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Research Article

The influence of fennel feeding on development, survival, and reproduction in *Podisus nigrispinus* (Dallas) (Heteroptera: Pentatomidae)

José Bruno MALAQUIAS[1], Francisco de Sousa RAMALHO[1,*], Jefferson Virgínio Silva SOUZA[1], Karjoene Cassimiro Vieira RODRIGUES[1], Paulo Alves WANDERLEY[2]

[1]Unidade de Controle Biológico, Embrapa Algodão; Campina Grande, PB 58107-720, BRAZIL

[2]Centro de Formação de Tecnólogos, Universidade Federal da Paraíba; Bananeiras, PB 58000-000, BRAZIL

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Abstract: The aim of this study was to determine the effectiveness of fennel (*Foeniculum vulgare* Mill.) leaves as food on development, survival, and reproduction in *Podisus nigrispinus* (Dallas). Newly hatched *P. nigrispinus* nymphs were used in this study. The prey consisted of 3rd-instar *Alabama argillacea* (Huebner) larvae. Fennel and cotton leaves were not sufficient to enable the full development of the predator to its adult stage. It was verified that 35% of the nymphs that fed on cotton leaves and water, and 31% of the nymphs that fed on fennel leaves and water completed their 2nd instar in 5.68 days and 6.30 days, respectively, while nymphs from the 1st instar that had a water diet did not complete their 2nd instar and achieved 4.12 days of longevity. The high fecundity in the *P. nigrispinus* females fed fennel or cotton leaves was mainly due to an increase in the number of egg clutches per female, which resulted in greater egg production, when compared to females that did not have plants in their diet. Phytophagy could make *P. nigrispinus* an efficient agent for the biological control in intercropping systems of cotton with fennel.

Key words: Fennel, feeding, Asopinae, behavior, predator

Introduction

The cotton leafworm, *Alabama argillacea* (Huebner) (Lepidoptera: Noctuidae), is the main cotton leaf feeder in Brazil (Ramalho 1994). In addition to chemical pesticides, alternative control methods, such as the use of resistant cultivars and biological control, have been studied in cotton leafworm (Santos and Boiça Junior 2002). Crops established in tropical regions usually have a wide range of natural enemies (Ramalho and Wanderley 1996); thus, native predatory arthropods that inhabit cotton fields play an important role in limiting the quantity of eggs and larvae of this pest (Gravena and Sterling 1983).

Studies carried out in Brazil have emphasized the potential of generalist stink bugs of the genus *Podisus* as cotton leafworm population regulators (Zanuncio et al. 2002; Lemos et al. 2003; Medeiros et al. 2004; Oliveira et al. 2004; Lemos et al. 2005; Pereira et al. 2005). It is known that limiting an organism's

* E-mail: ramalhohvv@globo.com

population to a relatively low level during a certain timeframe may be one of the main barriers to perpetuation in a specific agro-ecosystem. Thus, the abundance of plants for phytophagous insects is guaranteed by the implementation of a monoculture consisting of their host plants; however, for generalist predators that require diversification of the food supply, monoculture could become a major obstacle to the success of their colonization (O´Neil and Wiedenmann 1987).

Nevertheless, stink bugs of the genus *Podisus*, in addition to feeding on a variety of arthropod species (Waddil and Shepard 1975; De Clercq and Degheele 1994), can survive under different temperature conditions (Didonet et al. 1996; Medeiros et al. 1998; Medeiros et al. 2003) and are able to maintain a reasonable population level, even when prey is scarce, mainly due to their zoophytophagy (Lemos et al. 2001; Evangelista et al. 2003).

Among the most plants studied regarding the impact of biological variables on predacious stink bugs, are those of forestry (Assis Júnior et al. 1998; Zanuncio et al. 2000) and agricultural importance, such as cotton (*Gossypium hirsutum* L.) (Stoner 1970; Stoner et al. 1974; Lemos et al. 2001; Oliveira et al. 2002b), tomato (*Lycopersicum esculentum* Mill.) (Valicente and O'Neil 1993; Oliveira et al. 2002a), bean (*Phaseolus vulgaris* L.) (Stoner 1970; Stoner et al. 1974; Salas-Aguilar and Ehler 1977; Kiman and Yeargan 1985; Naranjo and Stimac 1985), soybean (*Glycine max* L.) (Stoner 1970; Naranjo and Stimac 1987), potato (*Solanum tuberosum* L.) (Ruberson et al. 1986; Valicente and O'Neil 1993), and sunflower (*Helianthus annuus* L.) (Stoner 1970; Stoner et al. 1974).

The zoophytophagic nature of predators in the field has positive implications for biological control programs, and they can also be used as an alternative source of food during laboratory rearing. To achieve success in biological pest control programs, it is crucial to know the feeding preference of predatory stink bugs (Lemos et al. 2001).

An improvement in the nutritional quality of predatory insects can be obtained by adding plants to their diet; thus, the supplementation of these insects' diet with plants may be reflected in their biological variables (Lemos et al. 2001). Studies have shown an increase in reproductive rates when zoophytophagic insects are submitted to dietary regimes of vegetable and animal origin simultaneously (Kiman and Yergan 1985).

Nymph development in predatory insects may also be influenced by the presence of host plants (Evangelista Jr. et al. 2003), which can also have a positive impact on weight gain by predatory Pentatomidae (Valicente and O'Neil 1993; Evangelista Jr. et al., 2003) and provide greater longevity in females (Zanuncio et al. 2000). According to Oliveira et al. (2002b), the composition of agro-ecosystems influences the use of plants as a dietary complement by stink bugs, which may or may not improve establishment of predatory stinkbug populations.

