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Squash Bug (Hemiptera: Coreidae): Biology and Management in Cucurbitaceous Crops

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Abstract

The squash bug, *Anasa tristis* (DeGeer), is an endemic species of the Americas that feeds on plants in the family Cucurbitaceae. The pest is particularly abundant and damaging on plants in the genus *Cucurbita* (i.e., zucchini, summer squash, and pumpkins). Squash bug has become problematic in recent years due to changes in insecticide use strategies by conventional growers, dramatic increases in organic vegetable production, and increasing incidences of cucurbit yellow vine disease, a phloem-clogging bacterial disease transmitted by the bug. A review of insect biology, description of life stages, host plants, damage, and management options for squash bug is presented.

Key words: *Anasa tristis*, cucurbit IPM, Coreidae, squash, pumpkin

Being endemic to North America, the squash bug, *Anasa tristis* (De Geer) (Hemiptera: Coreidae), has a long history as a pest of cucurbits in the United States (Britton 1919, Wadley 1920, Beard 1940). The pest status of squash bug remains considerably high because of changes in cucurbit production and pest management tactics, and because of its association with the bacterial disease cucurbit yellow vine disease (CYVD), which has occurred in several states in the United States in the past decade. This piercing–sucking insect is particularly problematic on *Cucurbita* vegetables like squash and pumpkin, but may attack other cucurbits as well (Bonjour and Fargo 1989; Bonjour et al. 1990, 1991). A discussion of the biology of the squash bug and integrated pest management options in cucurbit crops follows.

Description of Life Stages

Adult

The adult squash bug is typically a brindled grayish brown color 1.4–1.6 cm in length and 0.75 cm wide at the widest part of the abdomen (Beard 1940; Fig. 1). Although it is a member of the family Coreidae, commonly known as leaf footed bugs, *A. tristis* does not have a noticeable thickening of its hind tibia as most coreids do. The adults are darker on their dorsum and lighter gray in color ventrally.

Egg

Eggs are deposited in groups often on the undersides of leaves (Weed and Conradi 1902, Bonjour et al. 1990; Fig. 2). Clutch size can vary from only a few to more than 40 eggs, averaging 18 eggs per mass (Bonjour et al. 1990). As the female lays the eggs, she incorporates an adhesive to adhere each egg in the mass to the surface of the leaf. Individual eggs are oval shaped, around 1.5 mm long and 1.2 mm wide, and begin a pale off-white color that later darkens to a shiny, coppery maroon to brown color (Fig. 3). The egg is larger on one end and does not appear to have any external openings. The pseudo-operculum, visible once eggs have tanned, is an egg structure found throughout the corinae subfamily (Beard 1940, Koerber 1963, Roversi et al. 2014). This structure is reported to aid in gas exchange through micropores in the chorion as well as serving as a specific point of weakness exploited during egg eclosion.

Nymph

The nymph stage has five instars. Immediately following egg hatch, first instars (neonates) are 2–3 mm in length, and light green in color with red legs, head and thorax, which later darkens to black (Weed and Conradi 1902, Capinera, 2001; Fig. 4). Second instars are ∼3 mm long, a darker green color with black appendages. With each successive molt, the nymph's size increases, it becomes lighter gray in color and the end of the abdomen widens into a tear drop shape (Fig 5). The fourth and fifth instars have a more distinct thorax and wing pads and are ∼6.5 mm and 9.5 mm long, respectively (Beard 1940).

Insect Biology

Squash bugs overwinter in the adult stage and emerge from the soil or ground litter in the spring. Cooler spring temperatures may delay emergence of adults (Nechols, 1987). After emergence, overwintered

Fig. 1. Squash bug adult (actual size, 1.5 cm long by 0.75 cm wide).

Fig. 2. Ovipositing squash bug female and eggs.

Fig. 3. Squash bug eggs deposited on the underside of a squash leaf.

Fig. 4. Neonate squash bug nymphs.

