ENTOMOPHAGA 42 (3), 1997, 359-366

DEVELOPMENTAL RATE OF *OPIUS CONCOLOR* (*HYM.: BRACONIDAE*) AT VARIOUS CONSTANT TEMPERATURES

A. LONI

Dipartimento Coltivazione e Difesa delle Specie Legnose, Sezione Entomologia Agraria, Università di Pisa, 56100 Pisa, Italy

Opius concolor Szépligeti is a parasite of *Bactrocera oleae* (Gmelin) and other Tephritid flies. Its development rate was studied with the Sharpe-DeMichele mathematical model, modified by Schoofield *et al.* (1981), using the S.A.S. program elaborated by Wagner *et al.* (1984). This program chose a four parameter poikilotherm model with high temperatures inhibition. Duration of parasitoid development at seven constant temperatures ranged from 14.6 ± 1.7 days at 28°C (males), to 77.2 ± 5.5 days at 15°C (females). Male development was consistently found to be shorter than that of females. Low development threshold and degree-days needed to complete total development were determined with the "Regression Line" and "Thermal Summation" methods. Values (cumulated for both sexes) were found to be respectively 11.7°C and 11.8°C (low threshold), 255.9 and 251.9 ± 16.8 days (thermal constant). Considerations on the possibility of establishing *Opius concolor* in northern and central Italian regions are discussed.

KEY-WORDS: biological control, development, temperature influence, parasitoid establishment.

Opius concolor Szépligeti is a koinobiont endoparasitoid of *Bactrocera oleae* (Gmelin), the olive fruit fly, and of other Tephritidae such as *Capparimyia savastani* (Martelli), *Carpomiya incompleta* (Becker) L. and *Ceratitis capitata* (Wiedeman) (Feron, 1952; Biliotti & Delanoue, 1959; Monastero, 1969). Found originally in Tunisia as a parasitoid of *B. oleae* (Marchall, 1910) and described by Szépligeti in the same year, this parasitoid was subsequently and repeatedly released in other Mediterranean regions to improve biological control of *Bactrocera oleae* (Silvestri, 1916; Kapatos, 1977; Arambourg, 1986; Jimenez, 1990). In Italy it is now permanently established in the southern region, Sicily in particular, where the species was recovered by Monastero in 1931. In the remaining regions this species showed difficulty in establishing itself and many attempts at introduction, by releasing both wild and mass-reared specimens, have failed (Silvestri, 1940; Jannone & Binaghi, 1959; Fenili & Pegazzano, 1971; Monaco & Nuzzaci, 1970; Raspi & Loni, 1994).

Successful establishment of any insect species (acclimatation) in a new environment depends upon a combination of abiotic and biotic factors and, as concern *O. concolor,* it has been suggested that temperature could be the most important factor influencing its acclimatation capacity (Silvestri, 1940; Fenili, Pegazzano, 1971). The present study was therefore undertaken to provide specific quantitative data on temperature-dependent *O. concolor* development.

MATERIALS AND METHODS

The species was reared using *Ceratitis capitata* (Wiedemann) as laboratorial host. Tephritid larvae were reared using an artificial substrate previously proposed by Cavalloro and Girolami (1969) and the mass-rearing was conducted in cylindrical plexiglass cages (volume 0.063 m^3) following the technique described by Raspi and Loni (1994). Cages, each containing about 600 *Opius* females, were maintained at laboratory temperatures fluctuating between 20 and 25°C with 16:8 (L:D) photoperiod. After 20 minutes of exposure to parasitoids oviposition in parasitization units (foam-rubber tubes Ø 5 cm, supporting small net-nylon bags with about 600 host larvae) tephritids larvae were immediately placed in thermostatic cells under nine different constant temperature regimes: 13 - 15 -18 - 20 - 23 - 25 - 28 - 30 - 33°C (± 0.5°C) to evaluate total development time and developmental rate.