In the northeast of Brazil, especially in Paraíba State, fennel (*Foeniculum vulgare* Mill.) is cultivated on an intercropping basis with upland cotton (*G. hirsutum* L. race *latifolium* Hutch.). Given the importance of fennel intercropping with upland cotton and that the stink bug *Podisus nigrispinus* (Dallas), with zoophytophagic behavior, is an important pest population regulator in this diversified system, an attempt was made to study the effect of fennel plants, as food, on its development, survival, and reproduction.

Materials and methods

The study was carried out at the Biological Control Unit (UCB) of Embrapa Algodão, Campina Grande, Paraíba, Brazil. Laboratory specimens of the predatory *P. nigrispinus* and prey *A. argillacea* were kept in environmental chambers at a constant temperature of 26 ± 1 °C, RH of 70 ± 10%, and a photoperiod of 12:12 h (L:D).

The study comprised 2 experiments. The first evaluated the effect of plants on the presence of the prey. In this study recently hatched *P. nigrispinus* nymphs ≤ 24 h old were used. *A. argillacea* 3rd instar larvae, from colonies maintained at UCB, were offered to each nymph in accordance with the methodology described by Medeiros et al. (2004).

The experiment employed a randomized complete block design with 3 treatments: nymphs received (1) cotton leaves, cotton leafworm larvae, and water (Aca), (2) fennel leaves, cotton leafworm larvae, and water (Eca), and (3) cotton leafworm larvae and water (ca), distributed in 50 replications. The predators were kept in 100-mL transparent plastic cups. Plastic cups with 2 holes were used for treatments 1 and 2, and plastic cups with 1 hole in the cover were used for treatment 3. Into one these holes was inserted a plastic tube with 2.5 mL of distilled water that was plugged with cotton in order to supply water to the predator and to maintain the humidity inside the cups. Into the other hole was inserted a plastic tube with 2.5 mL of distilled water and 2 fresh leaves of upland cotton (*G. hirsutum* L. race *latifolium* Hutch.) cultivar CNPA 7H or 2 fresh leaves of fennel (*Foeniculum vulgare* Mill.) cultivar Montadas, obtained from the apical region of the plant. The petioles of the leaves were inserted inside the tube containing distilled water and the hole was plugged with cotton. Ten newly emerged nymphs were placed in each cup.

For treatments with prey, 6 cotton leafworm larvae per day were supplied for each 10 nymphs throughout the experiment. Third instar cotton leafworm larvae were used as prey for stink bug 1st, 2nd, and 3rd instars. Fourth instar prey were offered to 4th and 5th instar predators, and also to adults. After 24 h the prey and plant material were changed.

In the second experiment the effect of plants without the presence of the animal prey was evaluated. In this experiment 3 treatments were tested: nymphs received (1) cotton leaves and water (Aa), (2) fennel leaves and water (Ea), and (3) water alone (a), with 20 replicates of each. Each replication started with only 1 nymph aged ≤ 24 h per plastic cup, so as to avoid cannibalism, which is characteristic for this species under food shortage conditions. These cups received no cotton leafworm larvae.

For treatments with prey, 6 cotton leafworm larvae per day were supplied for each 10 nymphs throughout the experiment. Third instar cotton leafworm larvae were used as prey for stink bug 1st, 2nd, and 3rd instars. Fourth instar prey were offered to 4th and 5th instar predators, and also to adults. After 24 h the prey and plant material were changed.

In both experiments nymph mortality and development were recorded daily until adult eclosion. After the emergence of adult insects, they were sexed based on genitalia (Grazia and Hildebrand 1986) and each *P. nigrispinus* couple was held in a 500-mL plastic cup for mating. During the pre-oviposition period adults were maintained on the same food regimen as the nymphs from which they had originated. Three days after emergence, cotton or fennel leaves were withheld from the cotton leafworm larvae, cotton leaf, fennel leaf, and water group, so that none of the adults in any of the treatments had plant material during oviposition. All the *P. nigrispinus* couples received three 4th instar cotton leafworm larvae per day. We recorded the duration of the pre-oviposition period, the number of eggs per clutch, the number of egg clutches, the number of eggs in the first clutch, the total number of eggs laid over the life-time, the oviposition time (time from the first to the last egg clutch), and the post-oviposition time.

Data were subjected to analysis of variance (procedure GLM, SAS Institute 2006) and the means were compared using the Student-Newman-Keuls test. Data were also subjected to regression analysis ($P = 0.05$) (procedure REG, SAS Institute 2006).

Results and discussion

Nymphal development and survival

P. nigrispinus first instar nymphs that fed on cotton leaves and water, or fennel leaves and water had development times of 2.26 ± 0.09 days and 2.46 ± 0.16 days, respectively, which was shorter ($F = 8.42$; $P = 0.05$) than in those that were provided only with water (3.13 ± 0.13 days) (Figure 1a). Fennel and cotton leaves were not sufficient to enable full development of the insects into the adult stage; however, the 2 diets increased longevity in these individuals, as compared the insects given a diet consisting of only water; 35% and 31% of the nymphs that fed on cotton leaves, and water or fennel leaves and water, respectively, completed their 2nd instar in 5.68 ± 0.25 or 6.30 ± 0.33 days, respectively, while 1st instar nymphs that fed only on water did not complete their 2nd instar and had longevity of 4.12 ± 0.14 days ($F = 19.96$; $P = 0.05$) (Figure 1b). Although diets consisting of leaves and water did not provide the necessary conditions for insects to reach the adult stage, they did maximize the longevity of these predators, when submitted to dietary regimes without access to prey. Lemos et al. (2001) reported that diets consisting only of cotton leaves and/or water are insufficient to enable the

