Journal of Thermal Biology 51 (2015) 83–88

Contents lists available at ScienceDirect

Journal of Thermal Biology

journal homepage: www.elsevier.com/locate/jtherbio

Impact of fluctuating temperatures on development of the koinobiont endoparasitoid *Venturia canescens*

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ARTICLE INFO

Article history:
Received 5 December 2014
Received in revised form
25 March 2015
Accepted 26 March 2015
Available online 27 March 2015

Keywords:
Venturia canescens
Ephestia kuehniella
Fluctuating temperature
Adult longevity
Survival
Developmental threshold

ABSTRACT

The effect of temperature on the biology of *Venturia canescens* (Gravenhorst) (Hymenoptera: Ichneumonidae) is well understood under constant temperature conditions, but less so under more natural, fluctuating conditions. Herein we studied the influence of fluctuating temperatures on biological parameters of *V. canescens*. Parasitized fifth-instar larvae of *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) were reared individually in incubators at six fluctuating temperature regimes (15–19.5 °C with a mean of 17.6 °C, 17.5–22.5 °C with a mean of 19.8 °C, 20–30 °C with a mean of 22.7 °C, 22.5–27.5 °C with a mean of 25 °C, 25.5-32.5 °C with a mean of 28.3 °C and 28.5–33 °C with a mean of 30 °C) until emergence and death of *V. canescens* adults. Developmental time from parasitism to adult eclosion, adult longevity and survival were recorded at each fluctuating temperature regime. In principle, developmental time decreased with an increase of the mean temperature of the fluctuating temperature regime. Upper and lower threshold temperatures for total development were estimated at 34.9 and 6.7 °C, respectively. Optimum temperature for development and thermal constant were 28.6 °C and 526.3 degree days, respectively. Adult longevity was also affected by fluctuating temperature, as it was significantly reduced at the highest mean temperature (7.0 days at 30 °C) compared to the lowest one (29.4 days at 17.6 °C). Survival was low at all tested fluctuating temperatures, apart from mean fluctuating temperature of 25 °C (37%). Understanding the thermal biology of *V. canescens* under more natural conditions is of critical importance in applied contexts. Thus, predictions of biological responses to fluctuating temperatures may be used in population forecasting models which potentially influence decision-making in IPM programs.

1. Introduction

Venturia canescens (Gravenhorst) (Hymenoptera: Ichneumonidae) is a solitary endoparasitoid developing in the larvae of several pyralid moths, such as *Ephestia kuehniella* Zeller, *Plodia interpunctella* Hübner and *Ephestia elutella* Hübner (Lepidoptera: Pyralidae), which are considered major stored-product pests that cause serious economic looses (Salt, 1975, 1976). Numerous studies demonstrate how constant temperatures can affect several features of its preimaginal development and adult life (Ahmad, 1936; Nakahara and Iwabuchi, 2000; Eliopoulos and Stathas, 2003, 2005; Eliopoulos et al., 2003, 2005; Rahman et al., 2007; Spanoudis and Andreadis, 2012). For instance, temperature determines survival and development of *V. canescens* in late instar larvae of *E. kuehniella* (Rahman et al., 2007) while adult longevity decreases with increasing temperature within the optimum range regardless of its host (Eliopoulos et al., 2005; Spanoudis and Andreadis, 2012). However, individuals of *V. canescens* in the nature are not exposed to constant temperatures as they are faced with temperature variation on a daily basis. Thus, studies performed at constant temperatures have limited ecological significance (Foray et al., 2014).

Temperature is the most important environmental factors for insects. It affects directly the rate of biochemical reactions and therefore has a strong influence on growth rate as well as on many other life history traits (Cossins and Bowler, 1987; Hallmann and Denlinger, 1998; Davidowitz and Nijhout, 2004; Steigenga and Fischer, 2009). Thus, estimation of thermal requirements and development rates at different temperature regimes are useful and of critical importance for enhancing efficiency and determining the environmental conditions that foster greater fitness and

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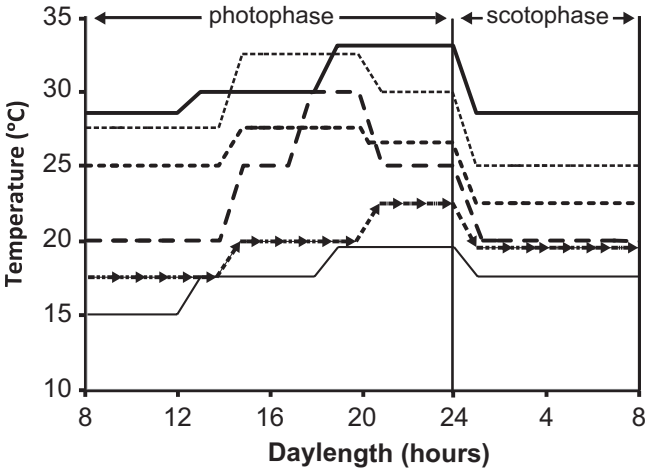
http://dx.doi.org/10.1016/j.jtherbio.2015.03.009
0306-4565/

population dynamics (Bahar et al., 2012). Results of laboratory studies using constant temperatures though being quite informative concerning the prediction of the lower and upper thermal limits of a species, they can hardly be extrapolated to natural populations due to incompatibility with the natural conditions characterized by daily thermal cycles, which species experience throughout their lifespan (Beck, 1983). Moreover, in nature animals are regularly exposed to thermal fluctuations, and the importance of measuring survival at both constant and fluctuating temperatures has previously been stressed by Bale (2002).

