Effect of Prey Species on Plant Feeding Behavior by the Big-Eyed Bug, *Geocoris punctipes* (Say) (Heteroptera: Geocoridae), on Cotton

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Environ. Entomol. 32(6): 1399–1403 (2003)

ABSTRACT The effect of prey species on plant feeding behavior by *Geocoris punctipes* (Say) females was determined by observing prey and plant feeding behavior on cotton plants for three prey treatments: 1) corn earworm, *Helicoverpa zea* (Boddie), eggs, 2) *H. zea* first instars, and 3) cotton aphid, *Aphis gossypii* Glover, adults. Feeding behavior of individual *G. punctipes* females was observed in the laboratory using caged cotton terminals with prey on the leaves. *A. gossypii* adults were less acceptable to *G. punctipes* females as prey than *H. zea* eggs and first instars. Female *G. punctipes* fed much less on cotton plants than prey when more acceptable prey, *H. zea* eggs and first instars, were available but exhibited no feeding preference for the cotton plant versus prey when less acceptable prey, *A. gossypii* adults, were available. Nevertheless, because *G. punctipes* females fed on cotton plants regardless of acceptability of prey even in the presence of abundant prey, we conclude that plant feeding is an integral part of the feeding behavior of *G. punctipes* in cotton. Conservation of *G. punctipes* by reducing applications of insecticides that are toxic to these predators when they feed on insecticide-treated foliage or by providing nutritionally good plant resources could increase their effectiveness as natural enemies of *H. zea* and other pests in cotton.

KEY WORDS *Geocoris punctipes*, *Helicoverpa zea*, *Aphis gossypii*, cotton, plant feeding behavior

THE CORN EARWORM, *Helicoverpa zea* (Boddie), and tobacco budworm, *Heliothis virescens* (F.), are two of the most economically important pests of cotton, *Gossypium hirsutum* L., in the United States. In 2001, *H. zea* and *H. virescens* were the most destructive pests of cotton (Williams 2002). Since the advent of *Bt* cotton, *H. zea* has become the predominant species of this pest complex. Cotton aphids, *Aphis gossypii* Glover, another pest in cotton, can exist concurrently with *H. zea* in cotton fields (Ables et al. 1978).

Of the many natural enemies associated with cotton, one of the most predominant and effective predators of *H. zea* and *H. virescens* is the big-eyed bug, *Geocoris punctipes* (Say) (Bell and Whitcomb 1963, Lingren et al. 1968, Lopez et al. 1976). The predatory diet of *G. punctipes* includes a variety of other cotton insect pests such as the plant bug, *Lygus hesperus* (Knight) (Cohen and Debolt 1983), the beet armyworm, *Spodoptera exigua* (Hübner) (Champlain and Sholdt 1966), pea aphids, *Acyrthosiphon pisum* (Harris) (Cohen 1989), and the sweet potato whitefly, *Bemisia tabaci* (Genn.) (Cohen and Byrne 1992). *G. punctipes* is omnivorous, feeding not only on prey, but also on plants including cotton (Ridgway and Jones 1968, Stoner 1970). Fortunately, plant feeding does not harm cotton (King and Cook 1932). Crocker and Whitcomb (1980) reported that *G. punctipes* fed on leaves of a variety of herbaceous angiosperms including crimson clover, *Trifolium incarnatum* L., a winter cover crop in cotton. Stoner (1970) showed that *G. punctipes* would readily feed on different plant structures of several plant species including sunflower seed, *Helianthus annuus* L., grain sorghum seed, *Sorghum vulgare* Pers., and fruits of green beans, *Phaseolus vulgaris* L.

Many explanations have been given for plant feeding by *G. punctipes* females: 1) it helps the insect survive prey-free periods (Stoner 1970, Naranjo and Stimac 1985, Eubanks and Denno 1999); 2) it provides extra nutrition when forced to feed on less nutritional prey (Eubanks and Denno 1999); 3) it is required for development (Naranjo and Stimac 1985, Eubanks and Denno 1999); 4) it is required for greater longevity (York 1944, Naranjo and Stimac 1985); 5) it is required for reproduction (Stoner 1970, Dunbar and Bacon 1972, Naranjo and Stimac 1985); and 6) it provides a water source (York 1944, Naranjo and Stimac 1985). Also, Ridgway and Jones (1968) found that the western big-eyed bug, *Geocoris pallens* Stål, fed substantially on cotton plants radiolabeled with inorganic ^{32}P, and they concluded that the predators used the plants to obtain moisture.