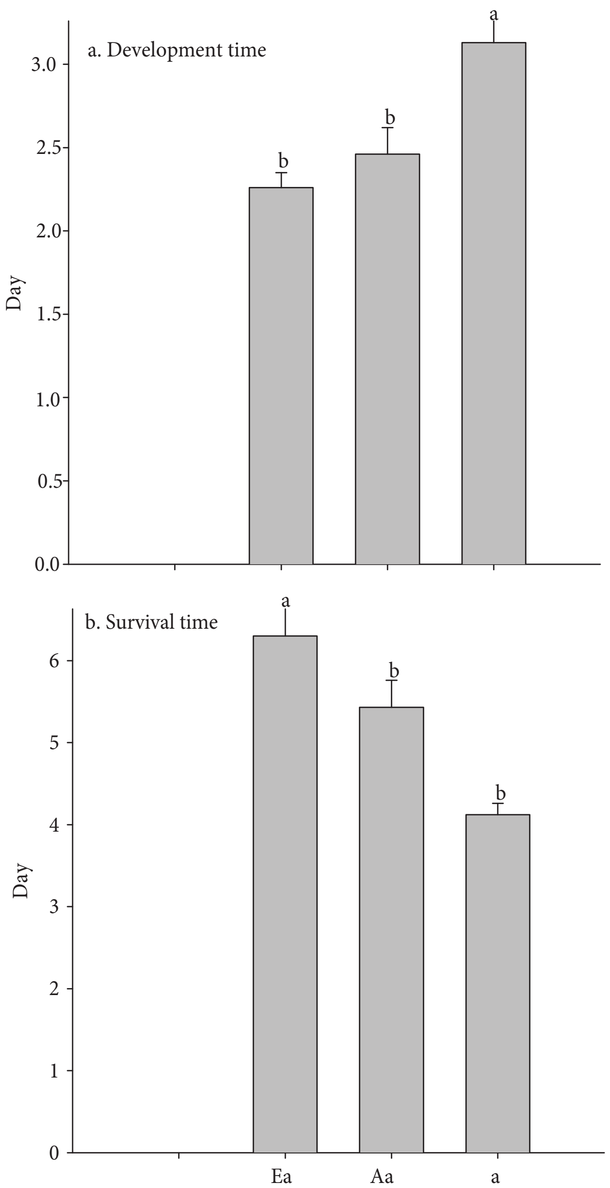

Figure 1. First instar development time (a) and nymph survival (b) in *P. nigrispinus* fed fennel leaf and water (Ea), cotton leaf and water (Aa), or water (a). Student-Newman-Keuls test: for each variable measured means with the same lowercase letter do not differ from each other (P = 0.05). Error bars indicate standard error.

complete development of *P. nigrispinus* to the adult stage; however, nymphs that fed on cotton leaves had greater longevity than those that received only water. *Podisus maculiventris* (Say) nymphs that fed on prey animals died 4 days after achieving the 2nd instar (Ruberson et al. 1986). According to De Clercq and Degheele (1992), approximately 90% of 1st instar nymphs of *P. maculiventris* and *Podisus sagitta* (Fabricius) that fed only on water or plants reached the 2nd instar; the rates of development in the predators were similar with both diets. The results achieved in the present study show that cotton and fennel leaves offered separately as food to *P. nigrispinus* did not provide the nutrients that the predator nymphs require to complete the 3rd instar. Although the plants offered separately as food to the predator did not allow its complete development, it may have contributed to the increase in longevity, possibly by providing certain nutrients that are used by the insect (Stoner 1970).

Although diets comprising cotton and water, or fennel leaves and water did not allow *P. nigrispinus* nymphs to reach the adult stage, they increased longevity significantly, thus showing that this plant's leaves contain nutrients that can be used by these predator nymphs.

Survivorship among the instars was affected by the predator's diet and age ($F = 2.28$; df = 8, 56; $P = 0.05$) (Table 1). Survivorship of *P. nigrispinus* 1st, 2nd, and 5th instar nymphs that fed on cotton or fennel leaves was significantly higher than in those that did not. According to Dunbar and Bacon (1972), survivorship of *Geocoris punctipes* nymphs increased when bean leaves were included in the diet. Salas-Aguilar and Ehler (1977) reported that the *Orius tristicolor* (White) mortality rate varied according to diet, and that the lowest mortality rate was observed when nymphs fed on leaves and animal prey.

The interaction between the sources of various foods and instar had a significant effect on *P. nigrispinus* instar longevity ($F = 8.54$; df = 8, 56; $P = 0.05$) (Table 2). This means that the duration of at least 1 of the predator's instars is influenced by the type of food it was offered. Duration of the 1st, 4th, and 5th instars was influenced by the type of food consumed. The duration of the development of 1st instar nymphs that were fed fennel leaves, larvae, and water, or cotton leaves, larvae, and water was 2.70 ± 0.21 days and 2.15 ± 0.08 days, respectively, while nymphs fed larvae and water took 3.03 ± 0.05 days to reach the 2nd instar. It is possible that nymphs from the 1st to 4th instars used cotton leaves and fennel leaves as essential sources of water and nutrients that promoted their development over these instars. Lemos et al. (2001)

Table 1. Percentage of stage-specific survivorship (mean ± SE) in *P. nigrispinus* nymphs fed fennel leaves, cotton leafworm larvae, and water (Eca), cotton leaves, cotton leafworm, and water (Aca), or cotton leafworm and water (ca).

