TEMPERATURE GRADIENTS AND THEIR EFFECTS ON THE INTERACTION OF AN INSECT HOST Plodia interpunctella AND ITS PARASITOID Venturia canescens

Pengaruh Gradien Suhu Terhadap Interaksi Serangga Inang Plodia interpunctella dan Parasitoid Venturia canescens

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ABSTRAK


Kata kunci: parasitoid, inang, Venturia canescens, Plodia interpunctella

INTRODUCTION

It has been known that biochemical, physiological and behavioural processes in animals are affected by temperature. Many studies have been done to explore the thermal sensitivity of organisms and factors that influence the evolution of thermal performance curves (Thomas & Blanford 2003).

The effect of temperature is crucial in determining the outcome of host-parasitoid interactions, particularly in determining the rate and success of the development of parasitoids. Normally, the development of parasitoids is longer in lower temperature and shorter in higher environments, up to a critical temperature (Bell et al. 2003). High temperature can also improve the survival of parasitized hosts, however, it is often not determined whether this is due to increased encapsulation of the parasitoid larvae by the host, or higher mortality of parasitoid caused by thermal sensitivity (Thomas & Blanford 2003).

Venturia canescens (Gravenhorst) (Hymenoptera: Ichneumonidae) is a solitary, endoparasitoid of many lepidopteran larvae (Salt 1976). This parasitoid mainly attacks pyralid moths whose larvae are pests of stored products. Female V. canescens lays a single egg inside its host (at the larval stage). The host larva continues to feed and grow after parasitoid oviposition (koinobiont). The host will stop feeding and growing when the parasitoid larva shifts from feeding on haemolymph to consumption of the host tissue. Consumption of host tissues always occurs after the parasitoid larva reaches its final instar (Harvey & Strand 2002). The parasitoid larva develops and pupates
within the host larva, then an adult of *V. canescens* emerges from the host pupa (Hajek 2004).

Endoparasitoid larvae or eggs may fail to develop and die due to a reaction of the host's immune system. The term immune system is used to describe the capability of the hosts in mounting a defensive response against foreign bodies within the hosts. There are several types of host defence reactions, but the most commonly physiological host defence is the ability to encapsulate eggs or early instar larvae of a parasitoid. Encapsulation involves the adhesion of host haemocytes to the surface of the parasitoid egg or larva. Encapsulation can result in the development failure and the death of parasitoid larva (Jervis et al. 2005).

Effects of biotic factors (such as different of host size, different age of host larvae, host densities) and abiotic factors (particularly temperature) on the performance of *V. canescens* in association with its host *P. interpunctella* have been investigated widely (Sait et al. 1997; Eliopoulos et al. 2005). The wasp parasitized more fifth instars larvae than it did on the earlier instars (Sait et al. 1997). Increasing temperature within the range 15-30 °C resulted in decreasing development time of the parasitoid. The lower developmental threshold of *V. canescens* is 10.86-11.37 °C and the upper one is 36.01-36.41 °C when the parasitoid is developed on *Ephesia kuehniella* Zeller (Eliopoulos & Stathas 2005).

The above studies mostly concerned interactions in constant environments throughout the experiment, while environmental variation can have important effects on both host and parasitoid populations. The integration of environmental variation addresses the long standing debate about the relative roles of biotic and abiotic factors in determining host dynamics. This is particularly important given predicted global change and its impact on biodiversity. Since the change of global climate in a long term becomes increasingly apparent, the short-term variance in various climatic variables is also expected to rise. The dynamic consequences of this variation will affect the emergence pattern of hosts and parasitoids from generation to generation (Hassei, Godfray et al. 1993).

This study was aimed at investigating the impact of changes in temperature along a gradient. Developmental asynchrony may occur between the host and parasitoid if they have different thermal optima and develop at different rates at different temperatures. Developmental asynchrony may increase the risk of parasitoid extinction. This asynchrony may occur if the time of parasitoid emergence is not synchronized with the availability of a suitable host. The results of this study can be used to determine how natural enemies, particularly parasitoids, will respond following the change of the host's expansion as a result of temperature variation during their interaction.