Although the benefits of plant feeding have been studied in detail for *G. punctipes*, only a single study

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quantifying plant feeding behavior of this predator has been conducted. Thead et al. (1985) determined that leaf sample ingestion by *G. punctipes* adults was greater on nectaried cotton without *H. virescens* eggs than nectaried cotton with eggs. Type of cotton, nectaried or nectariless, however, did not affect plant feeding. Our study was conducted to determine the effect of three prey treatments, *H. zea* eggs, *H. zea* first instars, and *A. gossypii* adults, on plant feeding behavior by *G. punctipes*. The hypothesis was that, in the presence of numerous prey, *G. punctipes* females would exhibit plant feeding behavior only when less acceptable prey were provided as the sole source of food.

Materials and Methods

Plants. Cotton (variety 'DP 5415') plants were grown in 2.8-liter plastic nursery pots (one plant/pot) in a greenhouse at 25–30°C with a photoperiod of 16:8 (L:D). Osmocote 14-14-14 (Scotts-Sierra Horticulture Products Co., Marysville, OH) was used as a time-release fertilizer. Plants were 5–6 wk old (vegetative stage) when used in experiments. Before the test, a cotton terminal (top 15 cm of the plant) was clipped off, placed in a cup of 200 g of wet sand to keep the terminal fresh, and covered with a plastic cylindrical plant cage (30.5 cm high with a 11.4 cm radius). The top of this cage was covered tightly with a plastic cup.

Insects. *Helicoverpa zea* were obtained from the USDA, ARS, Crop Protection and Management Research Laboratory in Tifton, GA. The colony originated from larvae collected from tobacco in 1997. Larvae were fed a bean diet (Perkins et al. 1973) and held in a climatic-controlled room at 25°C with a 14:10 (L:D) photoperiod. Cotton aphids, originating from a cotton field, were reared for only two generations on potted cotton plants in a greenhouse held at 25–30°C with a 16:8 (L:D) photoperiod. Young (3–10 d old), mated, egg-laying *G. punctipes* females collected from the field as last-instar nymphs and reared to adults in the laboratory on *H. zea* eggs were used in the tests. Adult females were used because they consume more food than immature and male *G. punctipes* (Crocker et al. 1975, Cohen 1984). Mean wet weights of 10% of the prey were obtained before each test using a UMT2 Mettler microbalance (Mettler, Hightstown, NJ). Voucher specimens of all insects are held in the USDA-ARS, Crop Protection and Management Research Laboratory, Tifton, GA.

Experimental Design. Food consumption can be greatly influenced by prey density, distribution of prey developmental stages available, and predator satiation (McMurty and Rodriguez 1987). Therefore, the experiment was designed to keep these factors constant. To ascertain the effect of prey species on plant feeding behavior of *G. punctipes* females, feeding behavior of *G. punctipes* females was observed on cotton for three prey treatments: 1) *H. zea* eggs (1 d old), 2) *H. zea* first instars (2 d old), and 3) adult *A. gossypii* (2–4 d old). McDaniel and Sterling (1979) reported that, in a cotton field, *G. punctipes* ingested 4.9 *H. virescens* eggs per day. Thus, in our test, we chose to place 25 prey on each plant in a cage to ensure that the number of prey in a cage was not a limiting factor. Adult aphids were used rather than mature apterae in an effort to reduce variability in size within the prey species. To establish a test cage, a single species of prey was randomly placed on the top of the first fully expanded cotton leaf of the caged cotton terminal. An individual *G. punctipes* female, previously starved overnight for 12 h, was released on the sand in this cage after prey were allowed to acclimate on plants for 30 min. Two cages per treatment were established per observation period for 20 observation periods so that a total of 40 females were observed for each treatment by the end of the test. New cages were established for each observation period. Occurrence and time of prey and plant feeding were observed and recorded continuously for 3 h for each female for each observation period. Observations were made in the laboratory during the morning. Timing of the feeding test began on the first occurrence of feeding. Timing of prefeeding periods also was recorded for each female.

Statistical Analyses. Mean total times (minutes) for prey feeding and plant feeding per female were analyzed using PROC analysis of variance (ANOVA) with least significant difference (LSD) for separation of means (SAS Institute 2000). χ^2 tests were done to compare differences in frequency of prey and plant feeding per treatment for all females. Mean times for prefeeding periods and prey and plant feeding were analyzed using PROC MIXED (SAS Institute 2000) with LSD for separation of means. Mean number of feeding events for prey and plants were analyzed using PROC ANOVA with LSD for separation of means (SAS Institute 2000). In the model for the *F*-tests, data were blocked by female (treatment) because there were different females for each date. *F*-tests with square root transformations improved the detection of treatment differences.