Because it is impossible to distinguish parasitized from unparasitized larvae, an extensive sample of exposed larvae was assayed to obtain a comparable number of parasitized hosts. For easier calculation of adult emergence, a total of 2500 larvae was used for each temperature equally distributed into 25 small transparent cylindrical plastic containers (diameter of 4,3 cm and about 125 cm^3 of volume). *Opius* adult emergence was checked daily and each specimen scored and removed. For each temperature, percentage of parasitoid emergence, sex-ratio and total developmental (egg/adult-emergence) time were recorded. Weighted averages were used to calculate preimaginal development time. The development rate was studied with Sharpe-DeMichele's mathematic model, modified by Schoofield (1981), using the equation:

$$r(T) = \frac{\mathrm{RHO25}\,\frac{T}{298.15}\exp\left[\frac{HA}{R}\left(\frac{1}{298.15}-\frac{1}{T}\right)\right]}{1+\exp\left[\frac{HL}{R}\left(\frac{1}{TL}-\frac{1}{T}\right)\right]+\exp\left[\frac{HH}{R}\left(\frac{1}{TH}-\frac{1}{T}\right)\right]} \qquad (1)$$

where *r*(T) = is the development rate at temperature T (°K), R = the universal gas constant (1.987 cal $degree^{-1}$ $mole^{-1}$), RHO25 = development rate at 25°C (298.15°K) assuming absence of enzyme inactivation, HA = enthalpy of activation of the reaction that is catalyzed by a rate-controlling enzyme, TL = Kelvin temperature at which the rate-controlling enzyme is half active and half low-temperature inactive, HL = change in enthalpy associated with low-temperature inactivation of the enzyme, TH = Kelvin temperature at which the rate-controlling enzyme is half active and half high-temperature inactive and HH = change in enthalpy associated with high-temperature inactivation of the enzyme. This equation was elaborated with the S.A.S program as described by Wagner *et al.*(1984) (Orr & Obrycki, 1990; Morales & Cate, 1993).

Low development threshold and degree-days needed to complete development from egg to adult were calculated both with thermal summation (Wigglesworth, 1972) and with the regression line. The first equation is:

$$t_1(T_1-c) = (T_2-c)... = t_n(T_n-c) = Thc \qquad (2)$$

where t_1, t_2...t_n represent test temperatures, c = developmental zero and Thc = the constant value of degrees needed to complete total development egg adult emergence ("thermal constant"). The regression line equation is:

$$y = ax - b \tag{3}$$

correlating the development rate, calculated as development duration inverse, and the tested temperature a and b are parameters.

RESULTS

Opius development occurred in the range between 15 and 30°C. No adult emergence was obtained at 13 and 33°C. Mean development time ranged from 14.62 ± 1.69 days at 28°C (males), to 77.25 ± 5.5 days at 15°C (females). Male development was consistently shorter than that of females but this difference was reduced at high temperatures (from 4.25 days at 15°C to 0.1 days at 30°C) (table 1).The parasitoid emergence range is given in table 2. Adult emergence peaked within a few days (2-4) under all experimental regimes and subsequently decreased. Fig. 1 shows the trend of adult emergence at 20°C. Percentage of emergence is also listed in table 1, calculated from samples of 2500 host larvae exposed to parasitization. It showed roughly similar percent values at 18, 20, 23 and 25°C (ranging from 31.84 to 36.16%). Values decreased markedly at 28°C (9.32%) and became very low at 15 and 30°C (< 1%).

TABLE 1

Development of O. concolor *at various constant temperatures*

Temp. (°C)	*Opius concolor* (adult n.)	♂	♀	Mean total development time (days)	S.D.	♂	S.D.	♀	S.D.	Emergence percentage (%)	♂	♀
13	0	0	0	0	0	0	0	0	0	0	0	0
15	10	2	8	74.3	4.5	73	4.8	77.25	5.5	0.4	0.08	0.32
18	846	218	628	42.68	1.96	40.20	2.04	43.54	2.5	33.84	8.72	25.12
20	796	198	598	33.87	1.89	30.67	2.63	34.93	3.08	31.84	7.92	23.92
23	867	251	616	21.52	1.42	20.33	1.33	22	1.55	34.68	10.04	24.64
25	905	288	616	17.87	1.36	16.89	1.41	18.36	1.55	36.16	11.52	24.64
28	233	88	145	15.38	1.43	14.62	1.69	15.83	1.65	9.32	3.52	5.8
30	18	7	11	14.72	0.78	14.67	0.66	14.77	0.92	0.72	0.28	0.44
33	0	0	0	0	0	0	0	0	0	0	0	0

The S.A.S Program adopted a four parameter poikilotherm model with high temperature inhibition. Table 3 shows parameters of the Sharpe-Demichele Mathematic Model elaborated with Wagner's S.A.S. Program. Graphical representation for both sexes is shown in fig. 2 (A, B).

