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TEMPERATURE AND HOST DENSITY DEPENDENT FUNCTIONAL RESPONSE OF *DINARMUS BASALIS* (HYMENOPTERA: PTEROMALIDAE) ON *CALLOSOBRUCHUS CHINENSIS* (COLEOPTERA: BRUCHIDAE)

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Abstract

The functional response of *Dinarmus basalis* Rondani (Hymenoptera: Pteromalidae) were estimated on parasitizing late larval-pupal stages of *Callosobruchus chinensis* L. (Coleoptera: Bruchidae) a major pest of stored legume over a range of temperatures and host densities. A functional response equation was used in which a quadratic component that included temperature was substituted for handling time. The instantaneous search rate was increased with increasing the temperatures. The searching rate was found the highest at 30°C but the lowest at 20°C. A linear relationship between the parasitization rate and prey density was observed with regression coefficient r^2 values lies between 0.951 and 0.997. The model predicts that the maximum number of *C. chinensis* (333.33) was parasitized per day by an individual *D. basalis* at 30°C. Handling time T_h was the lowest (0.003 minute or 4.32 day^{-1}) at 30°C while the highest (0.010 minute or 14.4 day^{-1}) at 20°C. Therefore, the ability of *D. basalis* to find and parasitized *C. chinensis* makes it as a good candidate for biological control in storage conditions.

Keywords: Parasitization; *Dinarmus basalis*; *Callosobruchus chinensis*; temperature; host density.

Introduction

Developmental temperature plays a pivotal role on the physiology, behaviour and biological attribute of insects (Irlich *et al*. 2009 and Jerbi-Elayed *et al*. 2021). It is one of the most important environmental factors that influence the distribution, abundance, immature development, adult emergence, fecundity, longevity, eficiency and fitness of parasitoids as well (Liu *et al*., 2012). The various symbol of this categories of an organism can roughly classified into three groups as reaction pattern, effect on stability, and daily cycles. So far, thermal intensity may contribute as a key factor which regulate seasonal rhythm and consequently compensate diverse aspects of insect biology (Danks, 2003). The thermo-rhythm strongly influences on parasitoid to facilitate on its position within the photoperiod (Reznik *et al.*, 2009). The thermo-period may be a very strong signal conjunction with the mean temperature. Response to a temperature of a prey-parasitiod interaction is a key component often dynamic as a stable critical effect.

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This study was done on a larval-pupal cosmopolitan ectoparasitoid *Dinarmus basalis* Rondani (Hymenoptera: Ptermalidae) hosted on *Callosobruchus chinensis* (Islam and Khan 2000 and Rojas *et al*., 2005). They were frequently presented in the natural conditions, and considerable check the pest population at certain time of the year in the granaries or stores infested by *C. chinensis* (Qumruzzaman, 2003). Now *D. basalis* is found in many wormer countries of the world as Egypt, Fiji, India, Nigeria, Peru South Africa, Sudan, Thailand, Togo and West Africa (Sanon *et al*., 2005) including Bangladesh (Qumruzzaman, 2003).

The relationship between prey density and a parasitism rate is known as the functional response (Abrams and Ginzburg, 2000 and Jeschke *et al*., 2002). A functional response per unit time is the change in prey-parasitization in relation to the change in prey density (Cogni *et al*., 2000) and is a behavioral response because it involves in host searching. Evaluation of optimum temperature for the development of a parasitoid is an important step in the mass production and a basic requirement of any biological pest control program (Meirelles *et al*., 2015). Such studies are important for predicting successful field releases of bio-control agents (Xiao and Fadamiro, 2010). Effects of temperature on the functional response of *D. basalis* have been limited studied. But some have proposed a general model of this parasitoid (Smith, 1994). Keeping these in view, the present research work was conducted to assess how *D. basalis* respond to changing prey density under simplified experimental conditions. In additional aimed, to determine the functional response of *D. basalis*, hosted on *C. chinensis* of four diverse intensive phases of temperatures.

