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Comparative biology and production costs of *Podisus nigrispinus* (Hemiptera: Pentatomidae) when fed different types of prey

Sergio A. De Bortoli [a], Alessandra K. Otuka [a], Alessandra M. Vacari [a,*], Maria I.E.G. Martins [b], Haroldo X.L. Volpe [a]

[a] *Laboratório de Biologia e Criação de Insetos, Departamento de Fitossanidade, Universidade Estadual Paulista FCAV/Unesp, Via de Acesso Prof. Paulo Donato Castellane s/n, 14884-900 Jaboticabal SP, Brazil*

[b] *Departamento de Economia Rural, Universidade Estadual Paulista FCAV/Unesp, Via de Acesso Prof. Paulo Donato Castellane s/n, 14884-900 Jaboticabal SP, Brazil*

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ABSTRACT

The objective of our work was to identify the prey that offers optimum production of the predator, *Podisus nigrispinus* (Dallas). The cost of predator production was determined for each prey. We test the hypothesis that prey types supporting optimal development do not facilitate cost-effective rearing of *P. nigrispinus*. Second-instar nymphs of *P. nigrispinus* were reared in 1000-ml transparent plastic containers and maintained under controlled conditions (temperature, 25 ± 1 °C; photophase duration, 12 h; relative humidity, 70 ± 10%), and the following biological aspects were evaluated: nymph viability, length of the nymphal period, and weight of fifth-instar nymphs. The adults were isolated in pairs (one female and one male) in Petri dishes, and the following biological aspects were evaluated: lifespan, adult weight after emergence, number of eggs per female, egg mass in females, number of eggs per egg mass, durations of the pre-oviposition, oviposition, and post-oviposition periods, viability, and length of the embryonic period. On the basis of our results, we conclude that the prey that leads to optimal development of *P. nigrispinus* is the larvae of *Diatraea saccharalis* (Fabr.), and the most cost effective prey for rearing *P. nigrispinus* is the larvae of *Musca domestica* L.

1. Introduction

Since integrated pest management in agricultural crops was introduced to reduce the use of pesticides, entomologists have faced major challenges in marketing and increasing the use of natural enemies as a method of biological control. Solutions to these challenges include the reduction in the production costs of these agents by improving rearing techniques and increasing their effectiveness in biological control in the field (Tauber et al., 2000).

The effectiveness of using natural enemies as biological control agents depends on how efficiently they can be reared in the laboratory. Chambers (1977) stated that mass rearing is the production of insects with an acceptable cost/benefit ratio. The study of technical and economic aspects of rearing a natural enemy is crucial to its effective use as a biological control agent in the field or greenhouses. According to van Lenteren (2000), the development of techniques of mass production, quality control, storage, transport, and release of natural enemies can lead to a decrease in production costs and improvement in the quality of the product.

The potential of using artificial diets to mass produce generalist predators, including predatory heteropterans, in lieu of natural or factitious prey has been investigated. Feeding an artificial diet rather than natural or factitious prey to the predator, *Podisus nigrispinus* (Dallas) (Hemiptera: Pentatomidae), does not have any benefits (Lemos et al., 2003). For example, predator nymphs reared on an artificial diet weighed significantly less than cohorts fed their natural prey, *Alabama argillacea* Hübner (Lepidoptera: Noctuidae) larvae. Moreover, fresh weight of the ovaries of newly emerged *P. nigrispinus* females was the least for individuals reared on artificial diet than on the yellow mealworm, *Tenebrio molitor* L. (Coleoptera: Tenebrionidae), house fly, *Musca domestica* L. (Diptera: Muscidae), or cotton leafworm, *Spodoptera littoralis* (Boisduval) (Lepidoptera: Noctuidae) larvae. In a subsequent study, Lemos et al. (2005) discovered that food source had a profound impact on ovarian development. Newly emerged *P. nigrispinus* females had ovaries containing oocytes in an advanced stage of development when fed *A. argillacea* larvae, intermediate stage oocytes when fed *T. molitor* or *M. domestica* larvae, and early stage oocytes when fed an artificial diet. Moreover, *P. nigrispinus* showed good growth and high fecundity when fed a factitious prey, *Diatraea saccharalis* (Fabr.) (Lepidoptera: Crambidae) (Vacari et al., 2007). Research on the usefulness of other potential factitious prey that can be produced at low cost is being conducted (Riddick, 2009).