**MATERIALS AND METHODS**

The experiment was held in The Ecology and Evolution Laboratory, Institute of Integrative and Comparative, Faculty of Biological Sciences, University of Leeds, The United Kingdom, starting January until July 2006. A stock culture of the host, *P. interpunctella*, has been maintained at Leeds for several years. The hosts were reared in a cylindrical clear plastic container (15 cm in height and 11 cm in diameter) containing a bran diet composed of 800 g broad bran, 200 ml honey, 200 ml glycerol, 160 g yeast, and 12 g preservative. The separate host colonies of *P. interpunctella* were already maintained at different temperatures of 24, 26, and 28 °C, a relative humidity of 60 ± 5 %, and light-dark cycle of 16:8 h.

The parasitoids *V. canescens* were reared in clear plastic containers (dimension 17 x 11 x 8 cm each). Around 10-15 newly emerged wasps were placed in each container with 50-70 fifth instar host larvae randomly selected from mass culture and honey water:solution of 9:1 as the wasps diet. The parasitoids were maintained in a constant environment of 28 ± 2 °C. Upon emergence the wasps were removed and placed in another container and fed with
honey water solution. Only parasitoid adults between 2-6 days post emergence were used in the study. The hosts used in this study came from the population that were already established at 24, 26, and 28 °C, while the parasitoids were from the established population at 28 °C.

To obtain singly parasitized host larva, a single wasp was placed in a clear plastic container (7.0 x 7.0 x 7.5 cm³ in dimensions) containing 20-25 fifth instar larvae of *P. interpunctella* from rearing temperature of 24, 26, or 28 °C. The wasp ovipositions then were observed carefully. Any stinging attempt by the wasp which was followed by a startle reaction from the host larva, combined with the characteristic cocking movement of the wasp’s ovipositor was considered as a successful oviposition event (Rogers 1972).

After being parasitized, the host larvae were removed and placed individually in a 4 cm³ clear plastic tube containing 1 cm thick of bran diet to allow the host to develop until the wasp emerged. The tube then was kept in an environmental chamber in which the host larvae were previously maintained at 24, 26, or 28 °C. This meant that the host-parasitoid interaction were shifted from 28 to 24 °C, 28 to 26 °C, and 28 to 28 °C as control treatments, in effect exploring the range expansion of the parasitoid. Each unit of experiment consisted of 15 or 20 parasitized host larvae and there were five replications for each temperature treatment. In total, there were 100 host larvae singly parasitized for a temperature shift of 28 to 24 °C, 28 to 26 °C, and 95 host larvae for 28 to 28 °C. Beside these treatments, the unparasitized fifth instar host larvae were also maintained at 24, 26, and 28 °C to observe the development time of the hosts when they were not parasitized.

Adult host or parasitoid emergence was observed daily, any adult that emerged was killed by freezing and the time of emergence was recorded. The impact of temperature variation on the host-parasitoid interactions was observed on (i) survivorship of the parasitoids: number of wasps emerged for each temperature treatment, (ii) encapsulation: number of adult hosts emerged; and (iii) development time of the parasitoid: the length of time needed for the wasps to develop until adults emerged; it has been known that the body size of parasitoid *V. canescens* is positively correlated to egg load and individual reproductive fitness (Harvey et al. 1994), which might be affected by temperature. Therefore, the fourth observation (iv) in the present study was done on the body size of the wasps, which was determined by measuring the length of the hind tibia under a calibrated stereomicroscope.

Data for the development time and the body size were analysed using general linear model (GLM) procedure in SPSS 13.0 data editors for windows (registered trademark), while data for survivorship and encapsulation were analysed using non-parametric test Chi-square calculated using Microsoft Excel 2000. All data sets used in the GLM analysis were observed ones, no transformation done since the data were normally distributed. Significant effect of the temperature treatment on development time and body size were further analysed by an LSD post-hoc multiple comparisons method. Results are presented as the mean values plus or minus their standard deviations (SD), based on observed means. Significance levels, degree of freedom, or χ² accompany all results performed.

**RESULTS**

Survivorships of *V. canescens* and *P. interpunctella*

The outcome of host-parasitoid interactions in this experiment is presented in Table 1. More than 75% of parasitized host larvae successfully turned into adult parasitoids of *V. canescens* despite the temperature treatment. Only a few of the parasitoid larvae died or adult hosts emerged (encapsulation).

