Phytophagy of the predator *Podisus nigrispinus* (Dallas, 1851) (Hemiptera: Pentatomidae) fed on prey and Brassicaceae

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Abstract

The purpose of this study was to investigate the development and reproduction of the zoophytophagous predator *Podisus nigrispinus* (Dallas) (Heteroptera: Pentatomidae) fed kale, broccoli and cabbage affects its. Nymphs and adults of this predator were fed on larvae of *Plutella xylostella* (L.) (Lepidoptera: Plutellidae) as prey with kale, cabbage, or broccoli. In the nymph period, the duration and prey consumption were similar with all the Brassicacea cultivar. However, nymph viability was higher for predators with broccoli leaves. The mean weight of 5th-instar nymphs, newly emerged females and the sex ratio were similar among the Brassicacea cultivars, while newly emerged males were heavier with kale and broccoli leaves. The supply of broccoli leaves resulted in greater oviposition, higher number of eggs per egg mass and longer longevity of *P. nigrispinus* males and females. Furthermore, the consumption of *P. xylostella* larvae by adult predators was higher with these cultivars. The net reproductive rate (R_0) and mean generation time (T) were highest for predators with prey and broccoli leaves. The reproductive parameters of *P. nigrispinus* were enhanced when fed on *P. xylostella* larvae with and broccoli leaves, which can be an alternative diet in laboratory rearing of this predator.

Keywords: biological control, mass rearing, predatory stinkbug, zoophytophagous.

Fitofagia do predador *Podisus nigrispinus* (Dallas, 1851) (Hemiptera: Pentatomidae) em diferentes brassicáceas

Resumo

O objetivo deste estudo foi verificar o desenvolvimento e reprodução do zoofitófago *Podisus nigrispinus* (Dallas) (Heteroptera: Pentatomidae) em couve, brócolis e repolho. Ninfas e adultos deste predador foram alimentados com lagartas de *Plutella xylostella* (L.) (Lepidoptera: Plutellidae) como presa e receberam folhas de couve, repolho ou brócolis. Durante o período ninfal, a duração do período e o consumo de presas foram semelhantes com as diferentes cultivares de brassicácea. Porém, a viabilidade ninfal foi maior para predadores com folhas de brócolis. O peso de ninfas de quinto instar e de fêmeas recém-emergidas e a razão sexual de *P. nigrispinus* foram semelhantes entre as cultivares de brassicáceas, enquanto que o peso de machos recém-emergidos foi maior com folhas de couve e brócolis. Folhas de brócolis proporcionaram maiores número de oviposições, ovos por postura e longevidade de machos e fêmeas de *P. nigrispinus*. Além disso, o consumo de lagartas de *P. xylostella* por adultos desse predador fora maiores com esta cultivar. A taxa líquida de reprodução (R_0) e o tempo médio de geração (T) foram maiores para predadores com presa e folhas de brócolis. *Podisus nigrispinus* alimentados com lagartas de *P. xylostella* e folhas de brócolis apresentaram melhores parâmetros reprodutivos, podendo ser uma alternativa para a criação deste predador em laboratório.

Palavras-chave: controle biológico, criação massal, percevejo predador, zoofitófago.

1. Introduction

Podisus nigrispinus (Dallas, 1851) (Hemiptera: Pentatomidae) is an important biological control agent in several crops (Medeiros et al., 2000). It can be found in Central and South America (Thomas, 1992), especially in the Neotropics (De Clercq, 2000). In Brazil, *P. nigrispinus* was reported in several States, e.g., Espírito Santo, Maranhão, Minas Gerais, Mato Grosso do Sul, Pará, and São Paulo (Oliveira et al., 2011). *Podisus* species have a generalist feeding habit, but mainly on lepidopteran larvae (Oliveira et al., 2004a).

Due to the ease of rearing this stinkbug in the laboratory, these insects are produced and released in biological control programs of defoliating larvae (Zanuncio et al., 2002). Alternative preys and artificial diets are used to mass rearing this predator *P. nigrispinus* (Fernandes et al., 1996; Zanuncio et al., 1996a; Saavedra et al., 1997; Zanuncio et al., 1996b), in view of the difficulties of using natural prey in the laboratory.

