing them to fall into pans held beneath them containing a "scum of kerosene." Later in the season when the insects attacked cabbage, even diluted kerosene could not be used because it would be injurious to the plant.

6.5.1.3 F. H. Chittenden

Chittenden (1908; slightly revised, 1920) agreed with much of what Smith (1897) said. He (1908) stated, "The experience of years has shown that in order to obtain the best results in the treatment of the harlequin cabbage bug preventives are necessary, as there is great difficulty in obtaining insecticides with are effective and which do not at the same time injure or kill the plants." He, then, discussed clean cultural methods, trap crops, and hand methods (= handpicking) in detail.

As with Riley (1884), Smith (1897), and others, Chittenden (1908) discussed the use of kerosene as an insecticide as well as whale-oil soap. He stated that "Prof. A. F. Conradi has found that a 10-per-cent kerosene emulsion is effective in killing the nymphs, as is also whale-oil soap, at the rate of 2 pounds to 4 gallons of water. If the insects are sprayed just after they have molted these insecticides almost invariably kill them."

Chittenden (1908) also discussed "other remedies." He noted that "since the harlequin cabbage bug feed exclusively by suction and does not chew its food, the arsenicals, hellebore, and such remedies as are useful against cabbage worms are absolutely valueless against the present species." Pyrethrum was not effective and too expensive. And, "the value of hand torches for insecticidal purposes is extremely limited." However, by 1920, Chittenden had changed his mind. He stated, "The value of the hand torch for the control of this insect has been proved by experimenters in Texas, as well as by the experience of the writer and investigators working under his direction" (see additional discussion of the torch by Thomas [1915]).

Chittenden (1908) discussed natural enemies of *Murgantia histrionica* (not mentioned in the 1920 paper). He listed the hymenopteran egg parasitoids *Trissolcus brochymenae* (Ashmead) (as *Trissolcus murgantiae* Ashmead), *Trissolcus euschisti* (Ashmead) (as *Trissolcus podisi* Ashmead), and *Ooencyrtus johnsoni* (Howard) but noted that *T. euschisti* had parasitized the eggs "artificially." But, he realized the control potential of these wasps. He stated (p. 9), "It is possible that some of the natural enemies of this species, especially southern egg parasites, might be utilized in its control; i.e., by shipping parasitized eggs from localities where they are abundant to northern regions in which do not occur."

6.5.1.4 W. A. Thomas

Thomas (1915) discussed cultural control of this bug under three primary practices: (1) remedial measures (= clean culture), (2) trap crops, and (3) burning.

6.5.1.4.1 Remedial Measures

Thomas recommended destroying winter quarters and winter food plants. First, the area around the garden should be cleaned up in late fall or early winter so that no grass or other rubbish is available for winter protection. Never plant young collard or cabbage plants intended for late spring or summer near old infested plants if this can be avoided.

6.5.1.4.2 Trap Crops

Thomas recommended planting several rows of early radish, kale, turnips, mustard, or rape at intervals in the field or garden. These plants are preferred by the bugs over cabbage and should be destroyed by spraying thoroughly with kerosene or a 25% emulsion "of this material" just before the cabbage begins "to form for heading."

6.5.1.4.3 Burning

Burning was recommended for control of this bug on cabbage, collards, and kolhrabi during late summer on small plots such as gardens. Two good torches are necessary about 18 inches long made of fat pine, rags, or cotton wrapped on a stick secured with wire and saturated with kerosene. The torches are lit and brought together just below the bottom leaves for no more than 1–2 seconds. The bugs either will be destroyed by the flame or burned enough that they can no longer injure the plants. Burning should be conducted only at night so that the plants will be able to "cool off and recover before the hot sun comes out (the) next day."

6.5.1.5 F. B. Paddock

Paddock (1915, 1918) divided his control recommendations into two categories: (1) preventive measures and (2) remedial measures, and in 1918 into (1) artificial control, (2) remedial measures, and (3) natural control. The 1918 publication is, by far, the most comprehensive treatment of *Murgantia histrionica* in the older literature, although Paddock did erroneously claim that the bug had six instars rather than five.