Fig. 5. Squash bug nymphs and an adult aggregating on fruit in late summer.

adults immediately seek out cucurbit plants on which to feed and mate. Adults are cryptic and prefer to remain hidden during the day (Nechols, 1987). They also can emit a distinct, unpleasant odor from their repugnatory glands, similar to stink bugs, when disturbed (Moody 1930). Gravid females can lay eggs 7–10 d after their emergence (Nechols 1987). They often prefer to deposit eggs on the undersides of leaves next to leaf veins (Fig. 3).

The squash bug typically completes its entire life cycle in 6–8 wk, and development can be predicted based on heat-unit accumulation. Using a lower and upper temperature threshold of 58°F and

92°F, respectively, degree-day (°F) accumulations required for eggs is 193 DD, nymphs is 554 DD, and a complete generation 747 DD (Fargo and Bonjour 1988). In the southern United States, egg development time is typically 6–15 d, and first to fifth instars last ~3, 9, 8, 7, and 9 d, respectively (Weed and Conradi 1902, Beard 1940, Bonjour and Fargo 1989, Capinera 2001).

Nymphs have a strong disposition toward aggregating (Palumbo et al. 1991), particularly after egg hatch on leaves (Fig. 3) and on fruit following leaf desiccation (Fig. 4). Both adults and nymphs prefer sheltered areas, with a partiality for the base of plants. Squash bug adults can be observed hiding in the center of plants, under large leaves, wilted leaves (Fig. 6), and in the transplant holes of plastic mulch.

Dependent upon location, the squash bug can have one to three broods (Wadley 1920). In coastal Virginia from 2009 to 2012, we observed one to two generations with new adults typically emerging in late July to early August and entering diapause in late September to early October. According to Nechols (1987), an overlap of overwintered adults and adults of the first summer generation can be observed.

Host Plants and Damage

Squash bug can feed on most cucurbit crops (Quaintance 1899, Beard 1935, Metcalf et al. 1962, Nechols 1985, Fargo et al. 1988, Bonjour et al. 1990, Edelson et al. 2002a). However, they strongly prefer summer squash (*Cucurbita pepo*) and pumpkin (*Cucurbita pepo*; *Cucurbita maxima*) for oviposition (Bonjour et al. 1993). Moreover, incidence in the field and survival from egg to adult is significantly higher on squash and pumpkins compared to cucumbers (*Cucumis sativus*) or muskmelons (*Cucumis melo*; Bonjour and Fargo 1989, Cook and Neal 1999). In addition, watermelons (*Citrullus lanatus*) also suffer important economic damage from squash bug in Texas and Oklahoma (Riley et al. 1998, Edelson et al. 2002b). In field surveys conducted in community gardens throughout Virginia in 2014 and 2015, we observed significantly more squash bug egg masses on zucchini squash compared with other squash varieties, gourds, or other cucurbit species (T. K. and J. W., unpublished data).

Squash bug is a piercing sucking feeder. During the feeding process, adults and nymphs pierce through the leaf with their stylets. Although it was once believed that a salivary toxin was injected during the feeding process (Surface 1902), the resulting leaf injury is chiefly explained by physiological dysfunctions of the leaf as well as disruption of the xylem (Neal 1993). Neal (1993) disputes that salivary fluids have no toxic effects but the injection of these fluids interrupt the flow of water and some nutrients in the xylem and can cause its collapse along with the general vessel disruptions resulting from the feeding. The subsequent wilting of the leaf tissue was historically referred to as "Anasa wilt" (Robinson and Richards 1931, Knowlton 1935, Hoerner 1938). Prolonged feeding by squash bugs will lead to this condition followed by leaf necrosis, fruit rot, and plant death (Fargo et al. 1988, Neal 1993, Capinera 2001). Plants colonized by squash bug nymphs in the 2–4 leaf stage may quickly succumb to feeding (Woodson and Fargo 1991). In addition, feeding injury occurring at flowering and fruit set can significantly impact fruit production. Palumbo et al. (1993) observed reductions in yield of over 50% in untreated summer squash plots that were invaded at flowering and fruit set by squash bug. In a laboratory and greenhouse study, Woodson and Fargo (1991) reported a decrease in vegetative growth rate and ovulate flower productivity in summer squash with increasing numbers of squash bug. In watermelon, seedlings also experienced more frequent mortality with increasing squash bug density (Edelson et al. 2002a).