Results and Discussion

Total feeding time for *G. punctipes* females eating *A. gossypii* adults was less than one-half the feeding time for females eating *H. zea* eggs and first instars (Table 1). Overall frequencies for feeding for all *G. punctipes* (Table 2) and number of feeding events were also lower for *A. gossypii* adults than for *H. zea* prey (Table 3). These results indicate that *A. gossypii* adults were much less acceptable as prey than *H. zea* eggs and *H. zea* first instars, which were about equally acceptable to *G. punctipes* females as prey.

Each *G. punctipes* fed on prey and plant fed, but the amount of time before females began to feed was significantly different among the treatments with the mean prefeeding time from highest to lowest occurring in the following order: *A. gossypii* adults > *H. zea* first instars > *H. zea* eggs (Table 1). Based on mean wet weight, *H. zea* first instars (0.453 ± 0.011 mg) were larger than *A. gossypii* adults (0.269 ± 0.012 mg), and both insects were larger than *H. zea* eggs (0.121 ± 0.002 mg; $F = 313.63$; df = 2; $P < 0.001$; LSD; $P > 0.05$).

Table 1. Mean time before feeding and total feeding time for prey and plant feeding per *G. punctipes* female provided 25 *H. zea* eggs, *H. zea* first instars, or *A. gossypii* adults on caged cotton terminals each for 3 h

Treatment	Time (minutes) before feeding per female[a]			Time (minutes) for feeding per female[a]					
				Prey			Plant		
	n^b	Mean	SE	n^c	Mean	SE	n^c	Mean	SE
H. zea egg	40	18.4 c	4.1	18.7	86.8a, A	4.8	2.6	6.2b, B	0.9
H. zea first instar	40	42.1 b	4.1	7.9	98.6a, A	4.6	2.1	6.5b, B	0.9
A. gossypii adult	40	96.8 a	5.5	6.1	38.9b, A	3.2	5.0	18.8a, B	1.8

[a] Means followed by the same lowercase letter within a column or by the same capital letter within a row are not significantly different (PROC ANOVA; LSD: $P > 0.05$, $F = 76.1$; df = 2; $P < 0.001$).
[b] Total number of females.
[c] Number of events per female.

Prefeeding time decreased with decrease in relative prey size for the two *H. zea* prey, suggesting that prey size affected prefeeding time. However, mobility of the *H. zea* first instars may also have affected prefeeding time when comparing the two *H. zea* immatures. Saltatory predators such as *G. punctipes* move through their environment in a stop-and-go fashion (Cohen et al. 1993). They scan the search universe, move a certain distance, and pause and scan again. When they detect prey, they go into a pursuit and capture mode. We observed that this stop-and-go behavior occurred more often when *G. punctipes* females encountered the most mobile prey, first-instar *H. zea*, than when they approached sessile *H. zea* eggs. *A. gossypii* adults are smaller and less mobile than *H. zea* first instars, and so differences in prey size and/or mobility do not explain why the prefeeding time for *G. punctipes* in the presence of these aphids was so very high. A better explanation is that *A. gossypii* were less acceptable to this predator than *H. zea* as prey.

Number of prey feeding events by individual *G. punctipes* females was higher for *H. zea* eggs than for *H. zea* first instars (Table 3) probably because of the differences in mobility between the two prey types mentioned above. The number of *H. zea* eggs eaten during these tests was much higher than the 4.9 *H. virescens* eggs per day reported by McDaniel and Sterling (1979) for *G. punctipes* feeding in a cotton field. The increase in searching time and predator competition in the field probably could account for this difference. Prey density (one egg per plant) also may have affected number of eggs eaten by *G. punctipes* in the field tests. *H. zea* females can oviposit up to five eggs per cotton plant when *H. zea* moths begin dispersing from corn into cotton (P.G.T., unpublished data), and *G. punctipes* may be able to ingest >5 eggs per day when prey density reaches this higher level. Time required to eat a prey was highest for *H. zea* first instars and lowest for *H. zea* eggs (Table 4). In part, differences in feeding event times between these prey may be because of differences in prey size. The toothed mandibular stylets of *G. punctipes* penetrate, rasp, and cut prey tissues even probing narrow recesses, such as legs and antennae, while maxillary stylets form salivary and food canals that deliver saliva and remove digested prey contents (Cohen 1990). Thus, considering the feeding activities of *G. punctipes* on prey, it is possible that time for feeding on an individual prey could be related to prey size. Cohen and Byrne (1992) reported that longer feeding time was necessary for large prey, pea aphids, than for small prey, the sweetpotato whitefly. Another possible explanation for the higher feeding events times could be that the defensive wiggling of *H. zea* first instars may increase the amount of time required to eat one of these prey over the sessile *H. zea* eggs. *G. punctipes* females ate more *H. zea* eggs than first instars but spent less time feeding on *H. zea* eggs than first instars, resulting in the similar total feeding times for *H. zea* eggs and first instars for the 3-h test. Therefore, although quantity of food ingested was not measured in this study, *G. punctipes* females may have ingested about the same amount of food from each of the *H. zea* prey.