6.5.1.5.1 Artificial Control

Here, Paddock (1918) discussed "fall destruction," "winter treatment," "spring treatment," "clean culture," and "trap crops." Fall destruction involved killing the bugs by handpicking, spraying, or burning as they concentrated in and around the remains of crops and weeds in preparation for overwintering. Winter treatment involved destroying excess plant growth in and around the field, including the remains of the last crop, by plowing under or burning, thereby destroying the overwintering sites of the bugs. Spring treatment involved destroying the bugs as they are leaving their overwintering sites but before they could reproduce. Clean culture emphasized destroying common weeds, particularly in the spring, upon which the bugs reproduce. This applied not only to the fields in which cabbage was to be grown but to the areas around the fields. Trap crops were those that were planted and were attractive to the pests before and after the main crop. Mustard was, perhaps, the best trap crop for this bug, but turnip, kale, or cabbage also could be used. These crops should be planted in the spring when they are attractive to the insects (i.e., from the time they leave overwintering sites until after oviposition). When populations build up, the trap crops could be destroyed by "spraying with pure kerosene, burning, or destroying the trap crop." In the fall, the trap crop should be planted at a time when they it is attractive because the main crop has been harvested, but the insects have not entered overwinter sites.

6.5.1.5.2 Remedial Measures

Here, Paddock (1918) included "hand picking," and "spraying." He noted that if the preventive measures (i.e., artificial control) had been followed carefully, the number of bugs present in the summer should be noticeably reduced. However, because some bugs would be missed, handpicking would probably be the most satisfactory method of control at this point. Although the process might appear expensive and tedious, it could be effective. Spraying was not particularly satisfactory. Any material that he was aware of that could kill the bugs also killed the plants. Kerosene was the most used material for killing the bugs when used in the undiluted state but, of course, also killed the plants. Therefore, it was best used against the bugs when they were on trap crops or crop residues. He also noted that a mixture of nicotine sulfate (40%); fish oil soap, and water was reported to kill 65–75% of the nymphs and 45–50% of the adults. Finally, Paddock stated that arsenical sprays such as Paris green, London purple, and arsenate of lead could not control this bug because it is a sucking insect. Contact sprays must be used, which meant that if the insects were not hit by the material, the bugs would not be injured. Finally, he, as well as some other investigators (e.g., Thomas 1915) stated that the plumber's torch could be effective in destroying these bugs on trap crops or trap remnants. "Under these conditions such treatment may be advisable, but the use of the torch is somewhat limited."

6.5.1.5.3 Natural Control

Under natural control, Paddock (1918) discussed the effects of weather on the survival of *Murgantia histrionica*. He stated that adults could survive cold much better than nymphs and, therefore, only adults were able to successfully overwinter (p. 52). In addition, excessive rainfall kills both the nymphs and adults.

Paddock (1918) saw no evidence of parasitoids for any stages of the bug during the 3 years of the study. However, "In 1892 Morgan found a parasite of the egg of the harlequin bug to be very common in Louisiana and Mississippi, and this was determined as *Trissoleus* [sic] *murgantiae* Ashm." (*Trissolcus murgantiae*; current name, *Trissolcus brochymenae*). "Morgan also records the parasite, *T. podisi* (current name, *Trissolcus euschisti*) reared from the eggs of the harlequin bug." Paddock reported the fire ant, *Solenopsis geminata*, carrying off nymphs of this bug and the leaffooted bug, *Leptoglossus phyllopus* (as *phyclopus*) (L.), destroying the adults.

6.5.1.6 B. B. Fulton

6.5.1.6.1 Soap Solutions as an Insecticide

Fulton (1930) reported on the use of soap solutions as an insecticide. He noted that soap killed the bugs "by penetrating deeply into the tracheal system through part or all of the spiracles." The spiracles are equipped with closing devices, which are better developed in adults than nymphs. Therefore, the soap can enter the tracheal system more easily in nymphs than in adults resulting in higher mortality in nymphs. Also, he found that "the efficiency of soap solution is indirectly proportional to the rate of evaporation."

6.5.1.7 J. G. Walker and L. D. Anderson

6.5.1.7.1 Contact Insecticides

Walker and Anderson (1933) reported on a severe outbreak of *Murgantia histrionica* during the summer of 1932 near Norfolk, VA, and included the results of tests of various materials in the control of this pest during this time. Among the materials tested was the 2% soap solution recommended by Fulton (1930). As Fulton had mentioned earlier, they found the adults more difficult to control than nymphs. Because the ideal conditions needed for satisfactory control, including low temperature, high humidity, and no wind, were seldom present, they tested a large series of contact sprays and wetting agents in an insectary; those showing promise then were tested in the field. The best control was with sprays containing rotenone (contained in a product known as Serrid, a derris extract) in combination with a 1% soap solution. In general, they found that nicotine, pyrethrum, and oil emulsion sprays were not effective except at high concentrations. They later reported (1939) that based on subsequent tests, thoroughly spraying infested plants with a "mixture containing 4 pounds of derris or cubé powder (rotenone content of 5 or 6%) to 50 gallons of water" plus a good wetting agent gave good control as did the concentrated derris extract plus soap they previous had recommended in 1933.