Table 4 lists data on *O. concolor* low development threshold and thermal constant, calculated with the regression line and thermal summation methods for males and females respectively. Table 5 lists the same data calculated for both sexes cumulated. The *O. concolor* low threshold was 11.7°C if calculated with the regression line and 11.85°C by the thermal summation method, whereas the thermal constant was 255.9 days with regression line and 251.887 days with thermal summation respectively. As a result of their faster development, the biological parameters were lower in males than in females. These

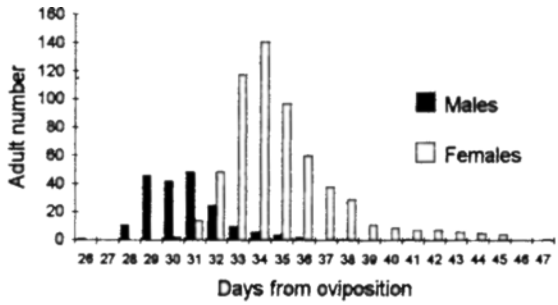

Fig. 1. *Opius concolor* emergence trend at 20°.

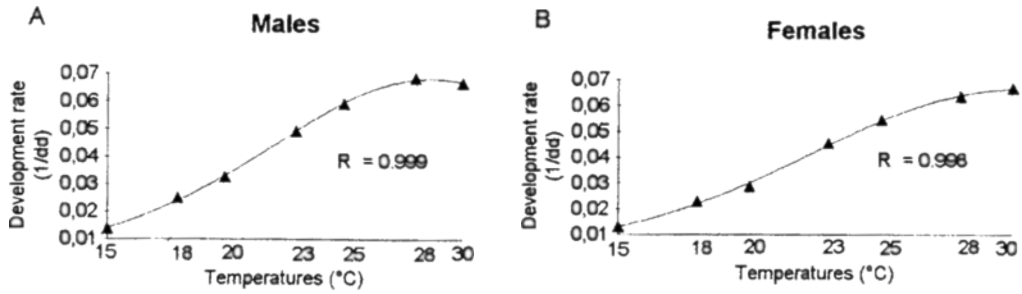

Fig. 2. *Opius concolor* Sharpe & DeMichele mathematical model graphic representation. (A) Males. (B) Females. The black triangles represent experimental data.

TABLE 2

Opius concolor *emergence range at various constant temperatures*

Temperatures °C	Emergence range (Days) ♂	Emergence range (Days) ♀
15	64 - 73	64 - 79
18	36 - 48	40 - 52
20	26 - 41	30 - 47
23	17 - 25	20 - 29
25	14 - 25	16 - 25
28	13 - 19	14 - 22
30	13 - 15	13 - 16

biological parameters were shown to be very similar in both methods. Graphics corresponding to these two equations are illustrated in fig. 3.

DISCUSSION

The *O. concolor* developmental temperature range lies between 15 and 30°C, with a mean development time lasting from 14.62 to 77.25 days. At the 13 and 33°C temperature regimes *O. concolor* was unable to complete its development. Adult emergence ranged from

TABLE 3
Opius concolor *poikilotherm model parameters*

Sharpe & deMichele parameters	♂	♀
RHO25	0.093	0.091
HA	31259.4	31628.4
TL	—	—
HL	—	—
TH	300.11	299.76
HH	51515.45	45065.74
R^2	0.999	0.998

0.1% to 36.16%. The percentage remained more or less constant between 18 and 25°C with a mean value of about 34%. At 15 and 28°C, on the other hand, a marked reduction was observed. Although a mean percentage of emergence of 34% may not seem very satisfactory, previous *O. concolor* mass-rearing experiences report adult emergence percentages of no more than 26% and often below 10%, even if parasitized larvae numbered over 90% (Monastero & Delanoue, 1966). Percentage values in the present experiment are thus fairly good in comparison. It's clear, however, that a mortality of about 66% cannot depend on temperature only, and must also be influenced by other complex biotic factors like bacterial infections, favourited by parasitoid activity especially in mass-rearing conditions, where results very high the superparasitization (An-Ly-Yao, 1987; Loni, 1994). Their influence is not considered in this paper.