Table 2. Overall frequencies for prey and plant feeding for *G. punctipes* females provided 25 *H. zea* eggs, *H. zea* first instars, or *A. gossypii* adults on caged cotton terminals each for 3 h

Treatment	Prey feeding		Plant feeding		Total	
	n^a	Frequency (%)	n	Frequency (%)	n	Frequency (%)
H. zea egg	763	88.1	110	11.9	873	50.7
H. zea first instar	312	78.8	90	21.21	402	23.2
A. gossypii adult	243	54.5	204	45.5	447	26.1
Total	1,318	77.2	404	22.8	1,722	100.0
				$\chi^2 = 189.6$	df = 2	$P < 0.001$

[a] Total number of feeding events.

Table 3. Mean number of prey and plant feeding events for *G. punctipes* females provided 25 *H. zea* eggs, *H. zea* first instars, or *A. gossypii* adults on caged cotton terminals for 3 h

Treatment	Number of feeding events[a]					
	Prey			Plant		
	n^b	Mean	SE	n	Mean	SE
H. zea egg	763	18.7a, A	1.0	110	2.6b, B	0.3
H. zea first instar	312	7.9b, A	0.3	90	2.1c, B	0.3
A. gossypii adult	243	6.1c, A	0.4	204	5.0a, A	0.5

[a] Means followed by the same lowercase letter within a column or by the same capital letter within a row are not significantly different (PROC ANOVA: LSD: $P > 0.05$). For insect species, $F = 125.37$, df = 2, $P < 0.001$. For plant, $F = 20.36$, df = 2, $P < 0.001$.
[b] Total number of feeding events.

Table 4. Mean time per feeding event for prey and plant feeding for *G. punctipes* females provided 25 *H. zea* eggs, *H. zea* first instars, or *A. gossypii* adults on caged cotton terminals for 3 h

Treatment	Time (minutes) per feeding event[a]					
	Prey			Plant		
	n[b]	Mean	SE	n	Mean	SE
H. zea egg	763	4.6c, A	0.070	110	2.2b, B	0.070
H. zea first instar	312	12.7a, A	0.082	90	3.2a, B	0.082
A. gossypii adult	243	6.4b, A	0.065	204	3.9a, B	0.065

[a] Time means followed by the same lowercase letter within a column or by the same capital letter within a row are not significantly different (PROC MIXED; LSD; $P > 0.05$). For female (insect species), $F = 4.31$, $P < 0.001$; for insect species, $F = 56.18$, df = 2, $P < 0.001$; for food type, $F = 528.04$, df = 1, $P < 0.001$; for interaction, $F = 75.59$, df = 2; $P < 0.0001$.

[b] Total number of feeding events.

Because total plant feeding time for *G. punctipes* females was similar for *H. zea* eggs and first instars (Table 1), prey size did not affect plant feeding. Prey densities were high in our experiment compared with field conditions and may have masked possible differences. A lower encounter rate of prey may affect plant feeding; *G. punctipes* fed first instars will be better nourished than those fed eggs and may require less plant feeding.

Female *G. punctipes* preferred feeding on *H. zea* eggs and first instars to feeding on cotton plants (Table 2). However, overall frequencies of prey and plant feeding showed little to no preference for feeding on *A. gossypii* adults compared with feeding on cotton plants. These feeding preferences resulted in greater plant feeding occurring in the presence of *A. gossypii* adults than when given *H. zea* to eat. Nevertheless, our results demonstrated that *G. punctipes* females will feed on cotton plants regardless of prey species, even when prey are abundant.