There are some companies that sell *Podisus* spp. in the United States and Europe to control caterpillars. In the United States, 250

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* Corresponding author.
E-mail address: amvacari@gmail.com (A.M. Vacari).

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eggs of the predator *Podisus maculiventris* (Say) (Hemiptera: Pentatomidae) are sold for $133.50 (http://www.arbico-organics.com/). In Minas Gerais State, Brazil, timber companies such as "CAF Florestal Ltda" (Belo Horizonte), "V & M Florestal Ltda" (Paraopeba), and "Refloralje" (Montes Claros) have established laboratories to produce Asopinae predators. The mass production and release of *P. nigrispinus* are based on the rotation cycle of eucalyptus forests (ca. 6–7 years) and forecasts of outbreak periods, allowing the adoption of inoculative release of this predator in areas susceptible to outbreaks (Torres et al., 2006; Vacari and De Bortoli, 2010).

P. nigrispinus is generally reared and maintained in the laboratory; it is fed on the larvae and pupae of *T. molitor* (Zanuncio et al., 2001; Oliveira et al., 2002; Vivan et al., 2002) because this insect is easy to rear. However, there are no reports in the literature on the production cost of this natural enemy. Therefore, the objective of our study was to determine the prey that offers optimum conditions for the establishment of *P. nigrispinus* and to calculate the production cost for each prey tested. In this study, we test the hypothesis that prey types supporting optimal development do not facilitate cost-effective rearing of the predator *P. nigrispinus*.

2. Materials and methods

The study was conducted at the Laboratory of Biology and Rearing of Insect (LBRI), FCAV/Unesp, Jaboticabal, São Paulo. The prey used included larvae of *Anticarsia gemmatalis* Hübner and *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) obtained by mass rearing at Dupont Agrosciences in Brazil located in Paulinia, São Paulo; larvae of *D. saccharalis*, obtained by mass rearing at Usina Santa Adelia located in Jaboticabal, São Paulo; larvae of *T. molitor*, obtained by mass rearing at LBRI, FCAV/Unesp; and larvae of *M. domestica*, obtained by mass rearing at the Laboratory of Frog Culture, CAUNESP, Unesp/Jaboticabal. The nymphs of *P. nigrispinus* were obtained by mass rearing at the LBRI, Department of Plant Protection, FCAV/Unesp, Campus de Jaboticabal.

2.1. Comparative biology

For the experiment, 100 second-instar nymphs were used per treatment. They were placed in two transparent 1000-ml plastic containers (50 nymphs per container); third-instar larvae were added in the container *ad libitum* as prey for the predators. The insects were maintained at a room temperature of 25 ± 1 °C, with a relative humidity of 70 ± 10% and a photophase duration of 12 h. Evaluations were performed daily. Water was provided using a tube fixed on the lid of the container, with the tip turned inwards and a piece of cotton placed in the tube hole to allow supply of water by capillary action. We measured the length of the nymphal period, nymphal consumption, and the weight of fifth-instar nymphs.

After emergence, the adults were isolated in pairs (one female and one male) and transferred to Petri dishes (9 cm × 1.5 cm). The prey species provided to the predators in the nymphal stage were also provided to the predators in the adult stage, and water was supplied via a cotton swab placed in the lid. All eggs were collected, counted, and placed in Petri dishes (6 cm × 2 cm) until hatching. For the adults, the following were determined: weights of recently emerged males and females; lifespan; adult consumption; number of eggs per female; number of eggs per clutch; and durations of the pre-oviposition, oviposition, and post-oviposition periods. For the eggs, length of incubation period and viability were evaluated.

