Development of the predatory pentatomid *Picromerus bidens* (L.) at various constant temperatures

Kamran Mahdian[1,2], Luc Tirry[1] & Patrick De Clercq[1*]

[1] **Laboratory of Agrozoology, Department of Crop Protection, Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium**

[2] **Department of Crop Protection, Faculty of Agriculture, Vali-e-Asr University of Rafsanjan, Rafsanjan, Iran**

Corresponding author : * Patrick De Clercq, Department of Crop Protection, Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium. E-mail: patrick.declercq@ugent.be

ABSTRACT. Development of the palearctic predatory heteropteran *Picromerus bidens* was assessed at constant temperatures (15, 18, 20, 23, 27, 32 and 35±1°C) using larvae of the cotton leafworm *Spodoptera littoralis* as prey. All experiments were done at a 12:12 (L:D) h photoperiod and 65±5% relative humidity. The predator developed to maturity between 18 and 32°C, but eggs failed to hatch at 15 and 35°C. Duration of development of the different immature stages of *P. bidens* decreased with increasing temperature from 18 to 32°C. The total development time for *P. bidens* ranged from 24.8 days at 32°C to 85 days at 18°C. The estimated lower thresholds for development varied between life stages and ranged from 8 to 16°C. The thermal requirements for development of the egg stage, completion of the nymphal period and total development of *P. bidens* were estimated to be 208, 270 and 500 degree-days with lower thresholds of 10.5, 13.8 and 12.2°C, respectively. Upper threshold temperature for development of eggs and nymphal stages was estimated to be between 32 and 35°C. Egg hatch percentage, nymphal survival and sex ratio were determined at each temperature. The data reported here should be helpful in predicting development of *P. bidens* populations in the field and offer valuable basic information for the use of this native predator in biological control programs.

KEY WORDS : *Picromerus bidens*, Pentatomidae, predator, temperature thresholds, thermal requirements

INTRODUCTION

Picromerus bidens (Linnaeus) is a predatory pentatomid, which is widely distributed in the western Palearctic region. In the Nearctic region this species has been recorded from more than 180 locations in North America since its introduction some time before 1932 (Larivière & Larochelle, 1989). This pentatomid is associated with a wide range of habitats including wet and dry areas such as bushes, fields and forests, where it prefers shrubby areas rich in woody plants (trees or bushes), but it is also found on herbaceous plants (Schumacher, 1911; Mayné & Breny, 1948; Southwood & Leston, 1959). *P. bidens* is a polyphagous predator that preys on larvae of many Lepidoptera, Coleoptera and leaf-eating Hymenoptera, and more rarely on pupae and adults of soft-bodied insects (Javahery, 1986; Larivière & Larochelle, 1989). Several authors have emphasized the potential of *P. bidens* for reducing populations of insect pests in a variety of ecosystems (see De Clercq, 2000).

P. bidens may be a possible alternative for the exotic species *Podisus maculiventris*, (Say) which is indigenous throughout North America. There have been multiple introductions of this species in Europe since the 1930s for classical biological control of the Colorado potato beetle, *Leptinotarsa decemlineata* (Say) but the predator has never succeeded in establishing. From the late 1990s up to recently, *P. maculiventris* was commercially available in Europe for augmentative biological control of caterpillar pests in greenhouse crops. However, commercialization of this exotic polyphagous predator was discontinued as a result of growing environmental concerns (van Lenteren et al., 2003). Considerable knowledge exists on the seasonal cycle of *Picromerus bidens* (Mayné & Breny, 1948; Javahery, 1986; Musolin, 1996; Musolin & Saulich, 2000) but information regarding the effect of climate on the bio-ecology of this species is still scarce. Understanding the relationship between temperature and development of arthropod predators is essential for accurately predicting natural enemy interactions with pests (Rosen & Huffaker, 1983; Obrycki & Kring, 1998; Nechols et al., 1999). Although temperature is only one of the ecological factors in predator-prey dynamics, it is a primary factor affecting the ability of a predator to regulate pest populations. The objective of the current study was to determine the temperature-dependent development of the different immature stages of *P. bidens* at constant temperatures.