Fluctuating temperatures are considered to be in general more beneficial to insects in terms of insect developmental biology rather than constant temperatures (Joshi, 1996; Fischer et al., 2011; Radmacher and Strohm, 2011), mainly because of acclimation responses, however, this is not always the case (Kjærsgaard et al., 2013). For example, exposure of the predatory bug *Orius niger* Wolff (Hemiptera: Anthocoridae) at fluctuating temperature resulted in an increase of incubation period, duration of nymphal development, total developmental time, generation time, and longevity compared with constant temperatures (Bahşi and Tunç, 2008).

Current knowledge on the effects of realistic temperature fluctuations on *V. canescens* biology is limited. The objective of the present study was to determine the effect of fluctuating temperatures on development and other biological parameters of *V. canescens*. A thorough understanding of its thermal biology may allow us to manipulate *V. canescens* in a more efficient way in order to enhance its ability to control *E. kuehniella* or other pyralid moths, major pests of stored products. Moreover, the estimation of parameters such as lower and upper developmental threshold, thermal constant and optimum temperature, which are considered good predictors of the timing of life history events (Honěk and Kocourek, 1988) as well as useful indicators for an insect potential distribution (Campbell et al., 1974), for each developmental stage of *V. canescens*, is essential to augment the possibilities of successful biological control.



Hours	Mean fluctuating temperature (°C)					
	17.6	19.8	22.7	25.0	28.3	30.0
08:01-12:00	15.0	17.5	20.0	25.0	27.5	28.5
12:01-14:00	17.5	17.5	20.0	25.0	27.5	30.0
14:01-17:00	17.5	20.0	25.0	27.5	32.5	30.0
17:01-18:00	17.5	20.0	30.0	27.5	32.5	30.0
18:01-20:00	19.5	20.0	30.0	27.5	32.5	33.0
20:01-24:00	19.5	22.5	25.0	26.5	30.0	33.0
00:01-08:00	17.5	20.0	20.0	22.5	25.0	28.5

Fig. 1. Schematic draw of temperature regimes used to compare the effect of fluctuating temperatures on developmental parameters of *V. canescens*.

2. Materials and methods

2.1. Study insects

Hosts and parasitoids were reared at 25 ± 1 °C, 60 ± 5% R.H. and under a 16:8 h (L:D) photoperiod since autumn of 2007. *Ephestia kuehniella* larvae were maintained in plastic boxes (17 cm × 11 cm × 5 cm) containing approximately 150–200 moth eggs and 200–250 g of semolina, which provided the larvae with sufficient food throughout their development. Emerging adults remained in the same boxes. A colony of *V. canescens* was maintained on *E. kuehniella* as a host. Adults of *V. canescens* were reared in clear plastic boxes (20 × 20 × 20 cm^3) and provided with honey solution (10%) as food. A number of 5th instar larvae from the host colony were placed in the clear plastic boxes with the adult parasitoids. The following day the potentially parasitized larvae of the host were transferred into plastic boxes (6 × 11 × 6 cm^3) with 30–40 g semolina until adult emergence. The abovementioned procedure was repeated every 2 days until the death of the adult parasitoids. Hosts and parasitoids were collected from dried nuts, originating from the Kavala region (41° 01′N, 24° 22′E) of northern Greece.

2.2. Effect of temperature on survival

Fifth instar larvae of *E. kuehniella* were placed into clear plastic boxes (20 × 20 × 20 cm^3), where young adults of *V. canescens* were reared, until parasitism occurred. Parasitism was easy to determine via a characteristic flexing or cocking of the abdomen of the wasp, which follows a successful oviposition, the “cocking” motion described by Rogers (1972). Parasitized larvae of *E. kuehniella* were removed and placed individually into small plastic cups (4 cm diameter, 3 cm height) provided with approximately 5 g semolina. Afterwards, they were transferred into incubators (Precision Scientific, General Electric, Louisville, KY) at six fluctuating temperatures with mean daily temperature of 17.6, 19.8, 22.7, 25, 28.3 and 30 °C and under a 16:8 h (L:D) photoperiod. The initial number of parasitized larvae used at each fluctuating temperature was 70, 105, 130, 83, 120 and 150, respectively. Fluctuation of the six temperatures regimes that were studied is presented in Fig. 1. The variations in temperature simulate to field and warehouse conditions that occur in Greece during the activity period of the major pyralid moths that infest stored products (Nastos et al., 2011). Daily observations were made, and the percentage of parasitoids that completed successfully development until adulthood at each fluctuating temperature regime was calculated.

2.3. Effect of temperature on developmental time

Developmental time of *V. canescens* at the six fluctuating temperatures was estimated from the same experiment. Daily observations were made to record the days needed for the emergence of the parasitoid’s pupa and adult eclosion at each fluctuating temperature regime.