Materials and Methods

The experiment was carried out at the Department of Entomology, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh during the period from June to October 2018 to investigate the functional response of *D. basalis* as biocontrol agents against *C. chinensis*. Stock cultures of *D. basalis* and *C. chinensis* on chickpea (*Cicer arietinum* L.) seeds were commenced at the laboratory in an incubator (BD 115 / 9010-0086, Germany) maintained 30 ± 1 °C, 75 ± 10 % RH, 12:12 (D: L) inside glass jars (47 H × 14 D cm).

Experimental protocol

Approximately 200 mated one-day old females of *C. chinensis* were taken from the stock culture and introduced in different Petri dishes (90 D × 20 H) containing fresh chickpea seeds. *C. chinensis* were removed from the Petri dishes after 3 hours of egg laying and the egg-bearing seeds were placed in the incubator for further development. The cycles were repeated for constant supply of different life stages of the host for this study. After 8, 10, 12, 14, 16 and 18 days, the egg-bearing seeds were checked for confirmation of the presence of different growth stages as stated by Islam (1997). It was found that after 8, 10, 12, 14, 16- and 18-days infested

seeds contained first, second, third, fourth instar larvae, pre-pupae and pupae, respectively.

From the stock culture 12 to 15-day old single hosted seeds infested by *C. chinensis* that were collected and placed in plastic containers (14 H× 11 D). Host densities were used as 20, 40, 60 and 80 number in each Petri dish. From the stock culture one pair (♀: ♂) of newly hatched *D. basalis* was introduced in each Petri dish for parasitization and the mouths of the containers were covered with fine perforated lids and placed inside the chamber of incubator for 20, 25, 30 and 35ºC and 75 ± 10% RH. All treatments were replicated five times. The released parasitoids were removed from the containers after 7 days and parasitized host seeds were left undisturbed for their development. Emergence of the adult *D. basalis* and *C. chinensis* were observed and counted daily and collected with an aspirator from the containers, and recorded.

The type II response is the most common for insect predators and parasitoids. Holing curvilinear type II equation (Holling, 1959) was used for calculation of functional response. In this model, the number of prey parasitism (*Pe*) is a function of prey density (*N*) as follows:

$$Pe = (aTN)/(1 + aThN)$$

Where *a* is the rate of attack (discovery) of the prey, *T* is the total time available (1 d or 24 h in this experiment), and T_h is the handling time for one prey. The parameter of Holling curvilinear type II equation were the handling time (T_h) and the attack constant (*a*) were estimated using Holling's disc equation (1959) modified by reciprocal linear transformation (Livdahl and Stiven, 1983). The modified equation is as follows:

$$\frac{1}{Pe} = \frac{1}{a}.\frac{1}{NT} + \frac{Th}{T}$$

Where $\frac{1}{Pe}$ represents y, $\frac{1}{a}$ represents α,$\frac{1}{NT}$ represents x and $\frac{Th}{T}$ represents ß. The linear regression form becomes y = α x + β. The maximum number of parasitized prey per parasitoid (asymptote), Ha_{max} =$\frac{T}{Th}$was found.

Statistical analyses

The data on attack rate, handling time, prey consumption rates, parasitization and suppression were analyzed using linear regression procedures (Rstudio 3.1.3). All graphical works were done by Microsoft Excel.

Results

Functional response of *D. basalis*

The functional response parameters as attack rates, handling times, parasitization (asymptote) and regression coefficient (r^2) of *D. basalis* were assessed with tested

densities of *C. chinensis* at different temperatures of 20, 25, 30 and 35 °C (Table 1). The type II Holling disc equation was fitted separately for each tested temperature level in order to compared the search rate *a* and handling times T_h for parasitization. The parasitization efficiency by the parasitoid was found to increase with increasing temperature. The instant search rate or handling time was found increasing as temperature increases. Among the temperatures, 30°C showed the highest rate of attack (0.975 d^{-1}) while 20°C exhibited the lowest (0.676 d^{-1}). Handling time decreased as temperature increasing except for 35°C temperature with all levels of parasitoid introduction. The predicted maximum numbers of prey parasitization (T/T_h) within 24 hours by an adult female of *D. basalis* were 100, 200, 333.33 and 142.86, respectively at four temperatures of 20, 25, 30 and 35 °C.