Nymph	Diet[1]		
	Eca	Aca	Ca
1st instar	100.00 ± 0.00aA	93.33 ± 14.81aA	81.78 ± 12.88abB
2nd instar	98.00 ± 4.47aA	98.00 ± 4.47aA	83.93 ± 16.85abB
3rd instar	97.50 ± 5.59aA	100.00 ± 0.00aA	96.67 ± 7.46cA
4th instar	95.28 ± 6.49aA	100.00 ± 0.00aA	93.14 ± 9.61bcA
5th instar	100.00 ± 0.00a A	100.00 ± 0.00aA	76.67 ± 6.24aB

[1] Student-Newman-Keuls test: for each instar or diet, means with the same uppercase letter (with the same instar) or lowercase letter (within the same diet), respectively, do not differ from each other (P = 0.05). Nymph vs. diet (F = 2.28; P = 0.05)

Table 2. Development time (mean ± SE) in *P. nigrispinus* nymphs fed fennel leaves, cotton leafworm larvae, and water (Eca), cotton leaves, cotton leafworm, and water (Aca), or cotton leafworm and water (ca).

Nymph	Diet[1]		
	Eca	Aca	Ca
1st instar	2.70 ± 0.21aA	2.15 ± 0.08aA	3.03 ± 0.05aB
2nd instar	2.27 ± 0.42cA	3.50 ± 0.11bA	3.06 ± 0.14aA
3rd instar	2.84 ± 0.16abA	2.59 ± 0.12aA	2.82 ± 0.33aA
4th instar	3.71 ± 0.41cB	2.59 ± 0.16aA	4.10 ± 0.09bB
5th instar	5.87 ± 0.43dB	5.35 ± 0.34cA	4.93 ± 0.66cB

[1] Student-Newman-Keuls test: for each instar or diet, means with the same uppercase letter (with the same instar) or lowercase letter (within the same diet), respectively, do not differ from each other (P = 0.05). Nymph vs. diet (F = 8.54; P = 0.05)

reported that the duration of the 1st instar of *P. nigrispinus* is influenced by the type of food consumed during this stage; however, Ruberson et al. (1986) reported that the duration of the 1st instar of *P. maculiventris* is not affected by diet—1st instar nymphs of *P. maculiventris* require only water to complete their development.

Although cotton plants provide predators with nutritional elements that guarantee their development during the 1st, 4th, and 5th instars, they have no effect on the 2nd or 3rd instars; however, the duration of 1st, 4th, and 5th instars is related to diet. Dunbar and Bacon (1972), Salas-Aguilar and Ehler (1977), Kiman and Yeargan (1985), Naranjo and Stimac (1985), and Ruberson et al. (1986) observed an increase in the rate of development in various species of predators fed an animal diet supplemented with plants. The differences in reported results could be attributed to differences in predator species.

In the present study the nymphs of the predator had longer development time during the 5th instar, particularly those that fed on fennel leaves, larvae, and water (5.87 ± 0.43 days) (Table 2). The presence of fennel leaves in the diet of *P. nigrispinus* prolonged its final stage of development. Fennel leaves, in addition to increasing the development time of the 5th instar nymphs of *P. nigrispinus* (Table 2), prolonged its nymphal development (Figure 2).

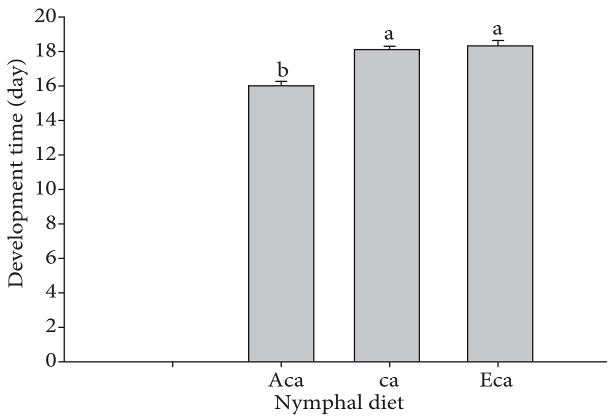

Figure 2. Development time (mean ± SE) in *P. nigrispinus* fed cotton leaf, cotton leafworm larvae, and water (Aca), cotton leafworm larvae, and water (ca), or fennel leaves, cotton leafworm larvae, and water. Means with the same letter are not significantly different from each other according to the Student-Newman-Keuls test (P = 0.05). Error bars indicate standard error.

Period of oviposition and fecundity

The presence of cotton and fennel leaves in the diet did not affect pre-oviposition, the number of eggs per clutch, the number of eggs in the first clutch, the interval between clutches, or the longevity of the predator females (Table 3); however, it did affect the oviposition and post-oviposition periods, the number of clutches per female, and number of eggs per female (Table 3). The predator females that had a diet consisting of larvae, cotton leaves, and water, or fennel leaves, larvae, and water during their final nymphal phase had a longer oviposition period, as well as more clutches per female, and eggs per female than those that fed only larvae and water (Table 3). The predators fed diets supplemented with cotton leaves had a shorter post-oviposition period (1.25 ± 0.16 days) than those fed diets consisting of fennel leaves, larvae, and water (2.33 ± 0.24 days), or larvae and water (3.08 ± 0.57 days) (Table 3). Similar results were obtained by Lemos et al. (2001), who reported that a diet supplemented with cotton leaves resulted in an increase in the duration of oviposition, the number of clutches per female, and eggs per female in *P. nigrispinus*. The high fertility rate in *P. nigrispinus* females given a diet supplemented with cotton leaves or fennel leaves was mainly due to the increase in the number of clutches per female, which resulted in the production of more eggs, when compared to females that did not have plants in their diet. Kiman and Yeargan (1985), and Naranjo and Stimac (1985, 1987) reported that the number of eggs deposited by *Orius insidiosus* (Say) and *Geocoris punctipes* (Say) was influenced by the addition of plants to their diet. Elsewhere, Ruberson et al. (1986) observed that a *P. maculiventris* diet supplemented with plants may improve its reproductive capacity.