To investigate the effect of temperature gradients on the survivorship of *V. canescens*, the data from the third and fourth columns of Table 1 were pooled to give total parasitoid mortality. All data sets then were analyzed using contingency tables (non-parametric test). The result is shown in Fig. 1.
Table 1. The outcome of host *P. interpunctella* – parasitoid *V. canescens* interaction under different temperature gradients

<table>
<thead>
<tr>
<th>Temperature treatment</th>
<th>Number of adult parasitoids emerged</th>
<th>Number of parasitoid larvae died</th>
<th>Number of adult hosts emerged (encapsulation)</th>
<th>Total parasitized host larvae</th>
</tr>
</thead>
<tbody>
<tr>
<td>28 - 24 °C</td>
<td>78</td>
<td>8</td>
<td>14</td>
<td>100</td>
</tr>
<tr>
<td>28 - 26 °C</td>
<td>80</td>
<td>9</td>
<td>11</td>
<td>100</td>
</tr>
<tr>
<td>28 - 28 °C</td>
<td>85</td>
<td>4</td>
<td>6</td>
<td>95</td>
</tr>
</tbody>
</table>

Fig 1. Effect of temperature gradients on the survivorship of *V. canescens* developed on fifth instar of *P. interpunctella*

Shifting the temperature for *V. canescens*-*P. interpunctella* interactions did not significantly affect the number of *V. canescens* which survived (successful parasitism) or the number of *V. canescens* which failed ($\chi^2 = 5.004$, 2 df, P = 0.082). This means that shifting the temperature of interactions from 28 to 24 °C or 28 to 26 °C did not affect the successful parasitism of *V. canescens* compared to those which were in a constant temperature of 28 °C.

The number of parasitoid which failed to develop was much lower compared to the parasitoid survivals. The failure of *V. canescens* to develop on parasitized host larvae was caused by the mortality of parasitized larvae and the encapsulation by the host. When the parasitoid was encapsulated, the host *P. interpunctella* will continue to develop and emerged from the interaction. However, there was no parasitoid or host survived when the parasitized
larvae died. The effect of temperature gradients on parasitoid failure is shown in Fig 2.

Parasitoid encapsulation

To determine the effect of temperature gradients on parasitoid encapsulation by the hosts, the data from the second and third columns of Table 1 were pooled. All data sets were then analyzed using contingency table. Encapsulation of the parasitoid *V. canescens* in this study was determined by the number of hosts that survived parasitism, which was the number of adult *P. interpunctella* which emerged. The results showed that encapsulation was not significantly affected by temperature gradients ($\chi^2 = 3.098$, 2 df, $P = 0.212$), even though there is a trend that the lower temperature applied during the host-parasitoid interaction resulted in a higher encapsulation.

Analysis on development time of the unparasitized and survived parasitized host showed that the development time of the host both in two treatments were not significantly different to each other when different temperatures were used ($F_{1,305} = 0.511$, $P = 0.475$) (Table 2). The result showed that parasitism did not affect the development time of survived hosts. Therefore the development data from both unparasitized and parasitized fifth instar larvae were pooled to evaluate the effect of different temperatures on the development time of *P. interpunctella*. The results showed that at the lower temperature, a significantly longer time was needed for *P. interpunctella* to develop ($F_{2,306} = 1252.11$, $P < 0.000$) (Table 3).

Development time and size of *V. canescens*

The results of development time and body size of *V. canescens* are shown in Table 4. Changing the temperature of the host-parasitoid interaction significantly affected the development time of parasitoid *V. canescens* ($F_{2,240} = 1173.18$, $P < 0.001$). Shifting the interaction from the temperature of 28 °C to 24 and 26 °C significantly increased the time needed for *V. canescens* to develop (Table 4). The shortest development time (21.20 ± 0.72 days) was found at the constant temperature of 28 °C. When interactions of host-parasitoid were shifted from 28 to 26 °C or 24 °C, development time of the parasitoid became significantly longer.

The body size of parasitoid *V. canescens* was also affected by shifting the temperature of the host-parasitoid interactions ($F_{2,240} = 14.17$, $P < 0.0001$). Shifting the interactions to lower temperatures, from 28 to 26 or 24 °C resulted in significantly larger body size compared to those at a constant

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Development time (days) (mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unparasitized larvae</td>
</tr>
<tr>
<td>24 °C</td>
<td>15.21 ± 0.80</td>
</tr>
<tr>
<td>26 °C</td>
<td>12.38 ± 0.84</td>
</tr>
<tr>
<td>28 °C</td>
<td>10.69 ± 0.62</td>
</tr>
<tr>
<td></td>
<td>Parasitized larva</td>
</tr>
<tr>
<td>24 °C</td>
<td>15.49 ± 0.60</td>
</tr>
<tr>
<td>26 °C</td>
<td>12.45 ± 0.69</td>
</tr>
<tr>
<td>28 °C</td>
<td>10.67 ± 0.52</td>
</tr>
</tbody>
</table>