From the biological data of *P. nigrispinus*, the following parameters were determined to construct a fertility life table by using the methods of Birch (1948), Silveira Neto et al. (1976), Southwood (1978), and Price (1984): x, the average age of parental females since emerging from egg stage; lx, life expectancy to age x, expressed as a fraction of females; mx, specific fertility or number of descendents per female produced at age x and that result in females; lx.mx, total number of females born at age x. The growth parameters obtained from the life table were calculated as described by the authors, with R_0 as the net reproductive rate (i.e., the rate of population increase), considering the females from one generation to another or the number of females produced per parental female per generation; T, mean generation time or average lifespan of one generation; r_m, intrinsic rate of increase in number; and λ, finite rate of increase, defined as the number of times the population multiplies in unit time. In addition to these parameters, TD, the time required for the population to double in number, was also determined according to the method of Krebs (1994).

The growth parameters (R_0, T, r_m, λ, and Dt) were calculated using the following equations:

$$R_0 = \Sigma(\mathrm{m}x.\mathrm{l}x)$$

$$T = (\Sigma \mathrm{m}x.\mathrm{l}x.x)/(\Sigma mx.lx)$$

$$r_m = \log R_0/T(0.4343)$$

$$\lambda = \text{anti-log}(r_m = 0.4343)$$

$$Dt = Ln(2)/r_m$$

The experimental design was completely randomized, with five treatments; each treatment included two rearing containers, each containing 50 nymphs of *P. nigrispinus*.

The fertility life table analyses and mean comparisons were done using PROC GLM (SAS Institute, 2002), as described by Maia et al. (2000). The proportion of surviving adults was compared between the treatments by the Kaplan–Meier method, using PROC LIFETEST (SAS Institute, 2002).

The values of the life table parameters were subjected to multivariate cluster analysis (Sneath and Sokal, 1973), and all biological characteristic data were used in the two-way analysis to determine the maximum similarity or the maximum dissimilarity between the groups by using the program Statistica version 7.0 (StatSoft Inc., 2004).

2.2. Production cost

In the second step, we calculated the predator production cost. For this, we used information on the establishment of *P. nigrispinus* in 1000-ml plastic containers with 50 nymphs each.

In Brazil, the production cost consists of the total production cost and the operational cost (Scorvo-Filho et al., 2004). The first includes all operating expenses plus depreciation and the interest on working capital and land remuneration of the investment and of the entrepreneur. The second involves only the operating expenses, including finance charges and depreciation of the physical structure and equipment specific to the activity studied. The total production cost can be divided into fixed and variable costs. Fixed costs are those that do not change with the quantity produced. Variable costs are those that depend on the production volume.

In this study, we considered only the total operational cost (effective operational cost + depreciation cost of specific items for the prey) because we assumed that the producer has a bio-factory where other natural enemies are reared.

The following definition of total operating cost was established by Matsunaga (1976) because of the difficulties in evaluating some fixed-cost items, such as land remuneration of fixed capital and of the entrepreneur, given the subjectivity of their meaning: it consists of items considered as direct costs (labor, supplies, equipment maintenance, and other fees) and costs representing the depreciation of specific materials Matsunaga (1976). Thus, in this structure, the following costs are included: (1) effective operational cost, which represents the annual expenditure incurred for the activity, and (2) total operating cost, which corresponds to effective operating costs, depreciation of the equipment, and specific costs on furniture.

The operating cost calculation allows a comparison of the product to that offered on the market. Such information is important to know whether it is feasible to produce the product and introduce it to the desired market segment (Reis, 2002). Our study considered effective operational costs, including expenses on diet, labor, energy consumed by the equipment, and other materials, as well as depreciation of the equipment and specific expenses on furniture. Effective operational costs on prey were estimated from the data obtained from the production unit of each insect. The depreciation cost of specific equipment and furniture was calculated as follows:

$$D = \frac{V}{\mathrm{VuHu}} * C$$

where D, depreciation; V, value of the equipment; Vu, life of the equipment (in years); Hu, hours of use per year; and C, cycle length in hours.

