Does Diet of Prey Affect Life Table Parameters of the Predator Podisus nigrispinus (Hemiptera: Pentatomidae)?

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Does diet of prey affect life table parameters of the predator *Podisus nigrispinus* (Hemiptera: Pentatomidae)?

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Abstract

Podisus nigrispinus Dallas (Hemiptera: Pentatomidae) is reared in the laboratory and released for biological control programs. The objective of this study was to evaluate, using life tables, *P. nigrispinus* development when fed on *Anticarsia gemmatalis* Hübner (Lepidoptera: Erebidae) reared on different diets, or with the alternative prey *Tenebrio molitor* L. (Coleoptera: Tenebrionidae). *Podisus nigrispinus* was reared with soybean plants supplemented with *A. gemmatalis* caterpillars fed an artificial diet (T1), with soybean plants supplemented with caterpillars fed soybean leaves (T2), with soybean plants supplemented with *T. molitor* pupae (T3), or with soybean plants supplemented with *A. gemmatalis* pupae from caterpillars fed soybean leaves (T4). The duration of instar V and of the total nymph period of this predator were longer when preying caterpillars fed soybean plants (T2). The survival of the nymph stage was greater when fed on soybean plants with *T. molitor* pupae (T3), with *A. gemmatalis* caterpillars fed on soybean plants (T2), and with *A. gemmatalis* caterpillars fed an artificial diet (T1), relative to *A. gemmatalis* pupae from caterpillars fed soybean leaves (T4). The weights of instar V nymphs and of adult male and female *P. nigrispinus* were greater when fed with *T. molitor* pupae (T3*)*. Life table parameters showed population growth for this predator in all treatments except when fed with *A. gemmatalis* pupae (T4). The net reproductive rate (Ro), the duration of a generation (DG), and time to double the population (TD) of *P. nigrispinus* displayed higher values when fed with caterpillars cultured on soybean (T2) and with *T. molitor* pupae (T3). The rates of increase (λ and rm) value were positive in all treatments. *Anticarsia gemmatalis* pupae from caterpillars fed soybean leaves (T4) are inadequate prey for *P. nigrispinus*. *Anticarsia gemmatalis* caterpillars fed soybean leaves (T2) or *T. molitor* pupae (T3) are a more suitable food for rearing this predator than *A. gemmatalis* caterpillars fed an artificial diet (T1).

Key Words: Asopinae; biological control; *Glycine max*; Heteroptera

Resumo

Podisus nigrispinus Dallas (Heteroptera: Pentatomidae) é criado em laboratório e liberado em programas de controle biológico. O objetivo deste estudo foi avaliar, utilizando tabelas de vida, o desenvolvimento de *P. nigrispinus* quando alimentado com *Anticarsia gemmatalis* Hübner (Lepidoptera: Erebidae), criado em diferentes dietas ou com a presa alternativa *Tenebrio molitor* L. (Coleoptera: Tenebrionidae). *Podisus nigrispinus* foi criado sobre plantas de soja suplementadas com lagartas de *A. gemmatalis* alimentadas com uma dieta artificial (T1), sobre plantas de soja com lagartas alimentadas com folhas de soja (T2), sobre plantas de soja com pupas de *T. molitor* (T3), ou sobre plantas de soja com pupas de *A. gemmatalis* de lagartas alimentadas com folhas de soja (T4). A duração do V ínstar e do período ninfal total deste predador foram mais longos quando consumiram lagartas alimentadas com soja (T2). A sobrevivência de ninfas foi maior quando alimentadas com pupas de *T. molitor* (T3), com lagartas de *A. gemmatalis* alimentadas com folhas de soja (T2) e com lagartas de *A. gemmatalis* alimentadas com dieta artificial (T1), respectivamente. O peso de ninfas de V estádio e de machos e fêmeas de *P. nigrispinus* foi maior com pupas de *T. molitor* (T3). Os parâmetros da tabela de vida mostraram crescimento populacional para este predador em todos os tratamentos, exceto quando o predador foi alimentado com pupas de *A. gemmatalis* (T4). A taxa reprodutiva líquida (Ro), duração de uma geração (DG) e tempo para dobrar a população (TD) de *P. nigrispinus* apresentaram valores melhores quando alimentados com lagartas que consumiram folhas de soja (T2) e *T. molitor* (T3). As taxas de aumento (λ e rm) foram positivas em todos os tratamentos. Pupas de *A. gemmatalis* alimentadas com folhas de soja (T4) são presas inadequadas para *P. nigrispinus*. Lagartas de *Anticarsia gemmatalis* alimentadas com folhas de soja (T2) ou pupas de *T. molitor* (T3) são presas mais adequadas para a criação deste predador que aqueles indivíduos dessa presa criados com dieta artificial (T1).