Population models

The relationship between age-specific fecundity in *P. nigrispinus* was described by a model composed of a linear function for the increase in fecundity at early ages combined with an exponential function for the subsequent decrease in egg laying at older

Table 3. Effects of the food[2] on the pre-oviposition period, oviposition period, post-oviposition period, number of egg clutches per female, number of eggs per female, number of eggs per clutch, number of eggs in the first clutch, interval between egg clutch, and longevity in *P. nigrispinus* adults.

Diet[2]	Pre-oviposition (days)	Oviposition (days)	Post-oviposition (days)	Clutch/female (n)	Egg/female (n)	Egg/clutch (n)	1st Egg clutch (n)	Clutch interval (days)	Longevity (days)
Eca	4.75 ± 0.28a	20.42 ± 0.52a	2.33 ± 0.24a	11.54 ± 0.82a	219.96 ± 15.41a	23.69 ± 1.89a	19.17 ± 3.47a	2.22 ± 0.14a	22.67 ± 4.28a
Aca	4.67 ± 0.71a	18.50 ± 2.41a	1.25 ± 0.16b	12.03 ± 1.92a	225.84 ± 42.76a	18.90 ± 1.03a	25.67 ± 2.80a	2.26 ± 0.06a	24.42 ± 3.17a
Ca	4.99 ± 0.78a	7.08 ± 1.94b	3.08 ± 0.57a	4.42 ± 1.38b	79.33 ± 15.48b	21.81 ± 4.21a	20.17 ± 5.40a	2.56 ± 0.32a	15.58 ± 2.18a

[2]Eca: Fennel leaves, cotton leafworm larvae, and water; Aca; cotton leaves, cotton leafworm larvae, and water; ca: cotton leafworm larvae and water
Means followed by the same letter within each column are not significantly different according to the Student-Newman-Keuls test (P = 0.05)

ages. This relationship was described by $f(x) = ax\ exp(-\beta x)$. In the model $f(x)$ is the daily age-specific fecundity rate (eggs/female per day or clutches/female per day), x is age in days (age class), and α and β are constants. The model was fitted to the data by the non-linear least square method (SAS Institute 2006) and weighted by the number of females contributing to the means, giving the curves in Figures 3 and 4. In the case of eggs per female per day, the parameters α (± SE) and β (± SE), respectively, were estimated to be 9.42 ± 4.49 and 0.05 ± 0.01 for females fed a diet of cotton leaves,

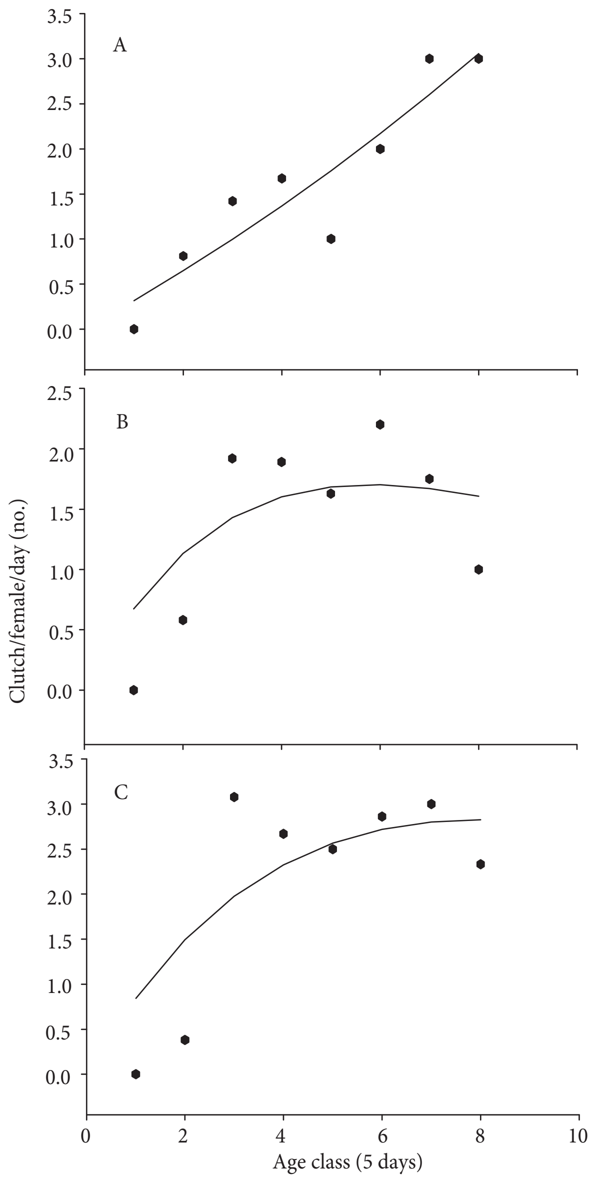

Figure 3. Observed (dots) and predicted (solid line model) age-specific fecundity (clutch/female/day) in *P. nigrispinus* fed cotton leaf, cotton leafworm larvae, and water (A), fennel leaves, cotton leafworm larvae, and water (B), or cotton leafworm larvae and water (C), as a function of female adult age. Age class 1 (0-5 days).