Although these predators plant fed on cotton plants while eating *H. zea* prey, total feeding time (Table 1) and time per feeding event (Table 4) for *G. punctipes* females was higher for prey than for plant feeding regardless of species. However, total plant feeding time for these predators feeding on *A. gossypii* adults *H. zea* prey was approximately three times longer than that for females eating *H. zea* prey. Also, overall frequency of plant feeding and occurrences of planting by individual females when *G. punctipes* females ate *H. zea* prey was lower than when females fed on *A. gossypii* adults. Thus, plant feeding was higher for the less acceptable prey. Plant feeding can enable *G. punctipes* to survive during periods when prey are absent or less acceptable. Eubanks and Denno (1999) conducted experiments to determine the effects of variation in plant quality and prey species on the survival *G. punctipes*. The survival of *G. punctipes* was high when fed *H. zea* eggs, but was relatively low when fed pea aphids. *G. punctipes* nymphs fed only lima bean pods developed only to the third instar. Only *G. punctipes* fed high quality prey or mixtures of low quality prey and high quality plant food (lima bean pods) developed beyond this stage.

Conservation biological control for insect pest management is an ecologically based strategy aimed at manipulating the environment within an agroecosystem to enhance survival, fecundity, longevity, and behavior of natural enemies to increase their effectiveness (Landis et al. 2000). Because feeding on plants is a normal part of the feeding behavior of *G. punctipes*, conservation strategies need to be designed to increase the availability of healthy food plants for these predators. Reducing applications of insecticides that are toxic to predators when they feed on insecticide-treated foliage is one conservation strategy that could protect plant feeding *G. punctipes* and other cotton predators. Many researchers, extension agents, and growers are aware of the deleterious effects of topical applications of certain insecticides. However, some insecticides have feeding activity (kill the insect when it feeds on insecticide-treated foliage) either with or without topical activity. Plant feeding behavior can expose natural enemies to these pesticides. Ridgway et al. (1967) reported that populations of hemipteran predators may be reduced by applications of systemic insecticides, and they suspected that feeding on treated plants had killed the predators. Hough-Goldstein and Whalen (1993) suggested that the mortality of *Podisus bioculatus* (F.) nymphs exposed to systemic insecticides may have been caused by the insects' habit of occasionally sucking plant sap. Tillman et al. (2001) demonstrated conclusively that feeding through dried residues of an insecticide (indoxacarb) on cotton leaves was highly detrimental to *G. punctipes* females.

Habitat management is a conservation biological control strategy in which the habitat is altered to improve availability of resources required by natural enemies for optimal performance (Landis et al. 2000). Resource needs can be met by providing alternative foods. Various crops have been shown to be useful in supplying food from floral and extrafloral nectar and pollen to increase rates of parasitism (Treacy et al. 1987, Bugg et al. 1989, Hickman et al. 1995).

Conservation of *G. punctipes* possibly could be accomplished by providing high-quality plant food in or around the cotton field. Dunbar and Bacon (1972) found that *G. punctipes* survival was good on eggs of the tubermoth, *Phthorimaea operculella* (Zeller), without feeding on green beans, but both prey and plant feeding were essential for maximal fecundity. Naranjo and Stimac (1985) reported that supplementing a prey diet with plant food improved development and increased survival and reproduction of *G. punctipes*. In the field, this predator probably feeds on all plant species that harbor their prey because feeding on cotton occurred in this study even when were given ample opportunity to feed on an optimal diet. Different plant species and plant parts provide different nutritional value, which may affect development and survival of *G. punctipes* in the field. Stoner (1970) reported that cotton leaves were not the most nutritious diet for *G. punctipes*. Stoner (1970) reported that adult longevity of *G. punctipes* was two times longer when feeding on grain sorghum seed than on cotton leaves. Nymphs reached the fifth-instar stage feeding on only grain sorghum seeds and only reached the fourth

instar when feeding on cotton leaves. Preliminary studies using grain sorghum as a trap crop for *H. zea* eggs showed that numbers of *G. punctipes* nymphs were high in the grain sorghum trap (P.G.T., unpublished data). Establishing grain sorghum as refuge for protection from harmful insecticides as well as for provision of high-quality prey and plant food is a conservation strategy that could be successful in increasing the effectiveness of this predator in a cotton agroecosystem.

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Received for publication 27 January 2003; accepted 26 September 2003.