The prey availability and quality can influence the development of *P. nigrispinus* (Valicente and O'Neil 1993; De Clercq et al., 1998; Molina-Rugama et al., 1998a; Mourão et al., 2003). However, this predator can also feed on plants without damaging them (Naranjo and Stimac, 1985; Ruberson et al., 1986; Naranjo and Stimac, 1987; De Clercq and Degheele, 1992; Lemos et al., 2001). This feeding behavior allows the classification of the insect as zoophytophagous (Coll and Guershon, 2002; Azevedo et al., 2007), since the combined use of plants and prey can improve their biological characteristics (Lemos et al., 2001; Oliveira et al., 2002).

There are at least three hypotheses to explain the zoophytophagous habit in predators: (1) equivalence - plants can provide nutrients when prey is absent or scarce; (2) facilitation – plants provides essential nutrients complementary to predation; and (3) independence - plant material provides essential nutrients absent in the prey (Lalonde et al., 1999; Eubanks and Denno, 2000; Gillespie and McGregor, 2000; Sinia et al., 2004).

Dietary habits can change the life cycle of insects, since well-fed individuals reproduce more and more frequently (Lenski, 1984; Molina-Rugama et al., 1997; Chapman, 1998; Molina-Rugama et al., 1998b; Lemos et al., 2001). The objective of this study was to evaluate the development and reproduction of *P. nigrispinus* in three different Brassicacea cultivars to improve laboratory rearing of this predator.

2. Material and Methods

The experiment was carried out in the Laboratory of Biology and Rearing of Insects (LBCI) of the Department of Plant Protection, FCAV/UNESP, in Jaboticabal, São Paulo, Brazil in an air-conditioned room at 25±1 °C, relative humidity of 70±10% and 12-hour photoperiod (12 h light and 12 hours dark). The treatments consisted of three Brassicacea species: kale *Brassica oleracea* var. *acephala* (kales 'Manteiga' hybrid HS-20), cabbage *Brassica oleracea* var. *capitata* (cabbage 'Bob Cat') and broccoli *Brassica oleracea* var. *italic* (broccoli 'Piracicaba'). In the tests, the predatory stinkbug *P. nigrispinus* was fed *ad libitum* on prey *Plutella xylostella* (L.) (Lepidoptera: Plutellidae) larvae. The mass-reared insects used in the experiment were from the LBCI, FCAV/UNESP, Jaboticabal, São Paulo, Brazil.

2.1. Biological parameters of Podisus nigrispinus nymphs feeding on Plutella xylostella larvae as prey and Brassicaceae

A completely randomized design with six replications was used to evaluate *P. nigrispinus* nymph stage. Transparent plastic cylindrical 1000 mL containers (diameter 15 cm, height 10 cm), covered with plastic lid were used. Two tubes (1.5 cm^3) were fixed to the lid, one to provide water and the other to fix a Brassicacea (cabbage, kales or broccoli) leaf.

Each container represented one replication, in which 10 predatory second-instar *P. nigrispinus* nymphs (<24 h old) were placed, which were initially fed with 20 fourth-instar *P. xylostella* larvae and a leaf of one of the Brassicaceae. As the nymphs developed, the number of larvae available increased, avoiding lack of prey, as well as cannibalism. The sterilization of the containers and exchange of water, leaves and containers, as well as evaluations were performed every 48 hours.

The following biological parameters were evaluated in the nymph stage: duration of each stage, duration of the nymph stage, nymph viability and nymph consumption. In addition, 10 to 24 h-old 5^{th}- instar nymphs were weighed per treatment.