MATERIALS AND METHODS

A culture of *P. bidens* was started with eggs originating from a laboratory colony at the Department of Entomology and Biological Control, All-Russian Research Institute for Plant Quarantine, Moscow, Russia. The colony of *P. bidens* used in this study was maintained at 23±1°C, 65±5% relative humidity (RH), and a 12:12 (L:D)h photoperiod. The food of the stock colony of the predator consisted mainly of larvae of the cotton leafworm *Spodoptera littoralis* (Boisduval) reared on an artificial diet modified from Poitout & Bues (1970).

Eggs of *P. bidens* undergo obligatory diapause and need to be stored at low temperatures (2-3°C) for at least one month to initiate embryonic development. Egg masses that underwent such cold treatment were used in the experiments on development. Development of *P. bidens* was monitored under the following constant temperatures: 15, 18, 20, 23, 27, 32 and 35±1°C. All experiments were done at a 12:12 (L:D) h photoperiod and 65±5% RH. At each temperature, development of the egg stage was monitored using 100 eggs and development of nymphs was followed starting with 40 first instars. Egg batches were taken from cold storage, transferred to plastic Petri dishes (9cm diameter) and placed in incubators at each of the test temperatures. Development of incubated eggs was monitored daily and hatching recorded. Newly emerged nymphs (less than 12h old) of *P. bidens* were transferred to individual Petri dishes (9cm diameter) lined with absorbent paper. A moist paper plug fitted into a small plastic cup provided water. Nymphs were offered prey from the second instar onwards because, as in other asopines, first instars of *P. bidens* do not feed and only take up water (De Clercq, 2000). Upon reaching the second instar, the predator was fed daily with an excess of fifth instars of the cotton leafworm *S. littoralis*. Nymph development and survival of *P. bidens* were monitored on a daily basis. Sex was determined when the individuals reached the adult stage.

Development rate of each immature stage of *P. bidens* was calculated using the reciprocal of the average development duration (i.e., 1/d). The relationship between development rate and temperature was described by a linear regression model (Arnold, 1959) fit to the linear section of the data points. Temperature points above and below the linear portion of the development rate curve were not used to estimate thermal requirements (in degree-days or DD) or lower threshold temperatures. The lower temperature thresholds for each of the immature stages of *P. bidens* were determined as the *x*-intercept (t=-a/b) (Arnold, 1959) and the degree-day requirements (K) were determined as the inverse of the slope (k=1/b) of the regression lines (Campbell et al., 1974).

TABLE 1

Duration (days) of the immature stages of *P. bidens* at five constant temperatures

Stage	Temperature				
	18°C	20°C	23°C	27°C	32°C
Egg	32.62±0.48	22.70±0.30	14.44±0.34	12.78±0.15	10.14±0.10
First instar	8.35±0.20	5.56±0.07	4.61±0.08	3.43±0.09	2.00±0.00
Second instar	9.15±0.22	7.54±0.12	6.07±0.19	4.56±0.16	3.20±0.07
Third instar	8.52±0.27	7.50±0.23	6.02±0.28	4.56±0.16	2.82±0.09
Fourth instar	9.46±0.29	8.23±0.25	6.45±0.16	3.79±0.10	2.82±0.10
Fifth instar	13.13±0.24	11.23±0.12	9.84±0.14	6.30±0.28	4.18±0.08
Total nymph period	47.60±1.08	39.80±0.46	32.40±0.42	19.26±0.34	14.80±0.21
Total development	85.00±1.39	62.43±0.59	47.32±0.50	35.77±0.46	24.75±0.27