Adding the operational cost to the cost of depreciation gives the total operating cost of production per cycle (in dollars):

$$\mathrm{TOC} = \mathrm{EOC} + \text{depreciation cost}$$

Where TOC, the total operating cost and EOC, the cost-effective operational cost.

The costs of each prey and each predator were also obtained by dividing the total operating cost by the number of individuals produced per cycle:

$$\text{Insect Cost}i = \frac{\mathrm{TOC}i}{Ni}$$

where TOCi = total operating cost of the insect species i; Ni = number of individuals of species i produced; and i = number of species (1–5).

3. Results

3.1. Comparative biology

To identify which prey led to optimum development of the predator *P. nigrispinus*, we used multivariate statistical techniques that allow the simultaneous evaluation of different biological characteristics. Thus, applying a 2-way analysis allowed us to observe the influence of different types of prey on the biological characteristics of the predator. Feeding *D. saccharalis* larvae resulted in a higher number of nymphs ($F_{4,15} = 5.17$; $P = 0.0081$), and heavier adult females ($F_{4,15} = 5.46$; $P = 0.0064$) with greater fecundity ($F_{4,15} = 10.84$; $P = 0.0002$). In addition, adult females had a shorter pre-oviposition period ($F_{4,15} = 7.52$; $P = 0.0016$) and better reproductive characteristics in a shorter time ($F_{4,15} = 4.16$; $P = 0.0183$) (Fig. 1).

Feeding on different types of prey showed differential effects on the parameters of the fertility life table of *P. nigrispinus* (Table 1). The net reproductive rate (R_0) of the predator was higher when it was fed larvae of *D. saccharalis* (213.1), *S. frugiperda* (162.3), and *M. domestica* (165.3). With regard to the mean generation time (T), the highest values were found for *M. domestica* (41.6) and *D. saccharalis* (39.3), and the lowest value for *S. frugiperda* (36.3). The intrinsic rate of increase (r_m) and the finite rate of increase (λ) were significantly higher for *S. frugiperda* (0.140 and 1.150, respectively), but similar between *A. gemmatalis*, *D. saccharalis*, and *T. molitor*, with values of 0.126 and 1.134, respectively, for *A. gemmatalis*, 0.137 and 1.146, respectively, for *D. saccharalis*, and 0.131 and 1.140, respectively, for *T. molitor*. The population doubling time (Dt) was significantly shorter for *S. frugiperda* (5.0), although it was similar among *A. gemmatalis* (5.5), *D. saccharalis* (5.1), and *T. molitor* (5.3). The fertility life table of *P. nigrispinus* showed that *D. saccharalis* and *S. frugiperda* had higher net reproductive rates, indicating production of a greater number of offspring per generation. Females that fed on *M. domestica* also showed higher mean generation time (T) and longer population doubling time (Dt) because of longer lifespan and lower offspring production during their lifetime (R_0, net reproductive rate).

For the parameters of the fertility life table, the dendrogram shows the formation of 2 groups, A and B (Fig. 2). *M. domestica* shows the greatest contrast to the other types of prey and does not belong to any group. The group formed by *D. saccharalis* and *S. frugiperda* provide better fertility life table parameters for