Palavras Chave: Asopinae; controle biológico; *Glycine max*; Heteroptera

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Podisus nigrispinus Dallas (Hemiptera: Pentatomidae), a generalist predator, has potential for use in integrated pest management programs (IPM) (Zanuncio et al. 2008) due to its high searching ability (Malaquias et al. 2015), feeding rates (Vacari et al. 2013), and low production costs (De Bortoli et al. 2011). This predator is reared in the laboratory and released for biological control programs (Zanuncio et al. 2014) so it is important to optimize its mass rearing techniques (Zanuncio et al. 2001). *Podisus nigrispinus* can survive periods of prey scarcity by feeding on alternative prey (Malaquias et al. 2010). Under laboratory conditions they accept *Tenebrio molitor* L. (Coleoptera: Tenebrionidae) pupae, *Musca domestica* L. (Diptera: Muscidae), and *Bombyx mori* L. (Lepidoptera: Bombycidae) larvae (Neves et al. 2010), and in the field they take natural prey such *Anticarsia gemmatalis* Hübner (Lepidoptera: Erebidae) caterpillars (Ferreira et al. 2008).

Predatory pentatomids are considered to be obligate zoophytophagous because they have better development when fed both insect prey and plants (Azevedo et al. 2007). Zoophytophagous behavior enables predatory bugs to obtain moisture and possibly nutrients (Torres et al. 2010).

The functional response of predators is affected by many factors, such as their development stage (Hassanpour et al. 2011), prey type (Farhadi et al. 2010), plant species, and plant physiology (De Clercq et al. 2000), food availability (Molina-Rugama et al. 1997), and food quality (Lemos et al. 2003). Commercialization and use of biological control agents for integrated management programs depends on producing these insects at a low cost. Life tables permit the analysis and understanding of the effect of external factors, including host plants, on the growth, survival, reproduction, and intrinsic rates of population growth (Chi & Su 2006).

The objective of this study was to evaluate, using life tables, the development of *P. nigrispinus* fed *A. gemmatalis* caterpillars reared on different diets.

Materials and Methods

PLANT AND INSECT CULTURE

The experiment was conducted in a greenhouse of the Plant Science Department at the Universidade Federal de Viçosa (UFV) in Viçosa, Minas Gerais, Brazil. Soybean seeds (cultivar UFV16) were planted in 3 L plastic pots every 15 d, from Jul 2006 to May 2007, irrigated, and thinned to 3 per pot. Fertilization was carried out according to recommendations (CFSEMG 1999). Chemical pest control products were not applied.

Anticarsia gemmatalis caterpillars were reared in the Insect Biological Control Laboratory (IBCL/BIOAGRO/UFV) on an artificial diet (Greene et al. 1976) or soybean leaves. *Tenebrio molitor* pupae were obtained from a culture (LCBI/BIOAGRO/ UFV) fed wheat bran and sugarcane.

Podisus nigrispinus egg masses were obtained from the LCBI/BIOAGRO/UFV, where this predator is fed on *T. molitor* pupae. *Podisus nigrispinus* eggs were placed in Petri dishes (9.0 × 1.2 cm) with a damp cotton ball to prevent drying out. Newly hatched *P. nigrispinus* nymphs were separated into groups of 60 per organza bag (30 × 60 cm) in pots encompassing a soybean plant at the V6 or V7 to R6 phenological stages.

The predator was reared for 2 generations (F2) with soybean plants supplemented with *A. gemmatalis* caterpillars fed an artificial diet (T1), with soybean plants supplemented with caterpillars fed soybean leaves (T2), with soybean plants supplemented with *T. molitor* pupae (T3), or with soybean plants supplemented with *A. gemmatalis* pupae from caterpillars fed soybean leaves (T4) before evaluation so it could adapt to dietary and experimental conditions. Water was supplied in anesthesia tubes sealed with a cotton ball and placed in the organza bags. Supplemental food was provided ad libitum.