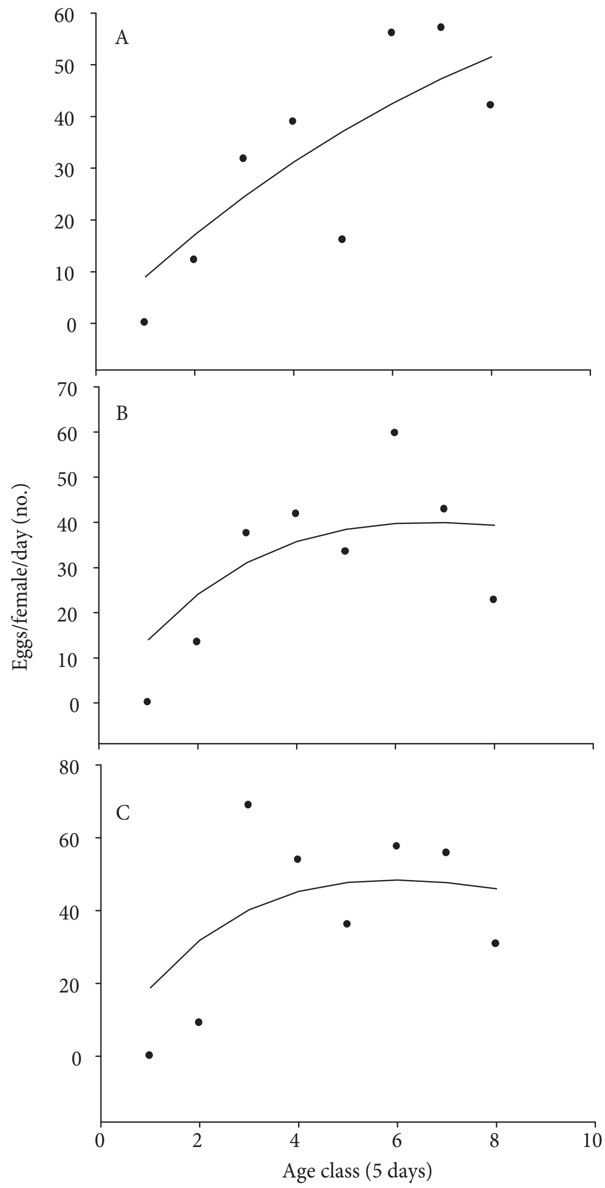

Figure 4. Observed (dots) and predicted (solid line model) age-specific fecundity (eggs/female/day) in *P. nigrispinus* fed cotton leaf, cotton leafworm larvae, and water (A), fennel leaves, cotton leafworm larvae, and water (B), or cotton leafworm larvae and water (C), as a function of female adult age. Age class 1 (0-5 days).

larvae, and water (F = 29.21; P = 0.05; R^2 = 0.91), 16.24 ± 6.81 and 0.15 ± 0.07 for females fed a diet of fennel leaves, larvae, and water (F = 25.37; P = 0.05; R^2 = 0.89), and 22.32 ± 10.57 and 0.17 ± 0.08 for females fed a diet of larvae and water (F = 18.52; P = 0.05; R^2 = 0.86). For the number of clutches per female per day, the values of the estimated parameters α (± SE) and β (± SE) were, respectively, 0.31 ± 0.11 and –0.03 ± 0.01 for females fed a diet of cotton leaves, larvae, and water (F = 70.60; P = 0.05; R^2 = 0.96), 0.80 ± 0.30 and 0.17 ± 0.07 for females fed a diet of fennel leaves, larvae, and water (F = 30.67; P = 0.05; R^2 = 0.91), and 0.95 ± 0.36 and 0.12 ± 0.06 for females fed a diet of larvae and water (F = 35.04; P = 0.05; R^2 = 0.92). The pattern in age-specific fecundity in *P. nigrispinus* for the number of clutches (F = 82.12; P = 0.05) per female and the number of eggs (F = 71.21; P = 0.05) per female varied according to the diet used. A similar pattern in age-specific fecundity was observed when *Macrolophus caliginosus* Wagner was fed various stages of *Tetranychus urticae* Koch (Acari: Tetranychidae) (Hansen et al. 1999).

Several researchers (Kiman and Yeargan 1985; Ruberson et al. 1986; Naranjo and Stimac 1987; Lemos et al. 2001) reported that some species of entomophagous stink bugs require food of vegetable and animal origin for their development and reproduction. Our study shows that *P. nigrispinus* can develop and reproduce solely on a diet of animal origin; however, this predator's reproductive capacity was enhanced when cotton or fennel leaves were included in the diet. Dunbar and Bacon (1972), and Tamaki and Weeks (1972) suggested that a diet comprising plants can be beneficial and may be essential for the predator's reproduction; however, the degree of its influence depends on the quality and quantity of prey.

The predator's ability to obtain nutrients from plant material may be an adaptation that enables it to exploit a feeding source available during periods when there is a shortage of prey (Salas-Aguilar and Ehler 1977). Ruberson et al. (1986) reported that plant material can also supply the predator with nutrients during movement or migration processes in areas where prey is scarce.

The predator's ability to feed on plants has both positive and negative implications for the biological control of pests. The positive side of this behavior is that the plant can temporarily serve as food during rearing in the laboratory or under field conditions, when prey is scarce, thus helping maintain populations of omnivorous predators at comparatively high levels despite a scarcity of prey (Ehler and Miller 1978). On the other hand, even when animal prey is available, the plant can enhance development, survival, and reproduction in predators. As a negative implication, Harris and Maramorosch (1980) reported that some predators, such as *Nabis* spp., have been cited as vectors of phytopathogenic agents; however, stink bugs of the *Podisus* genus have not been reported to injure crops. According to De Clercq and Degheele (1992), *Podisus* nymphs and adults feeding on green bean or potato foliage did not cause apparent injury to the plant tissues. *P. nigrispinus* has not been observed to transmit phytopathogenic agents directly or indirectly to cotton plants. It is thought that during periods of prey scarcity phytophagy may allow *P. nigrispinus* to maintain relatively high population levels in fennel crop and cotton crop agrosystems. *P. nigrispinus*, when fed simultaneously with prey animal and fennel leaves, or prey animal and cotton leaves, increased its reproduction; therefore, phytophagy may allow *P. nigrispinus* to be a more efficient biological control agent in intercropping systems of fennel with cotton.