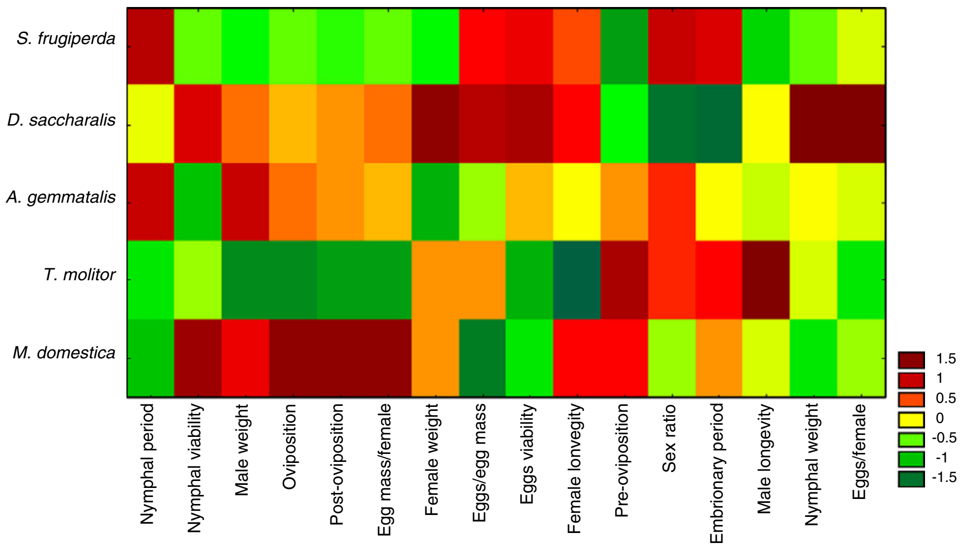

Fig. 1. Two-way analysis of the biological characteristics of *Podisus nigrispinus* fed on different types of prey.

Table 1
Parameters of the fertility life table of *Podisus nigrispinus* fed on different types of prey.

Preys	R_0	T	r_m	λ	Dt
Spodoptera frugiperda	162.3 ± 35.85^{ab}[1] (126.41–198.12)[2]	36.3 ± 1.05^{c} (35.23–37.34)	0.140 ± 0.0037^{a} (0.1360–0.1434)	1.150 ± 0.0043^{a} (1.1456–1.1542)	5.0 ± 0.13^{b} (4.83–5.10)
Anticarsia gemmatalis	126.3 ± 13.63^{b} (112.67–139.94)	38.4 ± 1.25^{bc} (37.17–39.67)	0.126 ± 0.0061^{ab} (0.1198–0.1321)	1.134 ± 0.0070^{ab} (1.1273–1.1412)	5.5 ± 0.27^{ab} (5.24–5.78)
Diatraea saccharalis	213.1 ± 24.29^{a} (188.84–237.41)	39.3 ± 1.90^{ab} (37.42–41.23)	0.137 ± 0.0086^{ab} (0.1279–0.1452)	1.146 ± 0.0099^{ab} (1.1364–1.1562)	5.1 ± 0.32^{ab} (4.78–5.41)
Tenebrio molitor	133.4 ± 59.21^{b} (74.18–192.60)	36.7 ± 0.72^{bc} (36.03–37.46)	0.131 ± 0.0096^{ab} (0.1216–0.1408)	1.140 ± 0.0110^{ab} (1.1293–1.1512)	5.3 ± 0.39^{ab} (4.91–5.70)
Musca domestica	165.3 ± 14.32^{ab} (150.99–179.63)	41.6 ± 0.69^{a} (40.90–42.29)	0.123 ± 0.0032^{b} (0.1196–0.1260)	1.131 ± 0.0036^{b} (1.1270–1.1342)	5.6 ± 0.14^{a} (5.51–5.79)
$F_{(4,15)}$	3.91	12.01	4.18	4.17	4.22
P	0.0228	0.0001	0.0181	0.0182	0.0173

R_0, net reproductive rate (female/female); T, mean generation time (days); r_m, intrinsic rate of increase; λ, finite rate of increase (female/day); Dt, doubling time.

[1] Means and confidence intervals followed by the same letter in the same column did not differ significantly (Tukey's test, $P > 0.05$; F(DF, Error));

[2] Confidence limits.

predators, and is more suitable for the establishment of *P. nigrispinus*, with the band showing the largest Euclidean distance in relation to other prey types. *T. molitor* and *A. gemmatalis* are similar, forming another group (B) that is considered intermediate prey for rearing *P. nigrispinus* (Fig. 2).