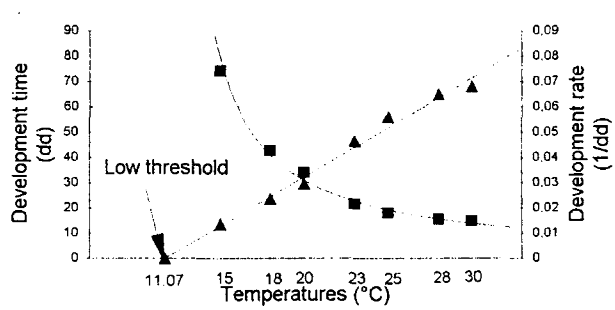

Fig. 3. *Opius concolor* — Regression line and thermal constant graphics. Continue lines represent mathematical models. The black square and the black triangles represent experimental data of thermal constant and regression line graphics respectively.

O. concolor shows a satisfactory development at temperature regimes in the 18-25°C range, where emergence varies from 33.84 to 36.16%. Assuming that the shortest developmental time is the optimal, then it can be assumed that the optimal temperature lies between 23 and 25°C where development time ranges from 17.87 to 21.52 days (table 1). A confirmation of this observation came from adults behaviour observed at the four constant temperature regimes. 20 and 25°C are temperatures well within the optimal development range in facts, adults living at these temperature regimes present a regular reproductive behaviour: females were able to mate immediately after emergence, matings were very rapid (5-10″) and female parasitization activity was very high with every host exposure (up to 400 females could be noted ovipositing on the muff surface). At 15 and 30°C, on the other hand, adult reproduction activity (mating and oviposition) was almost completely inhibited, parasitization activity was found to be strongly reduced and parasitoid adults spent must of their time on the cage surface, showing marked reduction in flight and walking movements.

TABLE 4

Opius concolor *total development (egg - adult)*

Total development	♂	♀
Linear regression		
Equation	$y = 0.00397x - 0.045$	$y = 0.00387x - 0.046$
Low threshold "c"	11.33	11.8
Thermal constant "Thc"	252.010	258.431
r	0.986	0.993
Thermal summation		
Equation	$y = \frac{249.363}{(x - 11.530)}$	$y = \frac{254.333}{(x - 11.964)}$
Low threshold "c"	11.5 ± 0.56	11.9 ± 0.44
Thermal constant "Thc"	249.363 ± 15.9	254.333 ± 16.6

The four parameter poikilotherm model with high temperature inhibition adopted by the S.A.S. program shows a highly significant linear correlation between the experimental development rate and the Sharpe DeMichele Model ($r^2 = 0.999$ for males and 0.998 for females) (Schoolfield et *al.*; 1981). The TH parameter value was 300.1 K for males and 299.76 K for females, suggesting that *O. concolor* will experience thermal stress at about 27°C. Similar considerations were made about *Catolaccus grandis* Burks (Hymenoptera, Pteromalidae) by Morales and Cate (1994). Analysis of the correlation between the *O. concolor* TH parameter value and the temperature range at which percentage emergence was markedly reduced led to a very interesting finding: this range was shown to lie between 25 and 28°C (table 3), the same temperature range within which *O. concolor* experienced thermal stress. Results obtained concerning the influence of temperaure on parasitoid emergence thus present an extremely good fit to the model predictions.