6.5.1.7.2 Natural Control

Walker and Anderson (1933) noted that swallows were observed feeding on the adults of this bug. Also, 35–55% of the eggs collected during August and September had been parasitized by *Ooencyrtus johnsoni*.

6.5.1.8 W. H. White and L. W. Brannon

The last paper we have selected for our brief survey of the early control practices for *Murgantia histrionica* is that of White and Brannon (1939). These authors discussed "Methods of Control," in which they began with the following statement, "For the best results in the treatment of the harlequin bug, preventive measures are necessary, as this insect is exceedingly difficult to combat after it has become numerous on its host plants." Following, they divided these measures into cultural methods and contact insecticides and included information on natural enemies.

6.5.1.8.1 Cultural Methods

Under cultural methods, they discussed clean culture, trap crops, handpicking, and the hand torch. These methods, by now, were standard procedure, including the use of a hand torch.

6.5.1.8.2 Contact Insecticides

Under contact insecticides, they repeated what earlier investigators has said about the difficulty in killing this bug with these insecticides because these chemicals had to come in contact with sucking insects to be effective. This was difficult because "the plants upon which the insects feed usually attain such a dense growth that it is practically impossible to reach the insects on all parts of the plant." They noted that several insecticides had been tested and that derris extract spray and derris dust was recommended for control of this bug. They also noted that more recent work by Walker and Anderson (1939) had shown that "derris or cube root powder (containing 5 or 6 percent of rotenone and used at the rate of 4 pounds in 50 gallons of water with wetting agent) is effective for control of the harlequin bug." In conclusion, they stated "It should be borne in mind that only those insects actually hit by the insecticide are killed. Thoroughness of application is therefore of prime importance."

6.5.1.8.3 Natural Enemies

White and Brannon (1939) discussed natural enemies of *Murgantia histrionica* but noted that the bug "is remarkably free from parasites and predacious insects. No internal parasite of the insect has been recorded." They stated that there were three known egg parasites, namely *Trissolcus brochymenae* (as *Trissolcus murgantiae*), *Trissolcus euschisti* (as *Trissolcus podisi*), and *Ooencyrtus johnsoni*, "but, so far as has been observed, they have never become abundant enough throughout the infested territory to serve as a natural means of control of this pest." However, they noted that *O. johnsoni* "appeared to be of considerable value in eastern Virginia during the unusually severe harlequin-bug outbreak of 1932." "During the latter part of August, approximately 50 percent of the eggs in some fields were parasitized," suggesting that "under favorable conditions this parasite may prove to be highly beneficial in some parts of the South." They also noted that "the wheel bug [*Arilus cristatus* (L.)], has been recorded as feeding on young harlequin-bug nymphs, and another, the leaf-foot bug [*Leptoglossus phyllopus* (L.)], is recorded as destroying the adult, but these are of slight importance as a means of natural control."

6.5.2 Age of Synthetic Insecticides

An "Age of Pesticides" began in the 1940s with Paul Müller's discovery of the insecticidal properties of DDT (Metcalf 1980) and, since that time, chemical control has persisted as the predominant tactic used for pest management in most agricultural systems including control of *Murgantia histrionica* on brassica vegetables. However, there have been major shifts in the classes of insecticides used over the years.

6.5.2.1 Chlorinated Hydrocarbons

In the 1940s, effective control of *Murgantia histrionica* was achieved with dust applications of DDT or other chlorinated hydrocarbons including chlorinated camphene (toxaphene), chlordane, and benzene hexachloride (BHC) (Brooks and Anderson 1947, Gaines and Deane 1948). The latter, in particular, was considered very toxic to this bug even at concentrations as low as 0.5% active γ isomer; chlordane and toxaphene were more toxic than DDT (Gaines and Dean 1948). Later, lindane (almost pure γ BHC) also would be shown to be highly efficacious on this bug (Brett and Campbell 1956) as would endosulfan and endrin (Hofmaster 1959). However, most agricultural uses of chlorinated hydrocarbon insecticides eventually would be canceled because of the persistence of these compounds in the environment, resistance that developed in several insect pests, and biomagnification of the toxicants in some wildlife food chains (Ware and Whitacre 2004). Only one chlorinated hydrocarbon insecticide, endosulfan, would maintain federal registration on vegetable crops in the United States into the 21st Century, but as of 2015, this chemical no longer is registered for use in the United States and many other countries.