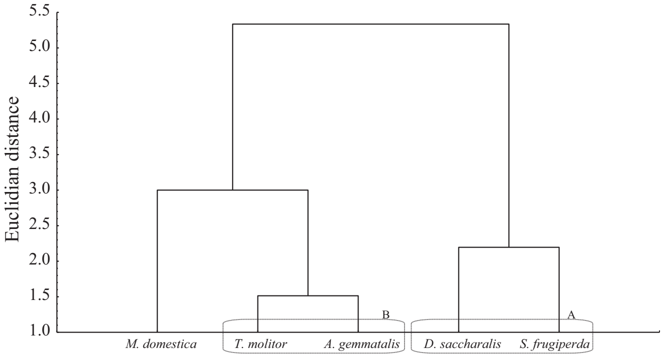

Fig. 2. Dendrogram showing the clustering of prey based on the life table parameters of *Podisus nigrispinus* fertility.

3.2. Cost of production

The quantitative planning in the rearing of *P. nigrispinus* was done considering the following data: a female predator fed on *D. saccharalis* produces an average of 797.7 eggs per cycle, *S. frugiperda* averages 442.0, *A. gemmatalis* averages 441.6 *T. molitor* averages 328.6 and *M. domestica* averages 407.8. The data were estimated considering an initial rearing population density of 1200 predators. These eggs were kept in glass Petri dishes (12 cm × 20 cm) and had average viabilities of 90%, 86%, 81%, 70%, and 73% and nymphal viabilities of 76%, 60%, 55%, 61%, and 80%, respectively, with average productions of 654,760 adults per cycle with *D. saccharalis*, 236,079 with *A. gemmatalis,* 547,410 with *S. frugiperda*, 168,359 with *T. molitor*, and 285,758 with *M. domestica*. Of the total number of individuals produced, 1200 pairs were returned to rearing conditions; thus, this system produced around 652,360 adults per cycle with *D. saccharalis*, 233,679 with *A. gemmatalis*, 545,010 with *S. frugiperda*, 165,959 with *T. molitor*, and 283,358 with *M. domestica*, which can be commercially sold or released in the field. Since the insects were reared in an acclimatized room, we obtained 7.5 cycles of 48–49 days per year with *D. saccharalis* and *A. gemmatalis*, 7.1 cycles of 51.2 days per year

Table 2
Operating costs per production cycle and per predator for *Diatraea saccharalis*, *Anticarsia gemmatalis*, *Spodoptera frugiperda*, *Tenebrio molitor*, and *Musca domestica* (US$).

Prey	*Diatraea saccharalis* US$[c]/ cycle	*Anticarsia gemmatalis* US$/ cycle	*Spodoptera frugiperda* US$/ cycle	*Tenebrio molitor* US$/ cycle	*Musca domestica* US$/ cycle
Matrices					
Labor cost	44.17	141.35	141.35	0.98	3.31
Costs on equipment and energy	70.55	291.47	291.47	15.05	0.00
Diet	29.21	29.21	29.21	0.78	0.48
Materials	2.48	0.49	0.49	0.00	0.00
Caterpillars					
Labor cost	128.83	212.02	212.02	0.98	3.68
Costs on equipment and energy	18.38	7.15	7.15	15.05	0.00
Diet	51.89	45.22	45.22	1.59	0.32
Materials	768.03	52.07	52.07	0.00	0.00
Operational cost	1117.59	778.96	778.96	34.43	7.61
Depreciation of specific materials	46.77	36.54	36.54	21.80	0.25
TOC[a]	1164.36	815.50	815.50	56.27	8.05
Production[b] (individuals/ cycle)	39,520	50,000	50,000	4000	8500
TOC/insect	0.03	0.018	0.018	0.012	0.001

[a] Total operating cost (TOC) considering only the depreciation of specific materials.