Fig. 6. Squash bug nymphs aggregating on a leaf exhibiting necrosis caused by feeding injury.

Squash bug feeding on fruit (Fig. 5) creates blemishes and sunken areas most likely resulting from the phenomenon previously described as "Anasa wilt" as well as the likely introduction of pathogens during feeding. The piercing of the fruit tissue by the squash bug certainly adds to the potential for diseases by creating an opportunistic gateway for the common squash fruit pathogens described by Ramsey et al. (1938) as anthracnose, choanephora fruit rot, gray mold rot, and rhizopus soft rot. Subsequently, a greater incidence of fruit rot in storage can be observed as a result.

In addition, squash bug can transmit the phloem-colonizing bacterium *Serratia marcescens* Bizio, which can cause significant yield losses due to CYVD (Bruton et al. 2003, Pair et al. 2004). This disease is a recent challenge for cucurbit growers, particularly since coreids or hemipterans in general are not widely known as disease-vectoring insects. According to Pair et al. (2004), adult squash bugs harbor the bacterium during winter diapause and can infect plants the following spring upon emergence. CYVD can inflict heavy losses to watermelon, pumpkin, cantaloupe, and squash (Bruton et al. 2003). Occurrences of the disease have been observed most often in Oklahoma and Texas (Pair et al. 2004), but more recently in several other midwestern and eastern states (Wayadande et al. 2005, Gugino et al. 2014).

Management of the Squash Bug

Chemical control is generally the most commonly used strategy by conventional growers, and there are a number of insecticides that are efficacious and registered for use. However, for organic production, squash bug is especially challenging to control because of the lack of efficacious approved insecticides and because the habitat on organic farms (i.e., weedy ground cover, straw mulch, etc.) is conducive to squash bug infestations (Cranshaw et al. 2001). Snyder (2015) reviews strategies for managing squash bugs in organic farming systems, and several of these tactics are described below.

Cultural Control

Before the advent of synthetic insecticides, a number of cultural practices were recommended to reduce squash bug populations, including proper field sanitation to reduce debris and old squash plants serving as shelters for squash bug, crop rotation to eliminate host plants on the farm, and early planting to reduce infestation levels (Weed and Conradi 1902, Wadley 1920, Woodson and Fargo 1992). Each of these strategies has merit and can contribute to the integrated pest management of this pest.

Because there is considerable variation among species and cultivars of squash with respect to susceptibility to damage and ability to support the development of squash bugs (Bonjour and Fargo 1989, Cook and Neal 1999, Capinera 2001), varietal selection can impact squash bug infestation levels. In Virginia, we consistently observed the highest densities of squash bug on zucchini (personal observation, Doughty 2015). Winter squash such as green striped cushaws and Waltham butternut are not as attractive to squash bug and the bug does not survive well on them compared to summer squash (Vogt and Nechols 1993). Other varieties of *C. moschata* (sweet cheese), *C. pepo* (royal acorn), and *C. maxima* (pink banana) also demonstrated resistance or less susceptibility to damage by the squash bug (Novero et al. 1962). However, during field observations in a commercial organic farm in Virginia in 2009 and 2010, squash bug infestations and damage were quite extensive on Waltham butternut squash (*C. moschata)*. Thus, there may be local adaptations and preferences among squash bug populations for certain cucurbit plants, or the availability of more preferred host plants may impact pest densities on a specific crop.

Eliminating weeds and straw or organic mulch, which provide hiding places for the insect, may reduce infestation levels and damage (Cranshaw et al. 2001). As squash bugs also have been observed quite frequently hiding in the planting holes, minimizing the use of plastic mulch also may reduce infestations. However, because there are many benefits of using both organic and plastic mulches (i.e., soil moisture retention, weed control, cleaner fruit at harvest, etc), it is often not a compatible pest management tactic to eliminate them from cucurbit production systems.