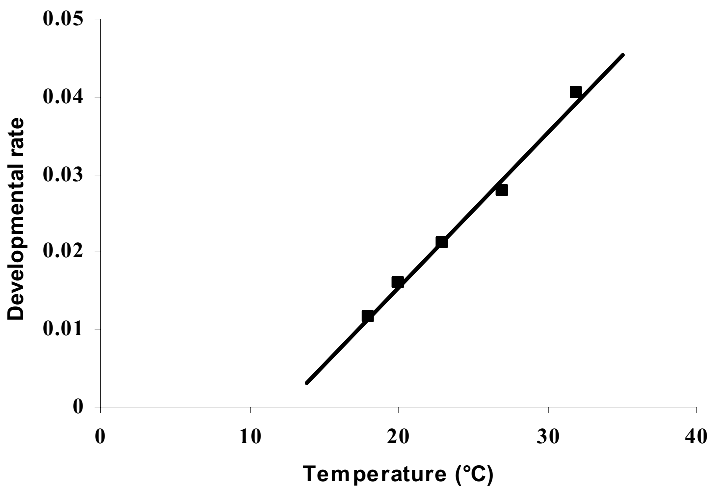

Fig. 1. – The relationship between temperature and development rate for total development (egg-adult) of *P. bidens* at constant temperatures. The line represents the linear regression of the data between 18 and 32°C.

RESULTS

Picromerus bidens developed to adulthood between 18 and 32°C, but eggs failed to hatch at 15 and 35°C, dying without any observed evidence of embryonic development. Therefore, the temperatures tested encompassed the range of constant temperatures allowing complete development of the predator. The total time for development of *P. bidens* ranged from 24.8 days at 32°C to 85 days at 18°C. Linear regression equations of development rate of each life stage versus temperature are given in Table 1. Fig. 1 shows the relationship between temperature and development rate for the total development (egg-adult) of *P. bidens*. High coefficients of determination (r^2>0.97, P<0.001) indicated a good linear model fit in all cases. The lower development threshold values and degree-day requirements for each life stage of *P. bidens* are presented in Table 2. The estimated lower thresholds for development varied between life stages and ranged from 8 to 16°C. The thermal requirement for development of the egg stage after cold storage was 208DD with a lower threshold of 10.5°C. The thermal requirement for completion of the nymphal period was 270DD with a lower threshold of 13.8°C. Total development of *P. bidens* required 500DD with a lower threshold of 12.2°C. Rapid decline of development rate between 32 and 35°C suggests that the upper threshold temperature for development (i.e. the temperature above which the rate of development starts decreasing) of eggs and nymphal stages was within this temperature range.

Egg hatch ranged from 65 to 86% at temperatures between 18 and 23°C and averaged 84 and 69% at 27 and 32°C, respectively (Table 3). Survival of nymphs increased from 28 to 69% with increasing temperature from 18 to 23°C, and subsequently decreased to 59% as temperature further increased up to 32°C (Table 3). Sex ratios of *P. bidens* adults ranged from 1 male: 0.6 female to 1 male: 1.7 female at the tested temperatures.

TABLE 2

Lower development thresholds (t), degree-day requirements (K) and linear regression equations and coefficients of determination for development of the immature stages of *P. bidens* at different constant temperatures

Stage	t (°C)	K (DD)	Regression equation	r^2	P
Egg	10.48	208.33	Y=-0.0503+0.0048X	0.97	<0.001
First instar	10.94	54.94	Y=-0.1991+0.0182X	0.98	<0.001
Second instar	9.12	81.96	Y=-0.1113+0.0122X	0.99	<0.001
Third instar	8.21	86.95	Y=-0.0945+0.0115X	0.99	<0.001
Fourth instar	14.48	49.26	Y=-0.2941+0.0203X	0.98	<0.001
Fifth instar	16.50	64.93	Y=-0.2541+0.0154X	0.99	<0.001
Total nymph period	13.76	270.27	Y=-0.0509+0.0037X	0.98	<0.001
Total development	12.25	500.00	Y=-0.0245+0.002X	0.99	<0.001

TABLE 3

Egg hatch, nymph survival, and sex ratio of adults of *P. bidens* at five constant temperatures

Temperature (°C)	Egg hatch (%)	Nymph survival (%)	Sex ratio (male: female)
18	65	28	1:0.6
20	71	48	1:0.9
23	86	69	1:1.7
27	84	60	1:1.0
32	69	59	1:0.9