Table 1. Type II functional response parameters of *D. basalis* fed on different densities of *C. chinensis*

Temperature (°C)	*a*	T_h (day/min.)	T/T_h	r^2
20	0.676	0.010 (14.4)	100	0.997
25	0.894	0.005 (7.2)	200	0.969
30	0.975	0.003 (4.32)	333.33	0.951
35	0.798	0.007 (10.08)	142.86	0.996

Where: *a* = Rate of attack, T_h = Handling time, $\frac{T}{Th}$ =Prediction of maximum prey consumption, r^2 = Regression coefficient

Parasitization rates over temperatures and prey densities

The results suggest that parasitization of *D. basalis* to *C. chinensis* increases with temperature and offered prey densities up to 30 °C, but have declined by 35 °C, although parasitization at 35 °C is still greater than that seen at both 20 and 25 °C (Figure 1).The differences in prey parasitization rate at various prey densities within a developmental stage of *D. basalis* were detected significant at all levels of temperature (20°C: $F = 234.02$; $df = 3$; $P = 0.0042$; 25°C: $F = 63.09$; $df = 3$; $P = 0.0155$; 30°C: $F = 38.82$; $df = 3$; $P = 0.0248$; 35°C: $F = 81.63$; $df = 3$; $P = 0.012$).Also, relationships of parasitization are negatively correlated against prey density offered at all temperatures level. The highest parasitization (90.0%) was calculated at the lowest prey density (20) offered while the lowest (71.25%) in the highest (80) prey density at 30 °C temperature (Figure 1).

Parasitization of *D. basalis* was estimated by offering tested host densities of *C. chinensis* to evaluate the form of its efficient response and the linier model of functional response corresponds to Holling disc equation II (Figure 2). The result indicates that the parasitization rate all tested temperatures decreased with increasing host density and all the values of linear constant were negative (Figure 2). The highest parasitization (57.0) was found while offered 80 hosts at 30 °C. Conversely, the lowest (11.8) parasitization experienced on 20 host density at 20 °C temperature.