EXPERIMENTAL STUDIES

For each treatment (T1–T4), 50 nymphs of third generation *P. nigrispinus* were separated into groups of 10 individuals per organza bag (10 × 20 cm), each representing 1 replication. These nymphs were reared to obtain adults, which were mated 3 d after emergence, with 12 pairs per treatment. The average temperature during the test was 25.8 ± 8.0 °C.

Duration and survival data for instars I, II, III, IV, and V of *P. nigrispinus* were determined. The survival curves of the nymph stage of this predator were obtained using the Kaplan-Meier model (SAS Institute 1991). The weights of instar V nymphs and of newly emerged males and females *P. nigrispinus* were obtained with a precision balance (Shimadzu model AY220, produced in The Philippines; resolution = 0.1 mg).

Population growth parameters and reproduction of *P. nigrispinus* were obtained using life table analysis. The net reproductive rate (Ro) (number of females added per female during her lifetime): Ro = Σlx.mx; duration of a generation (DG) (time between the parent and offspring birth): DG = Σx. lx. Mx/Ro; intrinsic rate of population increase (Rm) (population growth rate per unit time): Rm = ln (Ro)/DG; finite rate of population increase (λ) (number of females added to the population per female per unit time): λ = antilog (rm 0.4343); and time required for the predator to double its population in number of individuals (TD): TD = ln (2)/rm; were calculated (Maia et al. 2000) and analyzed using the SAS statistical software (SAS Institute 1991).

Results

The duration of instar I was similar among treatments. Instars II and III *P. nigrispinus* were longer when fed *A. gemmatalis* pupae (T4), and nymphs of this predator did not complete their life cycle, with 100% mortality during instar IV when fed this host. The duration of instar V and of the total nymph period of *P. nigrispinus* were longer when provided with caterpillars fed with soybean plants (T2) (Table 1).

The survival of the nymph stage of *P. nigrispinus* was higher when fed on soybean plants with *T. molitor* pupae (T3) (97.9%), with *A. gemmatalis* caterpillars reared with soybean leaves (T2) (93.8%), and with *A. gemmatalis* caterpillars fed an artificial diet (T1) (79. 2%), relative to *A. gemmatalis* pupae from caterpillars fed soybean leaves (T4) (Fig. 1).

Instar V, and both male and female adults of *P. nigrispinus*, were heavier when fed *T. molitor* (T3) (Table 2).

Life table parameters for *P. nigrispinus* varied with the prey supplied. The net reproductive rate (Ro), duration of a generation (DG), and time to double the population (TD) of this predator had higher values when allowed to feed on *A. gemmatalis* caterpillars reared on soybean leaves (T2) and on *T. molitor* pupae (T3), indicating increased offspring production per generation (Table 3). The finite (λ) and intrinsic (rm) rates of population growth of *P. nigrispinus* were similar among treatments.

Discussion

The quality and quantity of food affect parameters such as survival, weight gain, stage duration, egg numbers, and predator viability and longevity (Zanuncio et al. 2002). The equivalent duration of first instar *P. nigrispinus* is due to the pentatomid predators having no predatory

Table 1. Duration (mean days ± standard error) for instars I–V, and of the total nymph stage, of *Podisus nigrispinus* (Hemiptera: Pentatomidae) reared with soybean plants supplemented with *Anticarsia gemmatalis* (Lepidoptera: Erebidae) caterpillars fed an artificial diet (T1), on soybean plants with caterpillars fed soybean leaves (T2), on soybean plants with *Tenebrio molitor* (Coleoptera: Tenebrionidae) pupae (T3), or on soybean plants with *A. gemmatalis* pupae from caterpillars fed soybean leaves (T4).