Alternatively, because squash bugs have an affinity to seek shelter, the practice of placing wooden boards between the rows of crops can be used to trap bugs below where they may be crushed by stepping on the board (Weed and Conradi 1902, Smith 1910). We evaluated this strategy in summer squash in Virginia using 0.91- by 0.61-m sheets of plywood boards placed at opposite ends of squash rows. Insects were consistently found using the boards for harborage (Fig. 7), and there were numerically fewer adults and nymphs observed on those squash plots compared to plots with no boards (H. D., unpublished data).

Polyester floating row covers offered some respite from early infestations by the squash bug in summer squash but populations quickly rebounded following removal of the covers (Cartwright et al. 1990). In coastal Virginia, the use of row covers (Covertan 19) from the time of transplanting to first flowering (11 d) led to a reduction in squash bug adults and egg masses on plants (H. D., unpublished data). However, cucurbits need to be pollinated and row covers are only practical for a short time. Moreover, we observed that the use of row covers actually had a negative impact on squash yield despite removal at flowering. Row covers appeared to affect the overall health of the squash plants (wilted, shrunken appearances) under hot and humid conditions (H. D., unpublished data). In previous studies, floating row covers have been shown to increase humidity and temperature in zucchini and lettuce crops (Qureshi et al. 2007, Rekika et al. 2008a), leading to some negative effects in radish crops with reduced foliage health (Rekika et al. 2008b). Other effects have shown increased vegetative growth and reduced fruit production (Gaye et al. 1991).

As the squash bug has a preference for squash or pumpkin over other cucurbits (Bonjour et al. 1993), planting these as a trap crop for cantaloupes and cucumbers can be effective (Chittenden 1899, Bonjour et al. 1990). Treating the trap crop with a systemic insecticide has been shown to increase the efficacy of this strategy (Pair 1997, Wallingford et al. 2013).

Fig. 7. Squash bug adults and nymphs found sheltering under plywood boards placed between rows in a commercial squash field in Virginia.

Use of interplanting or companion planting with repellent plants is a strategy that needs further investigation. In a preliminary on-farm study in Virginia, we found fewer squash bug egg masses on squash plants that were interplanted with nasturtium transplants (H. D., unpublished data). Essential oils of clove, spearmint, lemongrass, rosemary, and geranium have been shown to act as a repellent to other insects including stink bugs (Zhang et al. 2014), and should perhaps be investigated for their use in squash bug control including a push-pull control strategy with an attractive trap crop.

Biological Control

Squash bug eggs, nymphs, and adults are attacked by various generalist predators such as spiders, carabids, staphilinids, geocorids, and coccinellids, all of which contribute to lowering population levels (Rondon et al. 2003, Decker and Yeargan 2008). Predation of squash bugs may be increased by employing farmscaping strategies that conserve predators (Snyder 2015). However, the most important natural enemies of squash bug are parasitoids.

The orange-bodied tachinid fly, *Trichopoda pennipes* F. (Diptera: Tachinidae; Fig. 8), deposits its eggs on late instar nymphs and adults of squash bug as well as other coreids and pentatomids (Fig. 9). The larva of *T. pennipes* will subsequently emerge and burrow into the body of its host, fastening itself onto the squash bug's tracheal trunk to ensure appropriate levels of oxygen (Beard 1940). Upon termination of its larval development, it will emerge through the posterior of its host to undergo pupation in the soil (Worthley 1925, Shahjahan 1968). Development from egg to adult averages 18 d (Shahjahan 1968). One or more eggs may be deposited by *T. pennipes* onto the body of its host (Beard 1940, Shahjahan, 1968, McPherson et al. 1982), but only one larva will undergo development in the squash bug (Beard 1940). *T. pennipes* will generally undergo two generations, emerging from squash bug soon after termination of diapause, developing to deposit eggs on new hosts in July (Worthley 1925). The following generation will develop mid to late summer to parasitize second generation squash bug in August–September (Worthley 1925). Beard (1940) reported that 20% of the squash bugs that were collected in Connecticut in late summer were parasitized by *T. pennipes*. In coastal Virginia in 2009, we recorded an average parasitism rate of 12% (20% in organic fields, 8% in conventional fields).