6.5.2.2 Organophosphates and Carbamates

Carbamates and organophosphates gradually would replace the chlorinated hydrocarbons in vegetable production in the United States in the 1960s and 1970s. These cholinesterase-inhibiting insecticides have broad-spectrum activity against many insect pests, and *Murgantia histrionica* is no exception. Most of the compounds in these two insecticide classes including parathion, carbaryl, acephate, and diazinon, and others provided effective control of this bug (Hofmaster 1959, Rogers and Howell 1972). However, many of the organophosphates later were determined to be too toxic for safe use on vegetables and either were not registered for use or later had registrations removed particularly after full enactment of the United States Environmental Protection Agency's Food Quality Protection Act of 1996.

6.5.2.3 Pyrethroids

Throughout the 1970s and into the 1990s, a large number of synthetic pyrethroid insecticides would be developed and registered for use on vegetables throughout the world. These insecticides, which included permethrin, bifenthrin, lambda-cyhalothrin, zeta-cypermethrin, cyfluthrin, and many others were shown to be highly efficacious at extremely low application rates for control of *Murgantia histrionica* (Edelson 2004a, 2004b; Edelson and Mackey 2006a). Because of their low cost and high efficacy, pyrethroids have been the predominant insecticide class used for control of this bug and other stink bugs for the past few decades. However, because these broad-spectrum insecticides also are detrimental to important natural enemies in the crucifer crop agroecosystem (Xu et al. 2001, 2004; Cordero et al. 2007), and because of the development of insecticide resistance to them in other pest species including diamondback moth, *Plutella xylostella* (L.) (Shelton et al. 1993), green peach aphid, *Myzus persicae* (Sulzer) (Castañeda et al. 2011) and beet armyworm, *Spodoptera exigua* (Hübner) (Brewer and Trumble 1994), the use of pyrethroids for control of this bug can be problematic.

6.5.2.4 Neonicotinoids

The neonicotinoids, which target the nicotinic acetylcholine receptors in insects, were introduced in the 1990s and have become the most widely used insecticides in the world. Virtually all of the registered neonicotinoids including acetamiprid, clothianidin, dinotefuran, imidacloprid, thiacloprid, and thiamethoxam have been shown to be effective at controlling this bug when used as a foliar spray (Edelson 2004a, Edelson and Mackey 2005a,b,c, 2006b; Walgenbach and Schoof 2005). Moreover, because neonicotinoids are water soluble and can be taken up by plants through the roots and translocated through the xylem vessels to plant tissues, exposing herbivores to the toxin only when they feed (Sur and Stork 2003, Tomizawa and Casida 2005), they offer a potentially less disruptive alternative for controlling hemipteran insects. Wallingford et al. (2012) evaluated soil-applied neonicotinoids and showed that labeled rates of either imidacloprid, thiamethoxam, clothianidin, or dinotefuran provided significant control of this bug for at least two weeks after application.

6.5.2.5 Other Insecticides

Over the past couple of decades, a wide range of other insecticides (often with reduced risks to non-target organisms) has been tested for activity on *Murgantia histrionica*. Edelson and Mackey (2006b) showed that the hemipteran feeding inhibitors pymetrozine and flonicamid were not active on this bug.

These same authors also showed that emamectin benzoate, spinosad, azadirachtins, and the insect growth regulator, methoxyfenozide also were not or only slightly effective against this bug (Edelson and Mackey 2006a). Among the new diamide class of insecticides, flubendiamide and chlorantraniliprole are not effective, but cyantraniliprole and the experimental compound cyclaniliprole have shown efficacy against this bug (Kuhar and Doughty 2009, T. Kuhar, unpublished data).

For organic growers, there are no insecticides that are highly efficacious against *Murgantia histrionica*. However, suppression of this bug, especially nymphs, can be achieved with various compounds including spinosad, pyrethrins, sabadilla, and azadirachtins (Overall et al. 2007). Overall et al. (2008) evaluated the toxicity levels of organic insecticides on this bug and showed that spinosad was about 10-fold more toxic to fourth instars than pyrethrins, which were about 10-fold more toxic than azadirachtins.