	Treatments			
Instars	T1	T2	T3	T4
I[ns]	3.00 ± 0.00	3.00 ± 0.00	3.00 ± 0.00	3.00 ± 0.00
II	3.96 ± 0.09 B	3.96 ± 0.11 B	4.32 ± 0.07 B	5.26 ± 0.13 A
III	3.49 ± 0.16 BC	4.00 ± 0.08 B	3.39 ± 0.07 C	4.91 ± 0.43 A
IV	4.21 ± 0.09 AB	4.38 ± 0.13 A	3.92 ± 0.06 B	—
V	5.63 ± 0.10 B	6.42 ± 0.12 A	5.85 ± 0.09 B	—
Total	25.20 ± 0.21 B	26.78 ± 0.26 A	25.38 ± 0.16 B	—

[ns]Non-significant. Means per row followed by the same letter do not differ by Tukey's test (*P* = 0.05).

habits at this age (Torres et al. 2006; Malaquias et al. 2010). *Podisus nigrispinus* predatory behavior begins as it attains the second instar (Torres et al. 2006) and the life cycle of this predator depends on food quality and quantity (Lemos et al. 2006). The duration of the *P. nigrispinus* nymph stage was shorter when their supplemental diet included *A. gemmatalis* caterpillars reared on an artificial diet (T1) or *T. molitor* larvae (T3) than when allowed to feed on *A. gemmatalis* caterpillars reared on soybean leaves (T2). In a similar study, Medeiros et al. (2000) reported that nymph development of this predator was shorter when allowed to feed on *A. gemmatalis* caterpillars reared on an artificial diet (T1) or caterpillars fed soybean plants (T2) or *T. molitor* larvae (T3) than when allowed to feed on *Alabama argillacea* Hübner (Lepidoptera: Noctuidae) larvae on cotton plants. Furthermore, the duration for instars II and III of this predator with *A. gemmatalis* pupae was longer than those fed on *Spodoptera frugiperda* (Smith & Abbot), *Spodoptera cosmioides* (Walker) larvae (Lepidoptera: Noctuidae) and eggs of *Euschistus heros* F. (Hemiptera: Pentatomidae) (Denez et al. 2014).

The heavier body of instar V nymphs and adult *P. nigrispinus* when fed *T. molitor* is important because heavier individuals have better reproductive success (De Bortoli et al. 2016; Lemos et al. 2003). *Podisus nigrispinus* females were heavier than the males, which is consistent with reports of adult weights from 45 to 140 mg for females and 35 to 100 mg for males (Torres et al. 2006), and independent of diet (Lemos et al. 2001, 2003). Better nutritional prey quality affects predator weight gain (Oliveira et al. 2004). Moreover, feeding on different prey throughout the life cycle, such as *T. molitor* and *M. domestica* on alternated days, supplements the predator nutritional requirements and increases production of heavier females (Zanuncio et al. 2001).

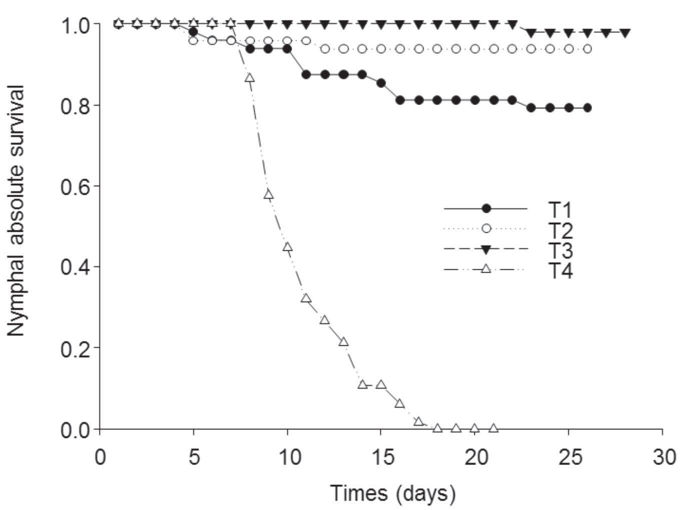

Fig. 1. Nymph absolute survival (according to Kaplan-Meier estimator) of *Podisus nigrispinus* (Hemiptera: Pentatomidae) reared with soybean plants supplemented with *Anticarsia gemmatalis* (Lepidoptera: Erebidae) caterpillars fed an artificial diet (T1); on soybean plants with caterpillars fed soybean leaves (T2); on soybean plants with *Tenebrio molitor* (Coleoptera: Tenebrionidae) pupae (T3); or on soybean plants with *A. gemmatalis* pupae from caterpillars fed soybean leaves (T4).