Egg parasitism plays a major role in the biological control of squash bug. Recognized egg parasitoids of this pest include *Gryon pennsylvanicum* (Ashmead) (syn. *Hadronotus ajax* Girault) (Hymenoptera:

Fig. 8. *Trichopoda pennipes* adult. Image courtesy of Russ Ottens, University of Georgia, Bugwood.org

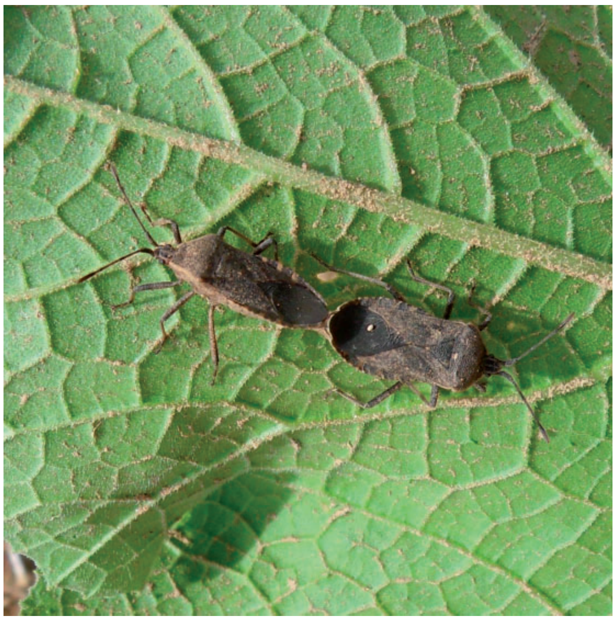

Fig. 9. Mating squash bugs revealing an egg of *Trichopoda pennipes* on the back of the bug to the right.

Platygastridae [formerly Scelionidae]), *Ooencyrtus anasae* (Ashmead) (Hymenoptera: Encyrtidae), and *Anastatus* sp. (Hymenoptera: Eupelmidae) (Schell 1944; Nechols et al. 1989). Squash bug egg parasitism levels in Florida were reported to be about 30% (Capinera 2001), but parasitism rates can be higher in individual fields particularly later in the season (Nechols et al.1989, Olson et al. 1996). Based on a collection of over 80 egg masses from two farms in southwest Virginia in 2013, we found that 66% of squash bug eggs were parasitized predominately by *G. pennslyvanicum* (Fig. 10) (J. W. and T. K., unpublished data). As this egg parasitoid species has been shown to readily parasitize and develop on other coreids, it has been released into Europe for control of *Leptoglossus occidentalis* Heidemann (Heteroptera: Coreidae) (Koerber 1963, Peverieri et al. 2012).

Entomopathogenic nematodes have also been investigated as biological control agents of squash bug adults. In laboratory studies, Wu (1988) indicated the potential of *Steinernema carpocapsae* Weiser (Nematoda: Steinernematidae), as it caused death to adult squash bugs by its symbiotic bacterium. Furthermore, nymphs hatched from egg masses laid by infected female squash bug before their death, were also infective (Wu 1988).

Fig. 10. *Gryon pennsylvanicum*, a major egg parasitoid of squash bug and other coreids.