[b] Number of individuals produced per cycle was obtained from each production unit.

[c] Currency Exchange quote for Brazilian Real (R$) to US Dollar (US$) 1.0 Brazilian Real = 0.601 US Dollar.

Table 3
Operating costs (US$) (per production cycle and per predator) of *Podisus nigrispinus* fed on different types of prey.

Treatments	*Podisus nigrispinus* *?tul?>* fed on *Diatraea saccharalis* US$[b]/cycle	*Podisus nigrispinus /ce:italic> fed on Anticarsia gemmatalis US$/cycle*	*Podisus nigrispinus /ce:italic> fed on Spodoptera frugiperda US$/cycle*	*Podisus nigrispinus /ce:italic> fed on Tenebrio molitor US$/cycle*	*Podisus nigrispinus /ce:italic> fed on Musca domestica US$/cycle*
Matrices (1200 insects)					
Labor	39.78	39.78	39.78	39.78	39.78
Equipment and energy	49.52	49.52	49.52	49.52	49.52
Diet	45.01	26.84	27.06	17.32	2.39
Materials	1.47	1.47	1.47	1.47	1.47
Costs until adult emergence					
Labor	69.00	69.00	69.00	69.00	69.00
Equipment and energy	49.52	49.52	49.52	49.52	49.52
Diet	16,088.53	3314.66	8066.51	3789.42	499.64
Materials	2.10	2.10	2.10	2.10	2.10
Operational cost	16,345.03	3552.91	8304.97	4018.14	713.45
Depreciation of specific materials	14.74	14.74	14.74	14.74	14.74
TOC[a]	16,359.78	3567.65	8319.72	4032.89	728.19
Production (individual/cycle)	652,360	233,679	545,010	165,959	283,358
TOC/insect	0.024	0.018	0.018	0.024	0.002

[a] Total operating cost (TOC) considering only the depreciation of specific materials.

[b] Currency Exchange quote for Brazilian Real (R$) to US Dollar (US$) 1.0 Brazilian Real = 0.601 US Dollar.

with *S. frugiperda*, 9.2 cycles of 39.7 days per year with *T. molitor*, and 7.7 cycles of 47 days per year with *M. domestica*.

For *D. saccharalis*, the cost of production was higher because of the high cost of materials (cotton, string, petri dishes, etc.) used in the experiments (Table 2). The higher cost of producing *M. domestica* was because of the high labor costs. The estimated production cost of the predator *P. nigrispinus* in a laboratory rearing system was US$ 0.024 when fed with the prey *D. saccharalis,* US$ 0.018 with *A. gemmatalis,* US$ 0.018 with *S. frugiperda,* US$ 0.024 with *T. molitor,* and US$ 0.002 with *M. domestica* (Table 3).

The cost of producing the predator was lower with *M. domestica* larvae, but its development was better with *D. saccharalis* larvae, although the predator's nymphal period was shorter with both types of prey. The predator production was higher when fed on *D. saccharalis*, almost double that when fed on *M. domestica*.

4. Discussion

The determination of population increase due to reproductive capacity is a crucial component of population studies. This increase can be analyzed with a fertility life table, which shows the reproductive potential of females at different times (Medeiros et al., 2000). The intrinsic rate of increase is represented by the combination of R_0 and T, and when the predator has lower offspring production in the same time span and/or has a longer lifespan, the r_m value becomes smaller (Vacari, 2006).

Vacari (2006) obtained the following values for the fertility life table parameters for *P. nigrispinus* that fed on *D. saccharalis* larvae: net reproductive rate (R_0), 78.18; mean generation time (T), 41.38; intrinsic rate of increase (r_m), 0.1053; finite rate of increase (λ), 1.1111; and doubling time of the initial population (Dt), 6.58. These values show that this prey provides the best parameters in the life table. These values are different from the values obtained in our study. The laboratory conditions were similar, and the prey were from the same population. However, the predators were reared in different numbers and in different containers.