2.2. Biological parameters of Podisus nigrispinus adults feeding on Plutella xylostella larvae as prey and Brassicaceae

After adult emergence, 10 pairs were formed per treatment, and one couple per container was placed in a transparent 1000 mL plastic container (diameter 15 cm, height 10 cm), and covered with a plastic lid. Two tubes (1.5 cm^3) were fixed to the lid, one to provide water and the other to fix a Brassicacea (cabbage, kales or broccoli) leaf. Per container, 50 fifth instar *P. xylostella* larvae were offered as prey. The experimental design used was completely randomized with three treatments (kales, cabbage, and broccoli) and 10 replications.

The following biological characteristics were evaluated: weight of newly emerged males and females (<24 h old), longevity of males and females, oviposition period, and total daily number of eggs per female, egg viability and egg incubation period.

2.3. Fertility life table of Podisus nigrispinus

The biological parameters of *P. nigrispinus* determined in three different Brassicaceae were used to establish a life fertility table (Birch, 1948; Silveira Neto et al., 1976; Price, 1984).

From the values of age ranges (x), specific fertility (m_x) and survival probability (l_x) of the life and fertility tables, the net reproductive rate (R_0), the generation time (T), the intrinsic growth rate (r_m), finite increase rate (λ) and the population doubling time (Dt) (Krebs, 1994) were calculated, where $R_0 = \sum(l_x m_x)$; $T = \sum(x l_x m_x)/\sum(l_x m_x)$; $r_m = \ln R_0/T$; $\lambda = e^{rm}$; and $Dt = \ln(2)/r_m$.

2.4. Data analysis

The data of biological parameters were subjected to Taylor's Power Law (Taylor, 1984) for homogenization of the means and reduction of the variances to indicate the best data transformation using arcsin $\sqrt{x/100}$ for the parameters sex ratio and egg viability. Analysis of variance (SAS INSTITUTE, 2000) was used and the means of the Brassicacea treatments were compared by Tukey's test at 5% significance.

The population parameters of the fertility life table were estimated (Maia et al., 2000), using SAS (SAS INSTITUTE, 2000) software, based on the jackknife method for estimating the parameters, confidence intervals, and to allow treatment comparisons.

3. Results

The duration of the second ($F_{2;15}$= 0.26; P>0.05), third ($F_{2;15}$= 3.64; P>0.05), fourth ($F_{2;15}$= 2.13; P>0.05), and fifth ($F_{2;15}$= 0.43; P>0.05) instars and the nymph period ($F_{2;15}$= 0.38; P>0.05) of *P. nigrispinus* fed on *P. xylostella* larvae on different Brassicaceae were similar. However, nymph viability ($F_{2;15}$= 4.09; P<0.05) of this predator on broccoli (80.00%) was longer then on kale (56.67%) and cabbage (61.67%), whereas nymph prey consumption ($F_{2;15}$= 1.75) was similar between treatments, 29.18 (cabbage) to 41.75 (kale) *P. xylostella* larvae per nymph of the predator (Table 1).

The mean weight of fifth-instar nymphs ($F_{2;15}$= 0.68; P>0.05) and newly emerged females ($F_{2;15}$= 0.45; P>0.05) as well as the sex ratio ($F_{2;10}$= 1.04; P>0.05) of insects were similar in all treatments. However, newly emerged males ($F_{2;27}$= 4.23; P<0.05) on cabbage and broccoli had higher mean weight. The mean weight of fifth- instar nymphs was similar between treatments, varying from 17.71 mg (kales and cabbage) to 19.70 mg (broccoli). The weight of newly emerged predator males was higher on kales (33.49 mg) and broccoli (28.61 mg) than on cabbage (23.58 mg), while no differences were observed in the mean weight of newly emerged females, 39.02 mg (cabbage) to 43.35 mg (broccoli). The sex ratio of this predator was similar in the three treatments, 0.44 (broccoli) to 0.68 (cabbage) (Table 2).

The parameters eggs per female ($F_{2;27}$= 6.41; P<0.01), number of ovipositions ($F_{2;27}$= 6.59; P<0.01) and eggs per egg mass ($F_{2;27}$= 3.56; P<0.05) differed between treatments with higher for *P. nigrispinus* nymphs fed on broccoli. The incubation period ($F_{2;27}$= 0.70; P>0.05) and viability ($F_{2;27}$= 1.85; P>0.05) were not different between treatments (Table 3).