Table 3. Development time of *P. interpunctella* under different temperature (means followed by the same letter within the same columns are not significantly different)

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Development time (days) (mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 °C</td>
<td>15.45 ± 0.64 a</td>
</tr>
<tr>
<td>26 °C</td>
<td>12.39 ± 0.82 b</td>
</tr>
<tr>
<td>28 °C</td>
<td>10.69 ± 0.61 c</td>
</tr>
</tbody>
</table>

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Table 4. Development time and body size of parasitoid *V. canescens* developed on fifth instar host *P. interpunctella* under different temperature gradients. (Means followed by the same letter within the same columns are not significantly different)

<table>
<thead>
<tr>
<th>Temperature treatment</th>
<th>Development time (days) (mean ± SD)</th>
<th>Body size (mm) (mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>28 - 24 °C</td>
<td>26.76 ± 0.71 a</td>
<td>1.54 ± 0.09 a</td>
</tr>
<tr>
<td>28 - 26 °C</td>
<td>22.96 ± 0.80 b</td>
<td>1.52 ± 0.07 a</td>
</tr>
<tr>
<td>28 - 28 °C</td>
<td>21.20 ± 0.72 c</td>
<td>1.47 ± 0.09 b</td>
</tr>
</tbody>
</table>

temperature of 28 °C. However, the body size of *V. canescens* which resulted from shifting the temperature from 28 to 26 or from 28 to 24 °C was not significantly different from each other (Table 4). Parasitoids developed in a constant temperature of 28 °C had the smallest body size (1.47 ± 0.09 mm).

**DISCUSSIONS**

**Effects of temperature gradient on survivorship of parasitoids**

Environmental temperature has an important role in mediating the outcome of host-parasitoid interaction (Thomas & Blanford 2003). The survivorship of the parasitoid *V. canescens* in this study was not affected by shifting the temperature of the host-parasitoid interaction to a lower temperature than the temperature they previously experienced. The parasitoid survival at a temperature gradient of 28-24 °C and of 28-26 °C are 78 % and 80 %, which are not significantly lower than the survival of *V. canescens* in a constant temperature of 28-28 °C (89.47 %). The result of this study shows that *V. canescens* is able to develop and emerge when in the situation where the temperatures were shifted lower to 26 and 24 °C during its development. Many studies have shown the effect of different constant temperatures on development and survival of *V. canescens* (Elipoupolus & Stathas 2005). It has been reported that *V. canescens* parasitizing fifth instar larva of *Ephesia kuehniella* Zeller (Lepidoptera: Pyralidae) is unable to develop and survive at a constant temperature below 15 °C.

It is expected that the variation of environmental condition of host-parasitoid interaction will affect the outcome of interaction. Variation in temperature, for instance, will influence the interaction between host and parasitoid, and the outcome will largely depend on how the host and/or parasitoid react to the temperature variation (Thomas & Blanford 2003). However, the interaction of *P. interpunctella-V. canescens* under different temperature gradients, in this present study, does not seem to affect the survival of the parasitoid.

**Effects of temperature on parasitoid encapsulation**

The total number of parasitoid failures in the present study is the combination of parasitized host mortality during development and encapsulation of the parasitoid by the host. When neither host nor parasitoid emerge there is total parasitoid failure, when just the host emerges there is encapsulation of the parasitoid. Shifting temperature from 28 °C to 26 or 24 °C has no significant effect on total number of parasitoid failures, even though there is a trend that shifting to lower temperatures result in higher numbers of parasitoid failures.

The cause of parasitized host mortality was not determined in the present study. Mortality of parasitized host may occur as early instar (dry host mummy), a late instar or pupa (dead larva/pupa), or a pharate (some part of the developing adult cuticle visible). Since encapsulation contributes higher numbers to parasitoid failure than that of larval mortality, the following discussion will focus more on the effect of temperature gradients on encapsulation by the host.