6.6 Current Management Techniques

In the southern United States, in particular, populations of *Murgantia histrionica* still can reach damaging levels if proper management tactics are not used. As was demonstrated in the early 1930s, the presence of a brassica crop remaining in fields throughout the winter, coupled with warm winter, can result in serious outbreaks of this pest (Walker and Anderson 1933). Thus, as was recommended a century ago by Thomas (1915), removing or destroying overwintering crop residue is a critical first step to reducing the overwintering populations of bugs that will invade crops early the next spring.

Trap cropping is another age-old preventative control strategy that is still used today. It was recognized early as a control tactic of this bug, using radish (*Raphanus sativus* L.), turnips (*Brassica rapa* L.), mustard (*B. juncea* L.), rapeseed (*B. napus* L.), or kale (*B. oleracea* L. *acephala* group) to draw pressure away from cabbage (*B. oleracea* L. *capitata* group) (Thomas 1915, Chittenden 1920, Fulton 1930). Ludwig and Kok (1998b) demonstrated that a small early planting of a crop such as broccoli could aggregate the bugs and keep them off of the later-planted main crop. Destruction of the bugs is necessary to prevent dispersal from the trap crop. Because these bugs prefer certain plant species such as mustard, turnip, and Chinese cabbage over crops such as cabbage, cauliflower, broccoli, collards, and radish (Sullivan and Brett 1974), there is great potential for utilizing multiple cropping or intercropping approaches as a trap crop management strategy, particularly in the interest of reducing chemical sprays. Bender et al. (1999) found that intercropping cabbage (*B. oleracea*) and Indian mustard (*B. juncea*) reduced the need for two insecticide sprays in a heavy infestation of *Murgantia histrionica*. More recently, using field cage choice tests and small plot field experiments, Wallingford et al. (2013) determined that mustard (*B. juncea* 'Southern Giant Curled') was the most consistently selected host plant by this bug over collard in choice tests and, when planted as a double row border, was found to be an effective trap crop for reducing feeding injury on collard. Augmentation of the mustard trap crop with a systemic neonicotinoid insecticide provided no added control of this bug for the 10-week duration of the experiment.

Nonetheless, insecticides remain the most widely used rescue control strategy when these bugs reach damaging levels. Pyrethroids often are used because they are cheap and effective. However, because they are broad-spectrum toxicants, pyrethroids can be quite disruptive to natural enemies that are essential to integrated pest management programs for other pests such as lepidopteran larvae and aphids.

6.7 Why Has *Murgantia histrionica* Been So Successful?

At the time of the invasion of this bug into Texas in the early 1860s, control practices were limited. As noted in this chapter, recommendations consisted primarily of various types of cultural control tactics, namely handpicking, clean culture, and trap cropping. Biological control was not considered important although parasites and predators had been reported. Early insecticides largely were ineffective and, often, dangerous to humans or to the crop plants. Therefore, the bugs were able to spread rapidly, but largely were confined to the southern states because of the inability of the adults to survive harsh winters. Although they were able to reach the more northern states, populations often were eliminated by

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subfreezing overwintering temperatures. Thus, the bugs' present and relatively permanent distribution in North America was reached by the early 1900s.

Nonetheless, despite being well established in the southern United States, and having at least three species of native hymenopteran wasps that parasitize the eggs including *Ooencyrtus johnsoni*, *Trissolcus murgantiae* (now *Trissolcus brochymenae*), and *Trissolcus podisi* (now *Trissolcus euschisti*) (White and Brannon 1939, Huffaker 1941, Ludwig and Kok 1998a, Koppel et al. 2009), natural enemies do not provide adequate control of this pest.

6.8 What Does the Future Hold?

Although the bug largely is confined to the southern states, the advent of climate change may allow it to extend its general distribution to regions that historically have not had problems with this pest. In general, the pest seems to be increasing in importance, perhaps because of a switch from broad-spectrum insecticides to more IPM-friendly insecticides for control of lepidopteran pests and aphids. Coupled with this, there has been a rapid increase in organic vegetable acres, which often maintain reservoirs of populations of this bug. Thus, the pest does not appear to be going away anytime soon and, unfortunately, there still is a need for an alternative management strategy for this bug that does not rely solely on the use of insecticides and can be integrated into current management strategies. Perhaps, transgenic (GMO) resistant crops for sucking pests could be future control strategy for this pest, but we are a long way from seeing that, especially in relatively small acreage vegetable crops. In addition, because semiochemicals are so critical to the ecology of this pest (Aldrich et al. 1996), and our understanding of aggregation pheromones and the importance of plant kairomones (Khrimian et al. 2014, Weber et al. 2014) is increasing, perhaps management strategies such as traps and toxic baits can be developed in the future.

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