Insect population growth may be evaluated with Ro values, which uses specific female fertility at different ages (Southwood 1978). The lower net reproductive rate (Ro) for *P. nigrispinus* females when their supplemental diet included *A. gemmatalis* caterpillars reared on an artificial diet (T1), as obtained in our study, indicates that this diet is less suitable for mass production of this predator resulting in production of fewer offspring during their lifetime (De Bortoli et al. 2011). Life tables show the reproductive potential of females at different times (Medeiros et al. 2000), but dietary quality during immature stages affects insect reproduction (Mayntz et al. 2003). For example, the net reproductive rate (Ro) for *P. nigrispinus* was higher when fed *Plutella xylostella* L. (Lepidoptera: Plutellidae) pupae (267.2) than when fed larva of this species (216.1) (Vacari et al. 2013).

Anticarsia gemmatallis reared on an artificial diet (T1) induced lower generational duration (DG), and the period for *P. nigrispinus* to double its population size (TD). Low values of these parameters (DG and TD) are desirable in biological control programs because the possibility of obtaining more annual generations is greater, which provides financial advantages (Menezes et al. 2014). The positive rate of increase (λ and rm) value in all treatments indicates higher birth than mortality rates (Santos et al. 2014). Higher values for the Ro parameter indicate greater numbers of offspring, with this parameter being more relevant than generational duration for population increase (Menezes et al. 2014).

Table 2. Weight (mean mg ± standard error) of instar V nymphs and of newly emerged *Podisus nigrispinus* (Hemiptera: Pentatomidae) adults reared with soybean plants supplemented with *Anticarsia gemmatalis* (Lepidoptera: Erebidae) caterpillars fed an artificial diet (T1), on soybean plants with caterpillars fed soybean leaves (T2), or on soybean plants with *Tenebrio molitor* (Coleoptera: Tenebrionidae) pupae (T3).

	Treatments		
Stages	T1	T2	T3
V	25.38 ± 1.00 B	26.66 ± 0.93 B	35.30 ± 1.64 A
Male	42.20 ± 1.08 B	40.61 ± 0.83 B	52.35 ± 1.06 A
Female	60.34 ± 2.03 B	55.02 ± 1.97 B	72.20 ± 2.87 A

Means per rows followed by the same letter do not differ by Tukey's test (*P* = 0.05).

Table 3. Life table parameters (mean ± standard error) of *Podisus nigrispinus* (Hemiptera: Pentatomidae) reared with soybean plants supplemented with *Anticarsia gemmatalis* (Lepidoptera: Erebidae) caterpillars fed an artificial diet (T1), on soybean plants with caterpillars fed soybean leaves (T2), or on soybean plants with *Tenebrio molitor* (Coleoptera: Tenebrionidae) pupae (T3).

	Treatments		
Parameters	T1	T2	T3
Ro	72.85 ± 13.96 B	113.10 ± 18.38 A	141.01 ± 31.65 A
DG	32.61 ± 0.79 B	37.66 ± 1.14 A	40.565 ± 3.39 A
TD	3.68 ± 0.16 B	5.52 ± 0.13 A	5.68 ± 0.37 A
Λ^{ns}	1.11 ± 0.00	1.13 ± 0.00	1.13 ± 0.01
rm^{ns}	0.12 ± 0.00	0.13 ± 0.00	0.13 ± 0.01

^{ns}Non-significant. Means per row followed by the same letter do not differ according to Tukey's test (P = 0.05). Ro: net reproductive rate; DG: duration of a generation; TD: time to double the population; λ: finite rate of increase; rm: infinitesimal rate of increase.

Thus, *A. gemmatalis* pupae fed on soybean leaves (T4) are inadequate prey for *P. nigrispinus*. *Anticarsia gemmatalis* caterpillars fed an artificial diet (T1) are less suitable prey for rearing this predator than *A. gemmatalis* caterpillars fed soybean leaves (T2) or *T. molitor* pupae (T3).