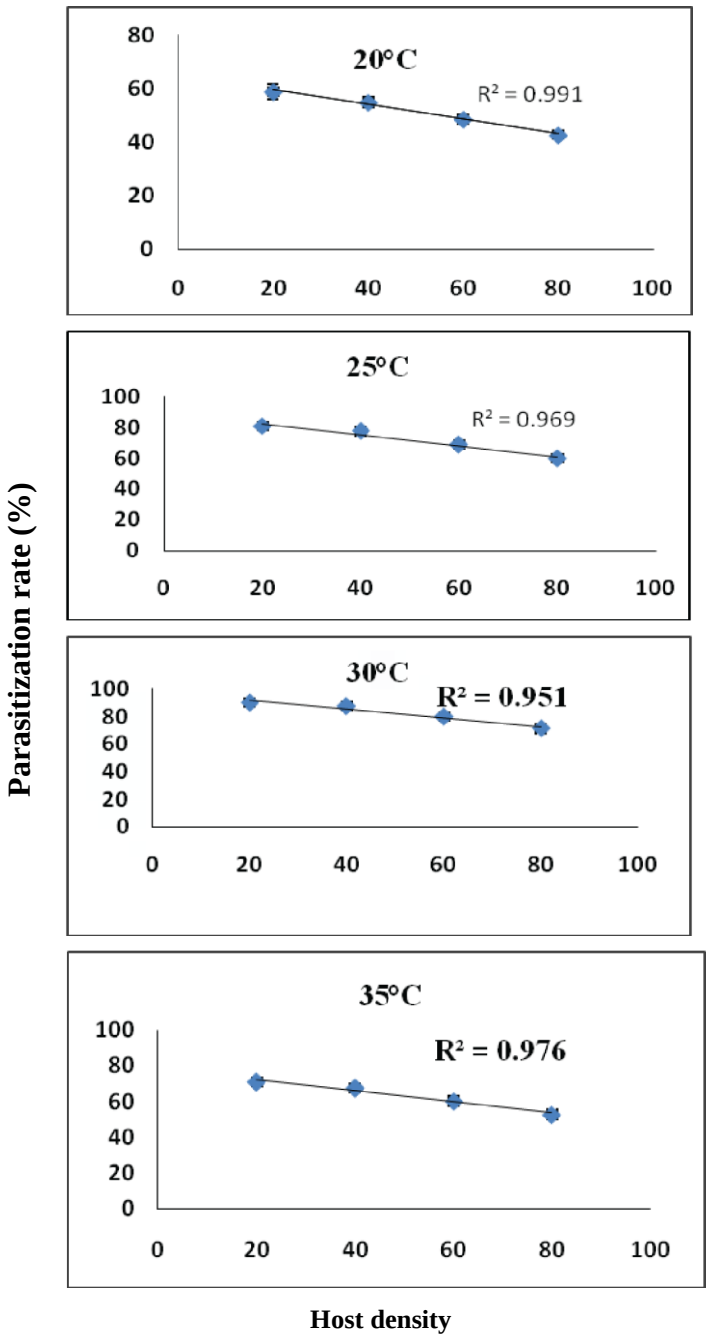

Fig. 1. Parasitization (%) of *D. basalis* to *C. chinensis* hosted on chickpea seed at tested temperatures and host density. Error bars show standard errors.