Sampling and Economic Thresholds

Inspecting plants to determine squash bug density should be done prior to making the decision to apply insecticides. Sampling plans for scouting in summer squash and watermelons have been developed. The recommended economic threshold in summer squash is one squash bug adult per plant (Palumbo et al. 1991) or one egg mass per plant (Doughty et al. 2014). In watermelons, the economic threshold is one to two squash bug adults per plant (Dogramaci et al. 2006). A fixed precision sampling plan of 64 plants in summer squash (Palumbo et al. 1991) and 54 plants in watermelons (Dogramaci et al. 2006) is suggested to determine the density of one squash bug adult per plant. Squash bug populations are indeed more heavily aggregated in summer squash than in watermelons therefore requiring a higher number of samples (Dogramaci et al. 2006). Fewer plants are required to determine egg mass density. Palumbo et al. (1991) suggested that 38 plants needed examining to determine the threshold of one egg mass per plant. In regions where CYVD is prevalent, such as Texas and Oklahoma, preventative control is recommended rather than the use of sampling and thresholds.

Chemical Control

Chemical control is the most widely used strategy to prevent crop damage from squash bug. Insecticides are often applied to target the nymphal stage, which is easier to kill than adults. Effective control of squash bug nymphs can be achieved with foliar applications of pyrethroids such as bifenthrin, cypermethrin, fenpropathrin, lambda-cyhalothrin, and others, as well as neonicotinoids such as thiamethoxam, imidacloprid, clothianidin, and acetamiprid, and organophosphates such as disulfoton and metasystox-R (Edelson et al. 2002b, 2003; Eiben et al. 2004; McLeod et al. 2003; Kuhar et al. 2005; Abney et al. 2011). However, foliar applications of pyrethroids, which are the most commonly used foliar insecticides by growers because of their low cost, have deleterious effects on natural enemy populations and can cause outbreaks of secondary pests such as melon aphids, *Aphis gossypii* Glover (Kuhar et al. 2005). All of the aforementioned foliar insecticides with the exception of acetamiprid are also highly toxic to pollinators (Johansen, 1977, Smith and Stratton 1986, Iwasa et al. 2004, Desneux et al. 2007, Laurino et al. 2011, Van der Sluijs et al. 2013). Thus, alternatives to their use have been explored.

One option is changing application method. Because of their ability to be taken up by the roots from the soil as systemic insecticides and transported to the foliage, neonicotinoids can be applied to cucurbits quite effectively, efficiently, and economically via drip chemigation (Ghidiu et al. 2012). Edelson and Otieno (2003) evaluated the efficacy of imidacloprid, thiamethoxam, as well as the carbamate, carbofuran applied as a soil drench, and showed that all three insecticides were efficacious on squash bug. However, the efficacy of soil-applied neonicotinoids will decrease over time and may not provide control over the growing season, particularly when needed for squash bug later in the crop cycle (Kuhar et al. 2005).

Other more IPM-friendly insecticides have been evaluated for squash bug control. Novaluron, a benzoylphenyl urea insecticide, has demonstrated efficacy against squash bug nymphs (Eiben et al. 2004). As an insect growth regulator, it offers an alternative to broad-spectrum insecticides with a better fit in an IPM program. The spinosyn, spinosad, has also been evaluated, but shown to be not very effective against squash bug (Edelson et al. 2002). Other reduced-risk insecticides that may show promise for control of this pest in the future include sulfoxaflor, flonicamid, and cyclaniliprole (Aigner et al. 2015, Wilson et al. 2015). Additional field efficacy tests are needed to confirm results from laboratory bioassays.

Organic producers have fewer chemical control options. Applications of pyrethrins and azadirachtins can suppress squash bug nymphal densities. However, under heavy pest pressure, these insecticides have not provided effective or consistent control in the field.

Concluding Remarks

Squash bug remains an important economic pest of cucurbit crops in the United States, particularly in areas where CYVD occurs. For conventional growers today, a number of insecticides, particularly pyrethroids and neonicotinoids, are registered that provide effective control of the pest. However, these insecticides pose risks to nontarget organisms such as natural enemies and pollinators and are not the most IPM-compatible control options. A combination of preventative and curative control measures discussed above provide a number of options to effectively manage this pest using an IPM approach. A greater focus on scouting for the pest before applying pesticides, awareness and conservation of natural enemies in the agro-ecosystem, and use of more selective narrow-spectrum insecticides, if and when they are needed, would provide a more sustainable approach to managing this pest.

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