Temperature-Dependent Development of the Convergent Lady Beetle (Coleoptera: Coccinellidae)

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ABSTRACT Development of the convergent lady beetle, Hippodamia convergens Guérin-Méneville, was compared at six constant temperatures. Two populations, one from Corvallis, Oreg., and another from Tucson, Ariz., did not differ in larval survival or developmental rates. Mortality from eclosion of the first instar to adult emergence was 100, 83, 15, 18, 10, and 5% at 13, 17, 21, 25, 29, and 33°C, respectively. Development from oviposition to adult ranged from 51.9 d at 17°C to 11.4 d at 33°C. The heat-unit requirements for development from egg to adult were 228 degree-days above a developmental threshold of 12.5°C. Published data on development of H. convergens from Ithaca, N.Y., and Bushland, Tex., suggest a constancy in developmental requirements for the species from four widely separated regions of North America.

KEY WORDS Insecta, lady beetle, degree-day, Hippodamia

The convergent lady beetle, Hippodamia convergens Guérin-Méneville, is a prominent species in the native North American fauna of natural enemies in many agroecosystems (Hagen 1962, Belnavis 1989, Elliott & Kieckheffer 1990). Although a polyphagous predator, the convergent lady beetle exhibits a preference for aphids. The developmental biology of H. convergens has been studied in detail to understand its function as a biological control agent (Nielson & Currie 1960, Butler & Dickerson 1972, Baumgaertner et al. 1981, Gutierrez et al. 1981, Obrycki & Tauber 1982, Wipperfurth et al. 1987). Data on development in relation to temperature are important to understanding the dynamics of predator-prey relationships. For instance, the conceptual model for growth, development, and reproduction of H. convergens (Gutierrez et al. 1981) requires data on temperature-dependent development. Also, population differences in developmental rates, if they exist, may be associated with certain climatic conditions and thereby influence population dynamics of natural enemies when imported for biological control of pests (Miller 1983).

The wide distribution of H. convergens makes the species an appropriate model organism for assessing geographical differences in developmental responses to temperature. Butler & Dickerson (1972) evaluated the development of H. convergens from Tucson, Ariz. These data were used by Gutierrez et al. (1981) in the development of a conceptual model of population biology of H. convergens. Obrycki & Tauber (1982) evaluated temperature-dependent growth in a population of H. convergens from Ithaca, N.Y. The results of these studies suggested growth rates were different between the New York and Arizona populations. Furthermore, determination of developmental thresholds and heat-unit requirements from the Butler & Dickerson (1972) data differed from analyses by Gutierrez et al. (1981) and Obrycki & Tauber (1982). Development of H. convergens also has been documented from a population in Bushland, Tex. (Michels & Behle 1991).

Three questions were the basis for the present study. First, what are the values for the lower developmental threshold and degree-day requirements to complete immature development for H. convergens from Corvallis, Oreg.? Second, what values describe the temperature requirements for the Tucson population? Third, do populations of H. convergens from Corvallis, Tucson, Ithaca, and Bushland possess different characteristics of temperature-dependent growth? The answers to these questions provide data for describing the development of the convergent lady beetle.

Materials and Methods

The study was conducted during the spring and summer of 1989. Adult beetles were collected from alfalfa fields in Corvallis, Oreg., and Tucson, Ariz., during April and May. The field-collected beetles were reared at 22°C and fed the Russian wheat aphid, Diuraphis noxia (Mordvilko), and the oat-bird cherry aphid, Rhopalosiphum padi (L.), to obtain egg clusters. Only F1 progeny from the field-collected adults were used in the study.