The response of predatory heteropterans to habitat diversification is similar to that of other natural enemies (i.e. higher densities in diverse habitats) when the bugs feed on prey and to that of herbivores (i.e. reduced densities in diverse habitats) when the predators feed on plants (Coll and Ruberson 1998). Polyculture is commonly practiced in the tropics and was also practiced in temperate areas until mechanization, and reliance on fertilizers and pesticides became prevalent (Vandermeer 1989). According to Coll (1997), the addition of cereal crops to a habitat is more important to enhancing the activity of insect parasitoids that the addition of legumes. If similar patterns are observed in predatory bugs, practical crop arrangements that enhance predatory activity may be suggested, as for example, fennel intercropped with cotton.

Zoophytophagy performed by *P. nigrispinus* using fennel or cotton plant supplements may contribute to the establishment of these predator insects in the intercropping of fennel with cotton, and to increasing the reproductive rate of these insects, contributing to maximum efficiency of these arthropods in programs of biological control.

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References

Assis Jr SL, Zanuncio TV, Santos GP, Zanuncio JC (1998) Efeito da suplementação de folhas de *Eucalyptus urophylla* no desenvolvimento e reprodução do predador *Supputius cincticeps* (Stall) (Heteroptera: Pentatomidae). *An. Soc. Entomol. Brasil* 27: 245-253.

Coll M (1997) Response of insect parasitoids to increased plant species diversity in intercrops. In: Enhancing Natural Control of Arthropod Pests through Habitat Management (Eds. CH Pickett, RL Buggs). University of California Press, Berkeley, CA, pp. 49-61.

Coll M, Ruberson JR. (1998) Predatory Heteroptera in agroecosystems: their ecology and use in biological control. Thomas Say Publications, Entomological Society of America. 233pp.

De Clercq P, Degheele D (1994) Laboratory measurement of predation by *Podisus maculiventris* and *Podisus sagitta* (Hemiptera: Pentatomidae) on beet armyworm (Lepidoptera: Noctuidae). J Econ Entomol 87: 76-83.

De Clercq P, Degheele D (1992) Plant feeding by two species of predatory bugs of the genus *Podisus* (Heteroptera: Pentatomidae). Meded Fac Landbouww Rijksuniv.57: 591-596.

Didonet J, Zanuncio TV, Zanuncio JC, Vilela EF (1996) Influência da temperatura na reprodução e na longevidade de *Podisus nigrispinus* (Dallas) e *Supputius cincticeps* (Stål) (Heteroptera: Pentatomidae). An Soc Entomol Brasil 25: 117-123.

Dunbar DM, Bacon OG (1972) Feeding, development, and reproduction of *Geocoris punctipes* (Heteroptera: Lygaeidae) on eight diets. Ann Entomol Soc Am 65: 892-895.

Ehler LE, Miller JC (1978) Biological control in temporary agroecosystems. Entomophaga 23: 207-212.

Evangelista Jr WS, Gondim Jr GC, Torres JB, Marques EJ (2003) Efeito de plantas daninhas e do algodoeiro no desenvolvimento, reprodução e preferência para oviposição de *Podisus nigrispinus* (Dallas) (Heteroptera: Pentatomidae). An Soc Entomol Brasil 32: 677-684.

Gravena S, Sterling WL (1983) Natural predation on the cotton leafworm (Lepidoptera: Noctuidae). J Econ Entomol 76: 779.

Grazia J, Hildebrand R (1986) Hemípteros predadores de insetos. In: Encontro Sul-Brasileiro de Controle Biológico de Pragas, (Ed. Aeapf/Embrapa-Cnpt). Passo Fundo, RGS, pp. 21-37.

Hansen DL, Brodsgaard HF, Enkegaard A (1999) Life table characteristics of *Macrolophus caliginosus* preying upon *Tetranychus urticae*. Entomol Exp et Appl 93: 269-275.

Harris KF, Maramorosch K (1980) Vectors of Plant Pathogens. Academic Press, New York. 350pp.

Kiman ZB, Yergan, KV (1985) Development and reproduction of the predator *Orius insidiosus* (Hemiptera: Anthocoridae) reared on diets of selected plant material and arthropod prey. Ann Entomol Soc Am 78: 464-467.

Lemos WP, Ramalho FS, Serrão JE, Zanuncio JC (2003) Effects of diet on development of *Podisus nigrispinus* (Dallas) (Het. Pentatomidae), a predator of the cotton leafworm. J Appl Entomol 127: 389-395.

Lemos WP, Medeiros RS, Ramalho FS, Zanuncio JC (2001) Effects of plant feeding on the development, survival and reproduction of *Podisus nigrispinus* (Dallas) (Heteroptera: Pentatomidae). Intern J Pest Manag 47: 89-93.

Lemos WP, Ramalho FS, Serrão JE, Zanuncio JC (2005) Morphology of female reproductive tract of the predator *Podisus nigrispinus* (Dallas)(Heteroptera: Pentatomidae) fed on different diets. Braz Arch Biol Technol 48: 129-138.