Watanabe et al. (1997) also estimated the parameters for *P. nigrispinus* that fed on *A. gemmatalis* larvae and found lower values, with the number of female offspring per female (R_0) being only 13.02, mean generation time (T) being 13.02, the intrinsic rate of increase (r_m) being 0.0809, and the doubling time of the initial population (Dt) being 8.85. The fertility life table showed that feeding on *D. saccharalis* larvae provided greater production of offspring per generation than feeding on *A. gemmatalis* larvae. The highest values of r_m (combination of R_0 and T) for the predators that fed on *S. frugiperda* and *D. saccharalis* can be explained by the greater production of offspring within the indicated time span and/or shorter lifespan (Evangalista Júnior et al., 2003).

Evangalista Júnior et al. (2004) fed *P. nigrispinus* under conditions of partial prey scarcity (3 days without food) and provided *T. molitor* pupae and plants (*Amaranthus hybridus* L. [Amaranthaceae], *Desmodium tortuosum* Sw. [Leguminoseae], *Euphorbia heterophylla* L. [Euphorbiaceae], *Ageratum conyzoides* L. [Compositae], *Bidens pilosa* L. [Asteraceae], *Ricinus communis* L. [Euphorbiaceae], and *Gossypium hirsutum* L. r. *latifolium* Hutch. [Malvaceae] cv. CNPA Early 1) as food supplements. They found that the life table parameters were better with some plants (*D. tortuosum* and *Ageratum conyzoides*) than they were with *A. argillacea* larvae. The values of these parameters were higher for all the plants studied, even when there was no food scarcity and no plant supplements (the same as indicated above). The highest values for R_0, T, r_m, and λ were 185.5 (*A. conyzoides*), 36.3 (*A. conyzoides*), 0.1525 (*B. pilosa*), and 1.1647 (*B. pilosa*), respectively (Evangalista Júnior et al., 2003).

The values obtained by Peluzio (2008) for the parameters of the fertility life table showed that for this predator, *T. molitor* was more suitable than *A. gemmatalis*. This result was not consistent with those obtained by us. This difference was probably due to the use of *T. molitor* pupae instead of larvae, indicating that *T. molitor* pupae can be more nutritious than the larvae. According to the author, *P. nigrispinus* can be reared with *T. molitor* with the aim of increasing the populations of this predator in the field for biological control of *A. gemmatalis*.

In terms of cost of production, one way to reduce material costs is to switch production to a larger scale, since rearing insects in large quantities can optimize the system, leading to economies of scale (i.e., reducing the cost per unit produced).

M. domestica had the lowest cost (Table 2) because this insect is less demanding in terms of the production process; fewer devices are required to maintain the climatic conditions of the laboratory since this prey can be reared at ambient temperature and produces a large number of individuals per cycle.

Mendes et al. (2005) calculated the cost of producing *Orius insidiosus* (Say) (Hemiptera: Anthocoridae) and observed that labor costs accounted for 62% of the total production cost. According to Parra (2002), in Brazil, labor costs represent 60–80% of the total cost of producing this predator in the laboratory.

Therefore, rearing predators on *D. saccharalis* can lead to greater production at the same initial population and time interval. However, economically, larvae of *M. domestica* are more viable because the final cost of rearing this prey is 10 times lower than that for *D. saccharalis*. The estimated cost of producing *P. nigrispinus* was lower than that for the pirate bug *O. insidiosus*, as reported by Mendes et al. (2005). However, one should bear in mind that we did not compute the depreciation of buildings and equipment, which would increase the cost of production.

In summary, producing the predator *P. nigrispinus* was almost twelve times as costly when they were fed *D. saccharalis* rather than *M. domestica*. Although *D. saccharalis* larvae are the best prey for the optimal development of *P. nigrispinus*. *M. domestica* larvae are the prey that gives the lowest cost of production of the predator *P. nigrispinus*.

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