Six constant temperatures were used: 13, 17, 21, 25, 29, and 33°C. Each temperature treatment was conducted at a photoperiod of 16:8 (L:D) in
Table 1. Average time (days) for development of first generation H. convergens from field-collected adults from Corvallis, Oreg., and Tucson, Ariz., at six constant temperatures, 1989

<table>
<thead>
<tr>
<th>Life stage</th>
<th>Source</th>
<th>Temp (°C)</th>
<th>± SE (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egg</td>
<td>Oregon</td>
<td>13</td>
<td>60 ± 3.2 (23)</td>
</tr>
<tr>
<td></td>
<td>Arizona</td>
<td>17</td>
<td>60 ± 3.2 (23)</td>
</tr>
<tr>
<td></td>
<td>Arizona</td>
<td>21</td>
<td>60 ± 3.2 (23)</td>
</tr>
<tr>
<td></td>
<td>Arizona</td>
<td>25</td>
<td>60 ± 3.2 (23)</td>
</tr>
<tr>
<td></td>
<td>Arizona</td>
<td>29</td>
<td>60 ± 3.2 (23)</td>
</tr>
<tr>
<td></td>
<td>Arizona</td>
<td>33</td>
<td>60 ± 3.2 (23)</td>
</tr>
</tbody>
</table>

Results and Discussion

Survival. Egg, larval, and pupal mortality did not differ between population sources (G = 1.94, df = 1, P > 0.05) but did differ by temperature (G = 103.4, df = 1, P < 0.001). Larvae eclosed from all eggs reared between 13 and 33°C. However, no larvae survived beyond the third instar at 13°C and mortality was high (83%) at 17°C. Michels & Behle (1991) observed that H. convergens failed to develop past the first instar at 15°C. Similarly, Orr & Obrycki (1990) noted that Hippodamia parenthesis (Say) exhibited relatively high mortality at 14°C. Thus, at least two species of aphidophagous coccinellids exhibit high mortality at temperatures around 13 and 14°C. In the present study mortality at the higher temperatures (21–33°C) ranged from 5–18%.

Growth and Development. The period of development for each life stage did not differ between population sources (F = 0.04, df = 1, P > 0.05) (Table 1). Development from eggs to adult ranged from 51.9 d at 17°C to 11.4 d at 33°C. Development of eggs, larvae, and pupae ranged between 14–19%, 56–60%, and 22–28% of the total developmental period, respectively. The time H. convergens spent in each life stage was in the same range of proportions to that of other aphidophagous coccinellids (Obrycki & Tauber 1981, Butler 1982).

A comparison of data from the present study to Butler & Dickerson (1972) is necessary for determining which values on development should be used to represent the Tucson population in a generalized degree-day model. The data exhib-
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MILLER: DEVELOPMENT OF H. convergens

Table 2. Developmental threshold (Dth) and degree-days (DD) requirements ± SE for first-generation H. convergens from field-collected adults from Corvallis, Oreg.; Ithaca, N.Y. (Obrycki & Tauber 1982); and Tucson, Ariz. Reanalysis of Butler & Dickerson (1972); AZb = author (JCM) calculations; AZo = Obrycki & Tauber (1982); AZg = Gutierrez et al. (1981).

<table>
<thead>
<tr>
<th>Life stage</th>
<th>Variable</th>
<th>N.Y.</th>
<th>Oreg.</th>
<th>Ariz.(^{a})</th>
<th>Ariz.(^{b})</th>
<th>Ariz.(^{c})</th>
<th>Ariz.(^{d})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egg</td>
<td>D(_{th})</td>
<td>10.3 ± 1.2</td>
<td>11.3 ± 1.1</td>
<td>11.7 ± 0.9</td>
<td>10.7</td>
<td>10.5</td>
<td>7.4</td>
</tr>
<tr>
<td></td>
<td>DD</td>
<td>44 ± 2.1</td>
<td>45 ± 3.0</td>
<td>41 ± 2.3</td>
<td>44</td>
<td>44</td>
<td>29</td>
</tr>
<tr>
<td>Instar I–IV</td>
<td>D(_{th})</td>
<td>12.7 ± 0.9</td>
<td>13.0 ± 0.6</td>
<td>12.9 ± 0.7</td>
<td>7.9</td>
<td>9.0</td>
<td>8.8</td>
</tr>
<tr>
<td></td>
<td>DD</td>
<td>113 ± 4.2</td>
<td>126 ± 5.7</td>
<td>136 ± 7.3</td>
<td>250</td>
<td>212</td>
<td>200</td>
</tr>
<tr>
<td>Pupa</td>
<td>D(_{th})</td>
<td>12.0 ± 1.2</td>
<td>14.1 ± 0.6</td>
<td>13.4 ± 0.2</td>
<td>10.7</td>
<td>9.5</td>
<td>8.8</td>
</tr>
<tr>
<td></td>
<td>DD</td>
<td>54 ± 0.5</td>
<td>49 ± 0.5</td>
<td>50 ± 0.7</td>
<td>65</td>
<td>65</td>
<td>42</td>
</tr>
<tr>
<td>Egg–Adult</td>
<td>D(_{th})</td>
<td>12.0 ± 0.7</td>
<td>12.6 ± 0.5</td>
<td>12.8 ± 0.6</td>
<td>8.1</td>
<td>10.6</td>
<td>8.8</td>
</tr>
<tr>
<td></td>
<td>DD</td>
<td>230 ± 6.8</td>
<td>228 ± 8.9</td>
<td>228 ± 10.3</td>
<td>375</td>
<td>313</td>
<td>338</td>
</tr>
</tbody>
</table>