DISCUSSION

Mayné & Breny (1948) reported that the second, third and fourth nymphal stadia of *P. bidens* are of equal length, about 12 to 14 days each, whereas the fifth stadium takes somewhat longer and total nymph time is about two months under summer field conditions in Belgium. These authors also noted that 30 to 35 days are required for development of *P. bidens* on larvae of *Ephestia kuehniella* Zeller, 1879, at a constant temperature of 25-26°C. Javahery (1986) reported that development duration of the nymphal stage of the insect in Québec was 44 days in field cages, and development of the first, second, third, fourth and fifth instars took on average 8, 8, 9, 9 and 10 days, respectively. Musolin & Saulich (2000) noted that different photoperiods had no effect on nymph development of *P. bidens* at 24.5°C. Nymph development took 25 to 26 days at different photoperiods except for nymphs reared at a 20:4 (L:D) h photoperiod, which took 28 days to develop (Musolin & Saulich, 2000). These authors showed that nymph duration of this predator averaged 36 days under field conditions in the Belgorod region of Russia. The development durations found in the current study are comparable with those previously reported by above-mentioned authors.

We know of no other studies in which temperature thresholds and thermal requirements for development of *P. bidens* have been estimated. Mahdian et al. (2006) indicated that predation behaviour of *P. bidens* was affected by temperature; all nymphal stadia of *P. bidens* from the second instar onward were able to prey successfully upon fourth-instar *S. littoralis* at temperatures between 18 and 27°C. Mean daily prey consumption by male and female adults of *P. bidens* increased with increasing temperature. Further, these authors showed that the type of functional response (i.e. the relationship between rate of prey consumption and prey density) of *P. bidens* switched from type II to type III as temperature increased from 18 to 27°C.

Several linear and nonlinear models have been proposed to describe the relationship between temperature and arthropod development (Campbell et al., 1974; Wagner et al., 1984; Lactin et al., 1995; Briére et al., 1999). The linear equation has been documented as a suitable model for calculation of lower development thresholds and thermal constants in a partial temperature range (e.g., Campbell et al., 1974; Honěk, 1999; Jarošik et al., 2002; Kontodimas et al., 2004). The variability of the estimated thermal thresholds for the successive developmental stages of *P. bidens* suggests, however, that the linear degree-day model may not always yield accurate estimates. For instance, the linear model estimated the lower thermal threshold for egg development of *P. bidens* to be 10.5°C, whereas our observations showed that eggs did not develop successfully at a constant temperature of 15°C. Further, estimates of lower development thresholds of fourth and fifth instars were considerably higher than those of the earlier instars. Other models, including nonlinear regression, may enable a more accurate description of the relationship between development of immature stages of *P. bidens* and temperature (for a review, see Kontodimas et al., 2004); however, non-linear models do not enable the calculation of thermal constants. Also given its ease of use, the linear degree-day model has therefore been widely used as a phenological model (Kontodimas et al., 2004).

The results of the current study on *P. bidens*, together with reported high predation capacities of this predator against noctuid caterpillars within a wide range of temperatures, indicate that *P. bidens* may perform well when released as a biological control agent of defoliator pests both in open fields and heated glasshouses. Whereas temperature is one factor that is important for the establishment of the predator's population in the crop and that will determine its foraging and predation capacity, there are considerable environmental complexities that may affect the predator-prey system and will eventually determine the outcome of a biological control programme. Nevertheless, the current data will be useful in the selection of the most effective life stage of the predator that is best adapted to conditions favouring the target pest in a given crop situation.

ACKNOWLEDGEMENTS

The statistical suggestions of Mohammad Amin Jalali are gratefully acknowledged. The authors are grateful to the Ministry of Science, Research and Technology of Iran for financial support to K. Mahdian (Ph.D. grant no. 781153)

REFERENCES

Arnold CY (1959). The determination and significance of the base temperature in a linear heat unit system. Proceedings of the American Society for Horticultural Science, 74: 430-445.

Briére JF, Pracros P, Le Roux AY & Pierre JS (1999). A rate model of temperature-dependent development for arthropods. Environmental Entomology, 28: 22-29.

Campbell A, Frazer BD, Gilbert N, Gutierrez AP & Mackauer M (1974). Temperature requirements of some aphids and their parasites. Journal of Applied Entomology, 11: 431-438.

De Clercq P (2000). Predaceous stinkbugs (Pentatomidae: Asopinae). In: Schaefer CW & Panizzi AR (eds), Heteroptera of Economic Importance. CRC Press, Boca Raton: 737-789.