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References Cited

Azevedo DO, Zanuncio JC, Zanuncio JS, Martins GF, Marques-Silva S, Sossai MF, Serrão JE. 2007. Biochemical and morphological aspects of salivary glands of the predator *Brontocoris tabidus* (Heteroptera: Pentatomidae). Brazilian Archives of Biology and Technology 50: 469–477.

CFSEMG – Comissão de Fertilidade do Solo do Estado de Minas Gerais. 1999. Recomendações para o uso de corretivos e fertilizantes em Minas Gerais. Quinta aproximação, Viçosa, Minas Gerais, Brasil.

Chi H, Su HY. 2006. Age-stage, two-sex life tables of *Aphidius gifuensis* (Ashmead) (Hymenoptera: Braconidae) and its host *Myzus persicae* (Sulzer) (Homoptera: Aphididae) with mathematical proof of the relationship between female fecundity and the net reproductive rate. Environmental Entomology 35: 10–21.

De Bortoli SA, Otuka AK, Vacari AM, Martins MIEG, Volpe HXL. 2011. Comparative biology and production costs of *Podisus nigrispinus* (Hemiptera: Pentatomidae) when fed different types of prey. Biological Control 58: 127–132.

De Bortoli SA, Vacaria MA, Laurentis VL, De Bortoli CP, Santosa RF, Otuka AK. 2016. Selection of prey to improve biological parameters of the predator *Podisus nigrispinus* (Dallas, 1851) (Hemiptera: Pentatomidae) in laboratory conditions. Brazilian Journal of Biology 76: 307–314.

De Clercq P, Mohaghegh J, Tirry L. 2000. Effect of host plant on the functional response of the predator *Podisus nigrispinus* (Heteroptera: Pentatomidae). Biological Control 18: 65–70.

Denez MD, Bueno AF, Pasini A, Bortolotto OC, Stecca CS. 2014. Biological parameters of *Podisus nigrispinus* (Hemiptera: Pentatomidae) fed with different soybean insect pests. Annals of the Entomological Society of America 107: 967–974.

Farhadi R, Allahyari H, Juliano SA. 2010. Functional response of larval and adult stages of *Hippodamia variegata* (Coleoptera: Coccinellidae) to different densities of *Aphis fabae* (Hemiptera: Aphididae). Environmental Entomology 39: 1586–1592.

Ferreira JAM, Zanuncio JC, Torres JB, Molina-Rugama AJ. 2008. Predatory behaviour of *Podisus nigrispinus* (Heteroptera: Pentatomidae) on different densities of *Anticarsia gemmatalis* (Lepidoptera: Noctuidae) larvae. Biocontrol Science and Technology 18: 711–719.

Greene GL, Leppla NC, Dickerson WA. 1976. Velvet bean caterpillar: a rearing procedure and artificial medium. Journal of Economic Entomology 69: 487–488.

Hassanpour M, Mohaghegh J, Iranipour S, Nouri-Ganbalani G, Enkegaard A. 2011. Functional response of *Chrysoperla carnea* (Neuroptera: Chrysopidae) to *Helicoverpa armigera* (Lepidoptera: Noctuidae): effect of prey and predator stages. Insect Science 18: 217–224.

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. Journal of Applied Entomology 127: 389–395.

Lemos WP, Ramalho FS, Serrão JE, Zanuncio JC, Bauce E. 2006. Diet affects reproduction and number of oocytes per ovary of the predator *Podisus nigrispinus* (Dallas) (Heteroptera: Pentatomidae). Animal Biology 56: 279–287.

Maia AHN, Luiz AJB, Campanhola C. 2000. Statistical inference on associated fertility life table parameters using Jackknife technique: computational aspects. Journal of Economic Entomology 93: 511–518.

Malaquias JB, Omoto C, Ramalho FS, Wesley WAC, Silveira RF. 2015. Bt cotton and the predator *Podisus nigrispinus* (Dallas) (Heteroptera: Pentatomidae) in the management of *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) resistance to lambda-cyhalothrin. Journal of Pest Science 88: 57–63.

Malaquias JB, Ramalho FS, Souza JVS, Rodrigues KCV, Wanderley PA. 2010. The influence of fennel feeding on development, survival, and reproduction in *Podisus nigrispinus* (Dallas) (Heteroptera: Pentatomidae). Turkish Journal of Agriculture and Forestry 34: 235–244.