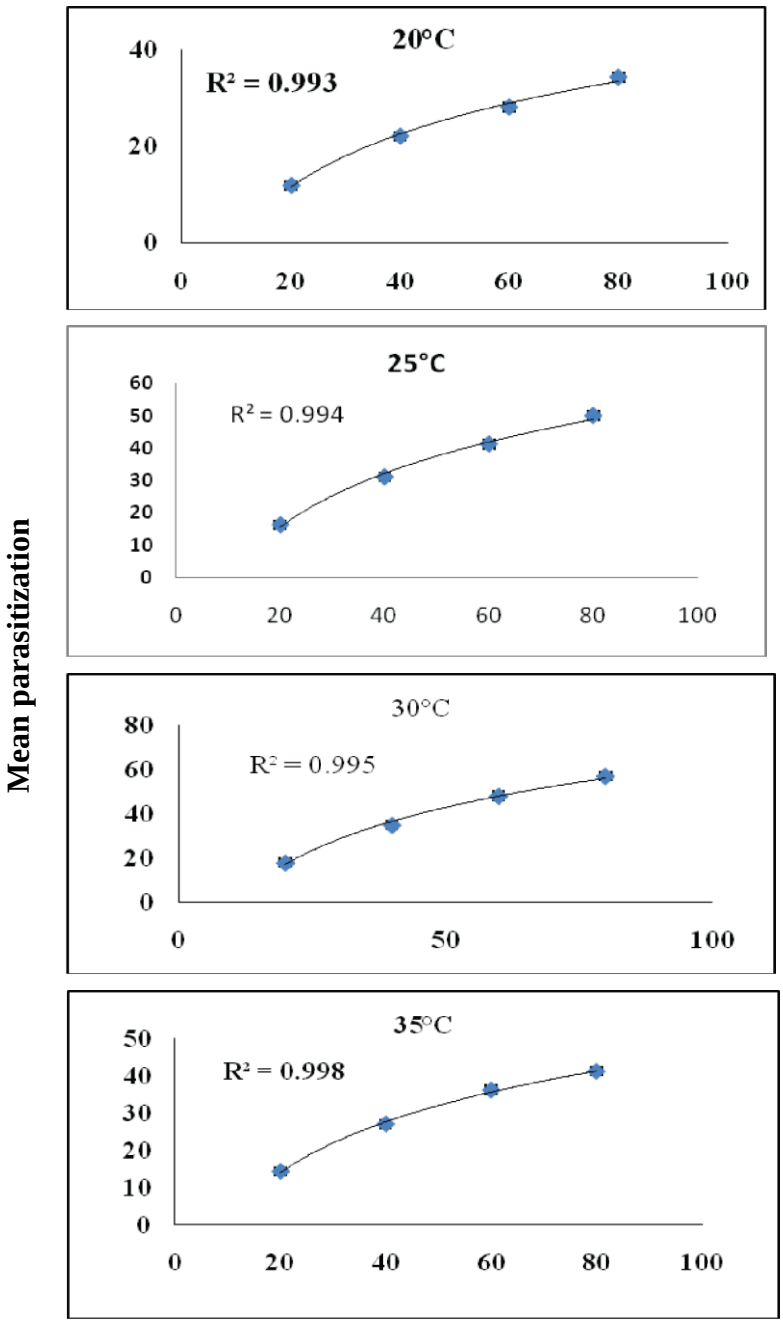

Fig. 2. Functional response of *D. basalis* parasitization to *C. chinensis* hosted on chickpea seed at tested four different temperatures and host density. Error bars show standard error.

Discussion

The functional response is a preliminary step in evaluating the efficiency of the parasitoid in biological control programs. The attractive suppression of pests using bio-control agent indicates fundamental aspects of ecological fitness ability. The adverse environmental conditions negatively affected the potentiality of diverse biological control programs. Development of a parasitoid in determination of optimal thermal requirement is a focal point of any bio-control program against the pests is the most important for its mass rearing, laboratory production, field release and efficiency. Since the potentiality of laboratory strains of parasitoids might be affected after releasing due to fluctuations of temperature as they cultured in confined conditions. So, in fact, the variation of temperature strongly affects the performance of parasitoids cultured in the laboratory (Firake and Khan, 2014).

The data indicates that all temperature levels exhibited to *D. basalis*, were found negative suggesting that the functional responses were type II (Figure 2). A logistic regression model of proportions of prey parasitized (*Pe/N*) versus host density (*N*) was also fitted to confirm the correctness of the functional response type that was obtained, because, it provides a more powerful and accuracy of distinguishing between type II and type III (Trexler *et al.,* 1988). In hypothesis, we have operated functional response by *D. basalis* in our experiment but, found no evidence of type III, suggesting this mechanism repulsive for this parasitoid-prey system. Our experiment was a short term, single-prey species, so that these two suggested mechanisms for type III functional responses couldn't have properly acted in our experiment. Similar type of functional response has been reported by many scientists with other insect species under various abiotic conditions (De Clercq *et al*., 2000; Zamani *et al*., 2006 and Fathi and Nouri-Ganbalani, 2009). This type of functional response earlier reports in support of different parasitoids, together with: *Gonatocerus tuberculifemur* (Hymenoptera: Mymaridae) attacking eggs of glassy-winged sharpshooter, *Homalodisca vitripennis* (Hemiptera: Cicadellidae) (Irvin *et al*., 2009); *Anisopteromalus calandrae* Rondani (Hymenoptera: Pteromalidae) preying on lesser grain borer *Rhizopertha dominica* (Coleoptera: Bostrychidae) (Menon *et al*., 2002); *Lysiphlebus testaceipes* Cresson (Hymenoptra: Braconidae) preying on wheat aphid *Schizaphis graminum* Rondani (Hemiptera: Aphididae) (Jones *et al*., 2003); *Spalangia cameroni* Perkins (Hymenoptera: Pteromalidae) attacking pupae of the stable fly *Stomoxys calcitrans* L. (Skovgard and Nachman, 2015), egg parasitoid of *Telenomus remus* Nixon (Hymenoptera: Scelionidae) to *Spodoptera frugiperda* (Lepidoptera: Noctuidae) (Carneiro, *et al*., 2010). Types of functional response of an insect species estimated parameters could be affected by many factors such as temperature, type of prey or host and host plant (Messina and Hanks, 1998 and Moezipour *et al*., 2008).