Low threshold and thermal constant values were found to be very similar for males and females, calculated both with the regression line and thermal summation method (tables 4 and 5). The *O. concolor* low threshold, cumulated for both sexes (11.7°C with line regression and 11.85°C with thermal summation) was just a little higher than that of *Bactrocera oleae* (10.01°C with thermal summation method) (Crovetti *et al.*, 1982), which usually survives at Tuscan latitudes (comprised between parallel). From the above considerations, it would appear that temperature influence alone is not sufficient to explain *O. concolor* establishment difficulties at Tuscan latitudes. Further studies are therefore necessary to provide data on its tolerance of extreme temperatures and on the complex of

TABLE 5

Opius concolor *total development male & female cumulated (egg - adult)*

	Equation	Low developmental threshold "c"	Thermal constant "Thc"	r
Linear regression	$y = 0.00391\,x - 0.046$	11.7	255.9	0.992
Thermal summation	$y = \frac{251.887}{(x - 11.849)}$	11.8 ± 0.42	251.887 ± 16.77	—

biotic factors influencing its biology. In particular, research should be focused on the relationship with its host complex and with other *B. oleae* parasitoids.

ACKNOWLEDGMENT

I would like to thank Dr. Alfio Raspi, of Entomology Section in C.D.S.L. Department of Pisa University, for the excellent support in establishing the trials and Dr. Russell Messing, of Entomology Department of College of Tropical Agriculture & Human Resources, University of Hawaii, for helpful comments and suggestions on the manuscript.

RÉSUMÉ

Vitesse de développement d'*Opius concolor* (Hym. : Braconidae) : à différentes températures constantes.

Opius concolor est un parasitoïde de *Bactrocera oleae* (Gmelin) et d'autres tephritidés. Sa vitesse de développement a été étudiée avec le modèle mathématique de Sharpe-DeMichele, modifié par Schoofield (1981), utilisant le programme S.A.S. élaboré par Wagner *et al.* (1984). Ce programme a choisi un modèle à quatre paramètres pour les poikilothermes avec inhibition aux températures élevées. La durée de développement du parasitoide sous sept différentes températures constantes est comprise entre 14,62 ± 1,69 jours à 28 °C (mâles) et 77,25 ± 5,5 jours à 15 °C (femelles). Le développement des mâles est nettement plus court que celui des femelles. Le seuil de développement et les degrés-jours nécessaires à un développement complet étaient déterminés par les méthodes de la « ligne de régression » et de la somme thermale. Les valeurs (pour les deux sexes cumulés) étaient respectivement de 11,7 °C et de 11,8 °C (seuil bas), 255,9 et 251,9 ± 16,77 jours (constante thermale). La possibilité d'acclimater *Opius concolor* dans le nord et le centre de l'Italie est discutée.

Received: 21 March 1996; Accepted: 22 May 1997.

REFERENCES

An-Ly Yao. — 1986. Ring like structure: a mortality factor due to *Opius concolor* (Hym.: Braconidae) besides parasitism on *Anastrepha suspensa* (Diptera: Tephritidae). (**Cavalloro R.**, ed.) *Second International Symp. fruit flies* (Crete, Sept. 1986): 511-514.

Arambourg, Y. — 1986. Traité d'Entomologie Oléicole. Conseil Oleicole International. Juan Bravo, 10-2° - Madrid, Espagne.

Biliotti, E. & Delanoue, P. — 1959. Contribution a l'étude biologique d'*Opius concolor* Szépl. (Hym. Braconidae) en élevage de laboratoire. — *Entomophaga,* 4, 7-14.

Cavalloro, R. & Girolami, V. — 1969. Miglioramenti nell'allevamento in massa di *Ceratitis capitata* Wiedemann (Diptera, Trypetidae). — *Redia,* 51, 315-327.

Crovetti, A., Quaglia, F., Loi, G., Rossi, E., Malfatti, P., Chesi, F., Conti, B., Belcari, A. & Raspi, A. — 1982. Influenza di temperature ed umidità sullo sviluppo degli stadi preimmaginali di *Dacus oleae* Gmelin. — *Frust. Entom.,* n.s., 5, 133-166.

Fenili, G. & Pegazzano, F. — 1971. Contributo alla conoscenza dei parassiti del *Dacus oleae* Gmel. Ricerche eseguite in Toscana negli anni 1967 e 1968. — *Redia,* 52, 1-29.