The number of eggs per female of this predator ($F_{2;27}$= 3.56; P<0.05) reared on broccoli was 2.38 folds higher than on kale and 2.44 folds higher than on cabbage, indicating that

Table 1. Duration of nymph stages (days), nymph period (days), nymph survival (%), and prey consumption (mean ± SE) by *Podisus nigrispinus* (Heteroptera: Pentatomidae) nymphs fed on *Plutella xylostella* (Lepidoptera: Plutellidae) larvae with leaves of three Brassicacea cultivars. Jaboticabal, São Paulo, Brazil, 2012.

Treatement	Nymph Stages				Nymphal Period	Nymph Survival	Prey Consumption
	2º	3º	4º	5º			
Kales	4.14 ± 0.22 a	2.73 ± 0.98 a	4.12 ± 1.10 a	5.90 ± 1.12 a	18.90 ± 1.65 a	56.67 ± 18.05 b	41.75±13.72 a
Cabbage	4.10 ± 0.75 a	4.18 ± 1.47 a	3.10 ± 0.46 a	5.36 ± 1.01 a	18.74 ± 1.42 a	61.67 ± 14.41 b	29.18 ± 8.04 a
Broccolis	3.95 ± 0.47 a	2.57 ± 0.54 a	3.87 ± 0.61 a	5.85 ± 0.73 a	18.23 ± 1.00 a	80.00 ± 12.65 a	31.55 ± 9.49 a

Means followed by the same letter per column did not differ by Tukey's test (P<0.05).

Table 2. Weight of fifth instar nymphs and of newly emerged males and females (mg) and sex ratio (mean ± SE) of *Podisus nigrispinus* (Heteroptera: Pentatomidae) fed on *Plutella xylostella* (Lepidoptera: Plutellidae) larvae with leaves of three Brassicacea cultivars. Jaboticabal, São Paulo, Brazil, 2012.

Treatement	Weight			Sex Ratio[1]
	5^{th}-instar	Males	Females	
Kales	17.71 ± 2.94 a	33.49 ± 7.58 a	41.49 ± 8.50 a	0.52 ± 0.24 a
Cabbage	17.71 ± 4.57 a	23.58 ± 9.65 b	39.02 ± 13.88 a	0.68 ± 0.22 a
Broccolis	19.70 ± 4.03 a	28.61 ± 4.86 ab	43.35 ± 7.05 a	0.44 ± 0.31 a

Means followed by the same letter per column did not differ by Tukey's test (P<0.05). [1]Original data. Data were transformed to $arcsin\sqrt{x/100}$ for statistical analysis (Taylor, 1984).

Table 3. Number of eggs per female, number of egg mass per female, egg incubation period (days), egg viability (%), and number of eggs per egg mass (mean ± SE) of *Podisus nigrispinus* (Heteroptera: Pentatomidae) fed on *Plutella xylostella* (Lepidoptera: Plutellidae) larvae with leaves of three Brassicacea cultivars. Jaboticabal, São Paulo, Brazil, 2012.

Treatement	Eggs/Female	Clutches	Incubation Period	Viability[1]	Eggs/Clutch
Kales	196.10 ± 57.53 b	5.80 ± 1.77 b	5.12 ± 0.80 a	55.60 ± 11.42 a	23.12 ± 0.54 b
Cabbage	191.90 ± 38.10 b	2.90 ± 2.46 b	5.05 ± 0.73 a	63.79 ± 13.03 a	17.74 ± 0.04 b
Broccolis	467.90 ± 87.12 a	13.10 ± 4.96 a	5.34 ± 0.86 a	59.69 ± 9.75 a	35.76 ± 0.89 a

Means followed by the same letter per column did not differ by Tukey's test (P<0.05). [1]Original data. Data were transformed to $arcsin\sqrt{x/100}$ for statistical analysis (Taylor 1984).