Honěk A (1999). Constraints on thermal requirements for insect development. Entomological Science, 2: 615-621.

Jarošik V, Honěk A & Dixon AFG (2002). Developmental rate isomorphy in insects and mites. American Naturalist, 160: 497-510.

Javahery M (1986). Biology and ecology of *Picromerus bidens* (Hemiptera: Pentatomidae) in southeastern Canada. Entomological News, 97: 87-98.

Kontodimas DC, Eliopolous PA, Stathas GJ & Economou LP (2004). Comperative temperature-dependent development of *Nephus includens* (Kirsch) and *Nephus bisignatus* (Boheman) (Coleoptera: Coccinellidae) preying on *Planococcus citri* (Risso) (Homoptera: Pseudococcidae): evaluation of linear and various nonlinear models using specific criteria. Environmental Entomology, 33: 1-11.

Lactin DJ, Holliday NJ, Johnson DL & Craigen R (1995). Improved rate model of temperature-dependent development by arthropods. Environmental Entomology, 24: 68-75.

Larivière MC & Larochelle A (1989). *Picromerus bidens* (Heteroptera: Pentatomidae) in North America, with a world review of distribution and bionomics. Entomological News, 100: 133-145.

Mahdian K, Vantornhout I, Tirry L & De Clercq P (2006). Effects of temperature on predation by the stinkbugs *Picromerus bidens* and *Podisus maculiventris* (Heteroptera: Pentatomidae) on noctuid caterpillars. Bulletin of Entomological Research, 96: 489-496.

Mayné R & Breny R (1948). *Picromerus bidens* L.: Morphologie. Biologie. Détermination de sa valeur d'utilisation dans la lutte biologique contre le doryphore de la pomme de terre – la valeur économique antidoryphorique des Asopines indigènes belges. Parasitica, 4: 189-224.

Musolin DL (1996). Photoperidic induction of aestivation in the stink bug *Picromerus bidens* (Heteroptera: Pentatomidae). A preliminary report. Entomological Review, 76: 1058-1060.

Musolin DL & Saulich AH (2000). Summer dormancy ensures univoltinism in the predatory bug *Picromerus bidens*. Entomologia Experimentalis et Applicata, 95: 259-267.

Nechols JR, Tauber MJ, Tauber CA & Maskai S (1999). Adaptations to hazardous seasonal conditions: dormancy, migration, and polyphenism. In: Huffaker CB & Guttierez AP (eds), Ecological entomology. 2nd ed. Wiley, New York: 159-200.

Obrycki JJ & Kring TJ (1998). Predaceous Coccinellidae in biological control. Annual Review of Entomology, 43: 295-321.

Poitout S & Bues R (1970). Elevage de plusieurs espèces de lepidoptères Noctuidae sur milieu artificiel riche et sur milieu artificiel simplifié. Annales de Zoologie, Ecologie Animale, 2: 79-91.

ROSEN D & HUFFAKER DR (1983). An overview of desired attributes of effective biological control agents, with particular emphasis on mites. In: HOY MA, CUNNINGHAM GL & KNUSTON L (eds), Biological control of pests by mites. University of California, Berkeley: 2-11.

SCHUMACHER F (1911). Beiträge zur Kenntnis der Biologie der Asopiden. Zeitschrift für wissenschaftliche Insektenbiologie, 7: 40-47.

SOUTHWOOD TRE & LESTON D (1959). Land and water bugs of the British Isles. Frederick Warne and Co., London, U.K.

VAN LENTEREN J, BABENDREIER D, BIGLER F, BURGIO G, HOKKANEN HMT, KUSKE S, LOOMANS AJM, MENZLER-HOKKANEN I, VAN RIJN PCJ, THOMAS MB, TOMMASINI MG, & ZENG QQ (2003). Environmental risk assessment of exotic natural enemies used in inundative biological control. BioControl, 48: 3-38.

WAGNER TL, WU HI, SHARP PJH, SCHOOLFIELD RM & COULSON RN (1984). Modeling insect development rates: a literature review and application of a biophysical model. Annals of the Entomological Society of America, 77: 208-225.

Received: August 8, 2006
Accepted: November 16, 2007