Feron, M. — 1952. Observation sur le parasitisme de *Ceratitis capitata* Wied. dans le sous Marocain. — *Rev. Pathol. vég. Entomol. Agric. France,* 31, 99-102.

Jannone, G. & Binaghi, G. — 1959. Primi esperimenti di introduzione in Liguria di un endofago della mosca delle olive: *Opius concolor* Szépl. (= *O. siculus* Mon.) (Hymenoptera: Braconidae) della Sicilia. — *Boll. Lab. Entomol. Agr. Portici,* 17, 89-123.

Jimenez, A., Castillo, E. & Lorite, P. — 1990. Supervivencia del himenóptero bracónido *Opius concolor* Szep. Parásito de *Dacus oleae* Gmelin en olivares de Jaén. — *Bol. San. Plagas,* 16, 97-103.

Kapatos, E., Fletcher, B. S., Pappas, S. & Laudeho, Y. — 1977. The release of *Opius concolor* and *O. concolor* Var. *Siculus* (Hymenoptera: Braconidae) against the spring generation of *Dacus oleae* (Dipt: Trypetidae) on Corfu. — *Entomophaga,* 22, 265-270.

Loni, A. — 1994. Studi bio-etologici sugli entomofagi della Mosca dell'olivo. Ph. D. dissertation, University of Pisa.

Marchall, P. — 1910. Sur un Braconide nouveau, parasite du *Dacus oleae.* — *Bull. Soc. Ent. Fr.,* 243-244.

Monaco, R. & Nuzzaci, G. — 1970. Osservazioni slla possibilità di svernamento in Puglia di *Opius concolor* Szépl. (Hymenoptera - Braconidae). — *Entomologica,* 6, 181-194.

Monastero, S. — 1931. Un nuovo parassita endofago della mosca delle olive trovato in Altavilla Milicia (Sicilia) - Fam. Braconidae, Gen. *Opius.* Atti R. Acc. Sc. Lett. ed Arti di Palermo, XVI (3).

Monastero, S. — 1969. Nuove osservazioni sulla biologia della *Carpomyia incompleta* Becker. — *Boll. Ist. Ent Agr. e Oss. Fitop. di Palermo,* 7, 147-157.

Monastero, S. & Delanoue, P. — 1966. Lutte biologique expérimentale contre la mouche de l'olive (*Dacus oleae* Gmel.) au moyen d'*Opius concolor* Szépl. *siculus* Mon. dans les îles Eoliennes (Sicilie) en 1965. — *Entomophaga,* 2, 411-432.

Morales-Ramos, J. A. & Cate, J. R. — 1993. Temperature-dependent developmental rates of *Catolaccus grandis* (Hymenoptera: Pteromalidae). — *Environ. Entomol.,* 22, 226-233.

Orr, C. J. & Obrycki, J. J. — 1990. Thermal and dietary requirements for development of *Hippodamia parenthesis* (Coleoptera: Coccinellidae). — *Environ. Entomol.,* 19, 1523-1527.

Raspi, A. & Loni, A. — 1994. Alcune note sull'allevamento massale di *Opius concolor* Szépligeti (Hymenoptera: Braconidae) e su recenti tentativi d'introduzione della specie in Toscana e liguria. — *Frust. Entomol.,* n.s., 30, 135-145.

Schoolfield, R M., Sharpe, P. J. H. & Magnuson, C. E. — 1981. Nonlinear regression of biological temperature-dependent rate models based on absolute reaction-rate theory. — *J. Theor. Biol.,* 64, 649-670.

Silvestri, F. — 1916. Sulle specie di Trypaneidae (Diptera) del genere *Carpomyia* dannose ai frutti di *Ziziphus.* — *Boll. Lab. Zool. Gen. e Agr. Portici,* 11, 170-182.

Wagner, T. L., Wu, Sharpe J. H., Schoolfield, R. M. & Coulson, R. N. — 1984. Modeling insect developmental rates: a literature review and application of a biophysical model. — *Ann. Entomol. Soc. Am.,* 77, 208-225.

Wigglesworth, V. B. — 1972. The principles of insects physiology, 7th ed. *Chapman and Hall,* London.