broccoli provided better conditions for oviposition of *P. nigrispinus*. The number of ovipositions ($F_{2;27}$= 6.59; P<0.01) was higher on broccoli (13.10) than on kale (5.80) and cabbage (2.90). The number of eggs per egg mass was higher on broccoli (35.76) compared to kale (23.12) and cabbage (17.74). However, the egg viability ($F_{2;27}$= 1.85; P>0.05) was similar between treatments, i.e., 55.60% (kale), 59.69% (broccoli) and 63.79% (cabbage). This pattern was similar to that of the incubation period ($F_{2;27}$= 0.70; P>0.05), 5.05 days (cabbage), 5.12 days (kale) and 5.34 days (broccoli) (Table 3).

The consumption of adult predators ($F_{2;29}$= 8.19; P<0.01), male ($F_{2;29}$= 15.80; P<0.01) and female ($F_{2;29}$= 18.42; P<0.01) longevities differed, with higher values of the predator with broccoli (Table 4).

The consumption of *P. nigrispinus* adults on broccoli t (306.21 larvae) was higher than with kale (182.21 larvae) and cabbage (172.50 larvae). Female longevity was longer on broccoli (37.86 days) than on kale (17.43 days) and cabbage (23.00 days). Male longevity was highest on broccoli (42.29 days) than on kale (25.00 days), that was higher than on cabbage (8.00 days) (Table 4).

The Brassicaceae affected population parameters of the life table of *P. nigrispinus*. The net reproductive rate (R_0) (75.3 females/female) and generation time (T) (37.6 days) of this predator were higher with broccoli. The intrinsic population increase rate (r_m), finite population increase rate (λ) and the time required for population doubling (TD) were similar between the Brassicacea cultivars (Table 5).

4. Discussion

Development and reproduction of *P. nigrispinus* varied with Brassicacea cultivar. The plant material can have positive effects on the development of predatory stinkbugs even under adverse situations (Lemos et al., 2001). Thus, the reproduction and population growth rates of this insect are high when fed on prey and plants (Guedes et al., 2007).

Podisus nigrispinus feeding on prey with broccoli had improved biological parameters what agrees with that found with *Eucalyptus urophylla* with reduced nymph mortality and increased adult longevity and the number of eggs per female and *P. nigrispinus* nymphs. This indicates that this predator can be fed with both prey and *Eucalyptus* in the field as well as in the laboratory (Holtz et al., 2011).

Results obtained in the present study could be explained because plant material can compensate a possible low nutritional quality of the prey by supplying water and nutrients that would increase weight, reproduction and longevity of these predators (Guedes et al., 2007). The development and reproduction of *Supputius cincticeps* (Stal) and *Brontocoris tabidus* Signoret (Hemiptera: Pentatomidae) was also improved when fed on *T. molitor* pupae on eucalyptus plants with exclusively prey (Zanuncio et al., 2000).

The duration of nymph period with kale (18.90), cabbage (18.74) and broccoli (18.23) were similar to that reported for the nymph period of *P. nigrispinus* fed only on *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) and on pupae of *T. molitor,* respectively, 21.6 and 20.4 days (Oliveira et al., 2004b).

The weight of fifth-instar nymphs and of newly emerged males and females in the three treatments were

Table 4. Consumption of *Plutella xylostella* (Lepidoptera: Plutellidae) larvae and longevity (days) of *Podisus nigrispinus* (Heteroptera: Pentatomidae) adults and longevity (days) of *P. nigrispinus* males and females (mean ±S E) fed on *P. xylostella* larvae with leaves of three Brassicacea cultivars. Jaboticabal, São Paulo, Brazil, 2012.

Treatament	Consumption	Longevity (days)	
		Male	Female
Kales	182.21 ± 21.29 b	25.00 ± 4.41 b	17.43 ± 1.81 b
Cabbage	172.50 ± 30.34 b	8.00 ± 4.31 c	23.00 ± 2.94 b
Broccolis	306.21 ± 31.09 a	42.29 ± 6.90 a	37.86 ± 1.89 a

Means followed by the same letter per column did not differ by Tukey's test (P<0.05).