Medeiros RS, Lemos WP, Ramalho FS (1998) Efeitos da temperatura no desenvolvimento de *Podisus nigrispinus* (Dallas) (Heteroptera, Pentatomidae), predador do curuquerê-do-algodoeiro (Lepidoptera, Noctuidae). Revta Bras Entomol 42: 121-130.

Medeiros RS, Ramalho FS, Zanuncio JC, Serrão JE (2003) Effect of temperature on life table parameters of *Podisus nigrispinus* (Het., Pentatomidae) fed with *Alabama argillacea* (Lep., Noctuidae) larvae. J Appl Entomol 127: 209-213.

Medeiros RS, Ramalho FS, Serrão JE, Zanuncio JC (2004) Estimative of *Podisus nigrispinus* (Dallas) (Heteroptera: Pentatomidae) development time with non linear models. N Entomol 33: 141-148.

Naranjo SE, Stimac JL (1985) Development, survival, and reproduction of *Geocoris punctipes* (Hemiptera: Lygaeidae): Effects of plant feeding on soybean and associated weeds. Environ Entomol 14: 523-530.

Naranjo SE, Stimac JL (1987) Plant influences on predation and oviposition by *Geocoris punctipes* (Hemiptera: Lygaeidae) in soybeans. Environ Entomol 16: 182-189.

Oliveira HN, De Clercq P, Zanuncio JC, Pedruzi EP (2004) Nymphal development and feeding preference of *Podisus maculiventris* (Heteroptera: Pentatomidae) on eggs of *Ephestia kuehniella* (Lepidoptera: Pyralidae) parasitised or not by *Trichogramma brassicae* (Hymenoptera: Trichogrammatidae). Braz J Biol 64: 459-463.

Oliveira JEM, Torres JB, Carrano-Moreira AF, Barros R (2002a) Efeito das plantas do algodoeiro e do tomateiro, como complemento alimentar, no desenvolvimento e na reprodução do predador *Podisus nigrispinus* (Dallas) (Heteroptera: Pentatomidae). N Entomol 31: 101-108.

Oliveira JEM, Torres JB, Carrano-Moreira AF, Ramalho FS (2002b) Biologia de *Podisus nigrispinus* predando lagartas de *Alabama argillacea* em campo. Pesq Agropec Bras 37: 7-14.

O'Neil RJ, Wiedemann RN (1987) Adaptations of arthropod predators to agricultural systems. Fla Entomol 70: 41-48.

Pereira AIA, Ramalho FS, Zanuncio JC (2005) Susceptibility of *Podisus nigrispinus* (Dallas) (Heteroptera: Pentatomidae) to gamma-cyhalothrin under laboratory conditions. Sci Agric 62: 1-6.

Ramalho FS (1994) Cotton pest management: Part 4. A Brazilian perspective. Ann. Rev Entomol 37: 563-578.

Ramalho FS, Wanderley PA (1996) Ecology and management of the boll weevil in South American cotton. Am Entomol 42: 41-47.

Ruberson JR, Tauber MJ, Tauber CA (1986) Plant feeding by *Podisus maculiventris* (Heteroptera; Pentatomidae): Effect on survival, development, and preoviposition period. Environ Entomol 15: 894-897.

Santos TM, Boiça Júnior AL (2002) Biological aspects and predatory capacity of *Podisus nigrispinus* (Dallas) (Hemiptera: Pentatomidae) fed on *Alabama argillacea* (Hubner) (Lepidoptera: Noctuidae) reared on cotton genotypes. Sci Agric 59: 671-675.

Salas-Aguilar J, Ehler LE (1977) Feeding habits *of Orius tristicolor*. Ann Entomol Soc Am 70: 60-61.

SAS Institute 2006. SAS User's Guide: Statistic. SAS Press, Cary, North Carolina. 846pp.

Stoner A (1970) Plant feeding by a predaceous insect, *Geocoris punctipes*. J Econ Entomol 63: 1911-1915.

Stoner A, Metcalf AM, Weeks RE (1974) Plant feeding by a predaceous insect, *Podisus acutissimus*. Environ Entomol 3: 187-189.

Tamaki G, Weeks RE (1972) Biology and ecology of two predators, *Geocoris pallens Stal* and *Geocoris bullatus* (Say). US Dep Agric, Tech Bull 1446. 158pp.

Valicente FH, O'Neil RJ (1993) Effects of two host plants on selected life history characteristics of *Podisus maculiventris* (Say) (Heteroptera: Pentatomidae) without access to prey. An Soc Entomol Brasil 22: 513-518.

Vandermeer J (1989) The Ecology of Intercropping. Cambridge University Press, Cambridge, UK, 468p.

Waddill V, Shepard M (1975) A comparison of predation by the pentatomids, *Podisus maculiventris* (Say) and *Stiretrus anchorago* (F.), on the Mexican bean beetle, *Epilachna varivestis* Mulsant. Ann Entomol Soc Am 68: 1023.

Zanuncio JC, Zanuncio TV, Guedes RNC, Ramalho FS (2000) Effect of feeding on three *Eucalyptus* species on the development of *Brontocoris tabicus* (Hete.: Pentatomidae) fed with *Tenebrio molitor* (Col.: Tenebrionidae). Biocontr Sci Technol 10: 443-450.

Zanuncio JC, Guedes RNC, Oliveira HN, Zanuncio TV (2002) Uma década de estudos com percevejos predadores: conquistas e desafios. In:.Controle Biológico no Brasil: Parasitóides e Predadores, (Eds: JR Parra, PSM Botelho, BS Corrêa-Ferreira, JMS Bento). Manole Editora, São Paulo, pp. 495-509.