Various effects of temperature on the occurrence of encapsulation have been
shown in many groups of insects. Encapsulation may not be influenced by the change in temperature or may increase with a rise in temperature (Blumberg 1997) depending on the host and parasitoid species involved (Salt 1976). In the present study, encapsulation occurred in all temperature gradients applied, which was shown by the emergence of *P. interpunctella* from the parasitized larvae. However, different temperature gradients employed during the course of host-parasitoid interaction did not significantly influence the occurrence of encapsulation. Shifting the temperature from 28 °C to 26 and 24 °C may not affect the host’s immune system, thus encapsulation of the parasitoid is not be affected.

The hosts used in the present study were the fifth instar larvae, which was the final instar before the pupa was formed. Therefore, the time available for the temperature to affect the interaction was more limited. It is suspected that had the host larva of *P. interpunctella* used in this study were earlier stages i.e. second, third, or fourth instar (instead of fifth instar), the effect of different temperature on encapsulation might have been significantly different due to the longer exposure of the host-parasitoid interaction to different temperature.

The result of this study showed that development time of *P. interpunctella* that survived parasitism by *V. canescens* was not significantly different from that of unparasitized larvae (Table 2). It seems that there is no cost paid by the survived host in terms of its development time. The host adults developed from parasitized and unparasitized fifth instar larvae both emerged at about the same time. The variation in development time of *P. interpunctella* in this study is solely influenced by the different temperature applied during the host development. A similar result has also been reported by Harvey et al. (1994), when different instars of the host *P. interpunctella* were provided for the parasitoid *V. canescens*, the parasitized hosts grew at the same rate as unparasitized hosts.

**Effects of temperature gradient on development time of parasitoid *V. canescens***

Analysing the effect of temperature on the autonomous development of endoparasitoids that allow their hosts to continue to develop after being parasitized is not an easy task. The parasitoids are exposed to continuously changing environment in the host hemolymph, therefore the development is likely to be controlled by the host physiological reactions (Beckage 1985). In general, it has been accepted that development of insects is temperature dependent (Kiritani 1997). The result of this investigation shows that shifting the temperatures of the host-parasitoid interaction to the lower temperatures significantly increases the development time of the parasitoid *V. canescens*. The development time of the parasitoid was significantly longer when the temperatures were shifted from 28 to 26 or 24 °C, compared to those of the constant temperature 28-28 °C.

Most studies of the temperature effects on development of parasitoids were based on constant temperature, while the parasitoid used in this study were maintained at different background temperatures. However, regarding the development time of the parasitoid *V. canescens*, the effect of temperature gradients employed is similar to that of parasitoid developed under different constant temperature. It has been known that the development of parasitoids is delayed at low temperature. The developmental delay at low temperature is caused either by the retarded growth of their hosts or their own temperature sensitivity. In vitro cultured larvae of *V. canescens* dissected from the host, *Ephesia kuehniella* (Lepidoptera:Pyralidae) shows that the development of parasitoids is affected by temperature. This result indicates that the parasitoid itself is sensitive to temperature, however, it does not mean that the parasitoid development is independent of the host physiology (Nakahara & Iwabuchi 2000).

It was reported that the developmental threshold for the host, *P. interpunctella* lay
between 14 and 18 °C (Johson et al. 1995), however, a different study showed that the temperature threshold for the development of this host could be as low as 10.8 °C (Kiritali 1997). On the other hand, the temperature threshold for the development of the parasitoid, *V. canescens* was estimated between 10.86-11.37 °C (Eliopoulo & Stathas 2003), which was not much different from the temperature threshold for *P. interpunctella* reported by Kiritali (1997).

The temperature threshold for *V. canescens* reported by Eliopoulo & Stathas (2005) was recorded when the parasitoid developed on *E. kuehiella*, while the temperature threshold for the parasitoid developed on *P. interpunctella* has not been investigated. The different temperature employed in the present study might not reach the lowest temperature threshold for both the parasitoid and the host, therefore the parasitoid is able to develop well regardless of the different of development time.

Effects of temperature gradient on body size of parasitoid *V. canescens*

Fecundity of a parasitoid is likely to be affected by variation in adult size, which in turn can influence the parasitoid reproductive success (Vinson 1990). Body size affects many ecological and biological parameters in parasitoids, including the number of eggs produced and ovariole number (Godfray 1994; Visser 1994). It has been shown that the size of parasitoid *V. canescens* is significantly correlated with its egg load, with larger parasitoid adults carrying more eggs than smaller adults (Harvey et al. 1994, Eliopoulo et al. 2003). The results of this investigation showed that different temperature gradients employed significantly affects the body size of adults *V. canescens* with the shortest hind tibia found on constant temperature of 28-28 °C. The body size of parasitoids developed at a temperature 28-26 °C and 28-24 °C is significantly larger than those at 28-28 °C. This means that the parasitoid developed at a lower temperature carries more eggs than those of developed at 28-28 °C.