Table 5. Fertility life table parameters (mean ± SE) of *Podisus nigrispinus* (Heteroptera: Pentatomidae) fed on *Plutella xylostella* (Lepidoptera: Plutellidae) larvae with leaves of three Brassicacea cultivars. Jaboticabal, São Paulo, Brazil, 2012.

Parâmetro[1]	Kales	Cabbage	Broccolis
R_0 (female/female)	57.1 ± 14.08 b[2]	47.6 ± 15.96 b	75.3 ± 13.90 a
T (days)	29.1 ± 6.89 b	28.8 ± 7.49 b	37.6 ± 7.23 a
r_m (fêmeas/fêmea*dia)	0.139 ± 0.0406 a	0.139 ± 0.0272 a	0.115 ± 0.0159 a
Λ (females/females/day)	1.149 ± 0.0463 a	1.149 ± 0.0312 a	1.122 ± 0.0179 a
TD (days)	4.9 ± 1.62 a	4.9 ± 0.98 a	5.9 ± 0.79 a

[1]$R_0 = \sum(l_x m_x)$, for the number of eggs per female per generation, where l_x = proportion of mated females alive at age *x;* m_x = age-specific fecundity rates multiplied by the sex ratio (0.52, 0.68, and 0.43 sex ratio on kale, cabbage, and broccoli, respectively); $T = \sum(x l_x m_x)/\sum(l_x m_x)$; $r_m = \ln R_0/T$; and $\lambda = e^{rm}$; [2]Means ± IC followed by the same letter per row do not differ from each other by the "t" paired comparison test by the Jackknife method.

lower than that of fifth-instar nymphs *and* males and females *P. nigrispinus* fed on *Thyrinteina arnobia* (Stoll, 1792) (Lepidoptera: Geometridae) with guava leaves (Oliveira et al., 2011). The higher weight of females than males was due to the biomass accumulated by females from the fifth-instar stage, necessary for reproduction. The weight gain of the females was also related to the ovary development and egg formation (Oliveira et al., 1999; Oliveira et al., 2002).

The mean number of eggs per *P. nigrispinus* female fed with *P. xylostella* and broccoli (467.90) was higher than with *T. arnobia* larvae on guava trees (314.90) (Oliveira et al., 2011), *Alabama argillacea* (Hüebner, 1818) (Lepidoptera: Noctuidae) on cotton (348.10) (Oliveira et al., 2002), and with *T. molitor* (296.66; 325.00) (Oliveira et al., 2004b; Espindula et al., 2006), *Diatraea saccharalis* (Fabricius, 1794) (Lepidoptera: Pyralidae) (97.12) (Vacari et al., 2007) and *T. arnobia* (57.00) on *Eucalyptus* (Holtz et al., 2006; Holtz et al., 2007). This high number of eggs suggests that the prey *P. xylostella* and broccoli leaf may have higher nutritional values for the predator *P. nigrispinus*.

In the field, plant-derived substances can be an alternative or complementing the diet of predatory bugs (Crum et al., 1998), allowing them to maintain their longevity (Valicente and O'Neil, 1995; Zanuncio et al., 2004). The use of plants as dietary supplement may or may not lead to a better establishment of predatory bug populations, depending on the composition of the agroecosystems (Oliveira et al., 2002). Food source may affect the development and reproduction of these species since the nutritional value of plants depends on their species and natural enemies (Wackers, 2004). The greater viability of nymphs on broccoli leaves indicates that this Brassicacea has a positive influence on the rearing of *P. nigrispinus*.

The use of predatory bugs in biological control programs can reduce the use of insecticides and the environmental impacts they cause. The mass rearing of insects is important to provide natural enemies for research and commercial purposes. The use of *P. xylostella* and broccoli leaves has proved promising in rearing the predator with longer longevity and better reproductive parameters.

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