Mayntz D, Toft S, Vollrath F. 2003. Effects of prey quality and availability on the life history of a trap-building predator. Oikos 101: 631–638.

Medeiros RS, Ramalho FS, Lemos WP, Zanuncio JC. 2000. Age dependent fecundity and life-fertility tables for *Podisus nigrispinus* (Dallas) (Heteroptera: Pentatomidae). Journal of Applied Entomology 124: 319–324.

Menezes CWG, Camilo SS, Fonseca AJ, Assis Júnior SL, Bispo DF, Soares MA. 2014. A dieta alimentar da presa *Tenebrio molitor* (Coleoptera: Tenebrionidae) pode afetar o desenvolvimento do predador *Podisus nigrispinus* (Heteroptera: Pentatomidae)? Arquivos do Instituto Biológico 81: 250–256.

Molina-Rugama AJ, Zanuncio JC, Torres JB, Zanuncio TV. 1997. Longevidad y fecundidad de *Podisus nigrispinus* (Heteroptera: Pentatomidae) alimentado con *Musca domestica* (Diptera: Muscidae) y frijol. Revista de Biología Tropical 45: 1125–1130.

Neves RCD, Torres JB, Zanuncio JC. 2010. Production and storage of mealworm beetle as prey for predatory stinkbug. Biocontrol Science and Technology 20: 1013–1025.

Oliveira HN, Pratissoli D, Pedruzzi EP, Espindula MC. 2004. Desenvolvimento do predador *Podisus nigrispinus* alimentado com *Spodoptera frugiperda* e *Tenebrio molitor*. Pesquisa Agropecuária Brasileira 39: 947–951.

Santos AA, Almeida LM, Castro-Guedes CF, Penteado SRC. 2014. Life table analysis and consumption capacity for *Harmonia axyridis* (Coleoptera: Coccinellidae), feeding on *Cinara atlantica* (Hemiptera: Aphididae). Florida Entomologist 97: 1702–1709.

SAS INSTITUTE. 1991. SAS/GRAPH software: usage, version 6. First ed. SAS Institute, Cary, North Carolina, USA.

Southwood TRE. 1978. Ecological Methods with Particular Reference to the Study of Insect Populations. Second ed. Chapman and Hall, London, United Kingdom.

Torres JB, Barros EM, Coelho RR, Pimentel RMP. 2010. Zoophytophagous pentatomids feeding on plants and implications for biological control. Arthropod-Plant Interactions 4: 219–227.

Torres JB, Zanuncio JC, Moura MA. 2006. The predatory stinkbug *Podisus nigrispinus*: biology, ecology and augmentative releases for lepidopteran larval control in Eucalyptus in Brazil. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 1: 1–18.

Vacari AM, De Bortoli SA, Goulart RM, Volpe HXL, Otuka AK, Veiga ACP. 2013. Comparison of eggs, larvae, and pupae of *Plutella xylostella* as prey for *Podisus nigrispinus*. Annals of the Entomological Society of America 106: 235–242.

Zanuncio JC, Molina-Rugama AJ, Serrão JE, Pratissoli D. 2001. Nymphal development and reproduction of *Podisus nigrispinus* (Heteroptera: Pentatomidae) fed with combinations of *Tenebrio molitor* (Coleoptera: Tenebrionidae) pupae and *Musca domestica* (Diptera: Muscidae) larvae. Biocontrol Science and Technology 11: 331–337.

Zanuncio JC, Molina-Rugama AJ, Santos GP, Ramalho FS. 2002. Effect of body weight on fecundity and longevity of the stinkbug predator *Podisus rostralis*. Pesquisa Agropecuária Brasileira 37: 1225–1230.

Zanuncio JC, Silva CAD, Lima ER, Pereira FF, Ramalho FS, Serrão JE. 2008. Predation rate of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) larvae with and without defense by *Podisus nigrispinus* (Heteroptera: Pentatomidae). Brazilian Archives of Biology and Technology 51: 121–125.

Zanuncio JC, Tavares WS, Fernandes BV, Wilcken CF, Zanuncio TV. 2014. Production and use of Heteroptera predators for the biological control of eucalyptus pests in Brazil. Ekoloji 23: 98–104.