According to Harvey et al. (1994) the wasps with the length of hind tibia almost 2.0 mm stored about twice as many eggs in their oviducts (180-220 eggs) as individuals with the length of hind tibia 1.4 mm (90-110 eggs). Previous study has shown that larger body size of *V. canescens* contain significantly more ovarioles than small parasitoids wasps when they were developed on the host, *E. kuehiella*. The higher number of ovarioles in larger parasitoid adults is correlated with a concomitant increase in maximum egg load (Eliopoulo et al. 2005). A similar result has been observed when *V. canescens* is reared on *P. interpunctella* (Harvey et al. 1994), the same hosts as used in this present investigation. It is suggested that the lifetime egg production of *V. canescens* will increase with the adult size (Harvey et al. 2001).

The size of adult has been considered the important target for selection of parasitoids, thus the offspring should develop in ways that maximize this trait (Visser 1994). One important trade-offs in life history evolution is whether to grow larger at the cost of longer development time, or to develop faster at the cost of reduced size of the adults. The importance of size and development time for fitness of koinobiont ichneumonoids varies with host feeding ecology, and is correlated with mortality risks. Parasitoid *V. canescens* parasitizes concealed hosts *P. interpunctella* and exhibits developmental strategy that favours progeny size over the development time. The adult size increases as development time is longer. In contrast, the closely related ichneumonid *Campoletis sonorensis*, that parasitizes exposed hosts *Pseudoplasia includens* Walker (Lepidoptera: Noctuidae), exhibits the opposite strategy that favours rapid development time over the adult size. In this case, the adult size decreases as development time decreases (Harvey & Strand 2002). The above study was conducted under constant temperature of 27 ± 2 °C across all experiment, while the effect of different temperature gradients on the relationship between development time and body size of parasitoids is not known.
The size of parasitoid adults also correlated with adult life span with larger parasitoids living longer than smaller individuals (Harvey et al. 1994; Harvey et al. 2001). Therefore, even when the host-parasitoid encounter rate is the same across different parasitoid sizes, larger parasitoid may come across more hosts and lay more eggs during their lifetime (Harvey et al. 1994). In the field situation, the size of parasitoid may also affect other factors influencing fitness, such as host searching and dispersal efficiency, which are difficult to measure in the laboratory. Metabolic costs associated with activity of parasitoid may increase, when hosts are spatially separated. This situation will benefit larger individual parasitoids that have greater storage sites than smaller individuals (Harvey et al. 2001).

Based on the above findings and personal observation on the culture stock in the laboratory, it is expected that the adults parasitoid V. canescens developed under temperature gradient of 28-24 °C and 28-26 °C, which have significantly larger body size, will live longer than those of developed at 28-28 °C. However, the fitness of the parasitoid under these different temperature gradients cannot be determined without further investigation.

Conclusions

The parasitoid V. canescens is able to develop and survive when the host-parasitoid interactions were shifted from 28 to 24 °C and 26 °C. The different temperature gradients employed resulted in different development time and body size of the parasitoid. The development time of parasitoid increased as the temperature gradients decreased. It took a longer time for the parasitoid to develop under the temperature of 28 - 24 °C and 28 - 26 °C than that of under the constant temperature of 28-28 °C. Shifting temperature from 28 to 24 °C; and from 28 to 26 °C increased the size of the parasitoid.

It is expected that the larger body size of the parasitoids the more egg loads they can carry, and the longer their life span. The development time of the host P. interpunctella that survived parasitism by V. canescens was not significantly different from that of unparasitized larvae, thus there is no effect of being parasitized on the development time of the survived host. Based on the result of this investigation, it is suggested that when the host P. interpunctella established in lower temperature, the parasitoid V. canescens will develop successfully following the establishment of the host population. However, this result has to be considered cautiously since the host may establish well even in a lower temperature than the temperatures imposed in this study, while the parasitoids ability to parasitize the host under this lower temperature has not been determined.

REFERENCES


Blumberg, D. 1997. Parasitoid encapsulation as a defence mechanism in the Coccoidea (Homoptera) and its importance in biological control. Biological Control. 8: 225-236.