The searching rates and handling time has major importance a fundamental aspect in functional response, that provide eminent information about interaction to parasitoid-host, since it can contribute the impact of *D. basalis* on *C. chinensis*

population dynamics. Our results suggested that the optimum temperature according to the highest value of *a* (searching ability of parasitoid) while the lowest value of T_h (handling time), was 30 °C. The coefficient of attack rate (*a*) and handling time (T_h) parameters were used to conclude the magnitude of the functional responses exhibited through tested temperature and host density (Table 1). Numerous temperature levels of parasitoid for the *C. chinensis* as prey species; the attack rate *(a*) and handling *(Th*) time rates were varied. The estimated handling time was the lowest (0.003 min) at 30°C while the highest (0.010 min) at 20°C. Similarly, the lowest (0.674) while the highest (0.894) attack rates were experienced at 20°C and 30°C. Similar functional responses have been found in *Euseius finlandicus* Oudemans to *Amblyseius andersoni* Chant (Koveos and Broufas, 2000), *Frankliniella schultzei* Trybom, to *Thrips imagines* Bagnall and *T. tabaci* Lindeman (Wilson *et al.*, 1996), to *Stethorus punctum* (LeConte) (Hull *et al*., 1977). All fitted Holling's type-II responses, in which parasitoid display a decrease in attack rate at increasing prey densities (Sabelis, 1985). Results of the present findings are comparable with (Islam *et al*., 2006). They cited that the search rate and handling of the parasitoid *D. basalis* was a'= 0.123 time and T_h= 0.056 life span-^{1}, respectively. The type of functional response of parasitoid/predator may change from one type to another as environmental conditions (temperature mainly) change (Wang and Ferro, 1998 and Mohaghegh *et al*., 2001).

The suppressive efficiency of the parasitoid was consequently changed with fluctuate of the parasitoid density at corresponding tested temperatures. The parasitism and suppression trends by the parasitoid of the existing study are parallel. The percentage of parasitism among various temperatures were minimum (65.25%) at 20°C temperature while offered 80 host densities although maximum (95.73%) at 30°C temperature of 20 host densities. The suppression by the parasitoid was experienced minimum (68.35%) at 20°C temperature with 80 host densities but maximum (97.44%) at 30°C temperature with 20 host densities. *D. basalis* parasitized 21.4-91.0%, *Anisopteromalus calandrae* parasitized 19-67.2% and a combination of both species parasitized 18.9-82.5% of *C. chinensis* hosted on lentil seed (Qumruzzaman and Islam, 2005). Hossain *et al*., (2014) observed the parasitization rates of *D. basalis* were 62.83 to 99.25% on its habitual host *C. chinensis*.

The parasitization ability of *D. basalis* on *C. chinensis* over a broad range of temperatures makes them good candidates for biological control of stored grain pest. Based on the handling time (the time taken by a parasitoid in locating, capturing, subduing, parasitizing and digesting one prey), attack rate, and the parasitization of pulse beetle, it can be use as a biocontrol agent of *C. chinensis* at temperatures ranging between 25 and 30°C. The findings of the functional response of *D. basalis* on *C. chinensis* at different temperatures could be incorporated as a model to be used in such a system. However, additional studies on the interaction, fecundity, development, potentiality, reproductive ability of *D. basalis* will be needed to develop this for augmentative or conservational bio-

control tactics against *C. chinensis*. Therefore, it could be concluded that the parasitoid *D. basalis* may be released shortly to reduce the infestation against notorious pulse beetles to ensure bio-safety and food security as a vital component of integrated pest management.

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