Predicted no. days, 20°C

- Predicted no. days, 20°C: 30.8, 28.8, 31.7, 31.5, 33.3, 30.2

Predicted no. days, 25°C

- Predicted no. days, 25°C: 18.4, 17.7, 18.7, 22.2, 21.7, 20.9

Predicted no. days, 30°C

- Predicted no. days, 30°C: 13.1, 12.8, 13.3, 17.1, 16.1, 15.9

Reanalysis of Butler & Dickerson (1972).

\(^{a}\)This study.

\(^{b}\)Author calculations.

\(^{c}\)Obrycki & Tauber (1982).

\(^{d}\)Gutierrez et al. (1981).

Ited similarities and differences in developmental time depending on life stage and temperature. Butler & Dickerson (1972) reported values for egg development that differed from the present study by 0% at 20–21°C, 7% at 25°C, 4% at 28.9–29°C, and 5% at 33–33.9°C. Similarly, they reported values for pupal development that differed from the present study by 3% at 20–21°C, 11% at 25°C, 9% at 28.9–29°C, and 8% at 33–33.9°C. These data suggest the two studies produced similar results. However, data on larval development in Butler & Dickerson (1972) differed from the present report by 1% at 20–21°C, 54% at 25°C, 47% at 28.9–29°C, and 41% at 33–33.9°C. The time required for H. convergens larval development as reported by Butler & Dickerson (1972) was consistently longer. Conditions contributing to the differences noted in larval development between the two studies of the Tucson population follow the discussion on estimates of lower developmental thresholds and degree-day requirements.

The lower temperature threshold for development of the Corvallis and current Tucson populations was determined from data on growth rates between 17 and 33°C (Table 2). Lower developmental thresholds for eggs, larvae, and pupae differed according to life stage but not population source (F = 0.01, df = 1, P > 0.05). Differences in the developmental threshold for eggs were 1.2–1.7°C and 1.7–2.8°C below the larval and pupal thresholds, respectively. The larval threshold for development was 0.5–1.1°C below the pupal developmental threshold.

Degree-day requirements above the developmental threshold for each life stage were not significantly different (F = 0.12, df = 1, P > 0.05) between population sources of the current study (Table 2). Because the accumulation of degree-days is dependent on the estimated developmental threshold, comparison of degree-day requirements are best conducted by assessing predicted days for development at various temperatures. Data for the Corvallis and Tucson populations of the current study differed by 1–3% in predicting days for development from egg to adult at 20, 25, and 30°C. In contrast, various analyses of the Butler & Dickerson (1972) data exhibited an 11–17% difference for 25 and 30°C. Only at 20°C did the prediction of developmental time result in similar values.

An analysis determining the developmental threshold for H. convergens using the data from Butler & Dickerson (1972) resulted in different values from the same data by either Gutierrez et al. (1981) or Obrycki & Tauber (1982) (Table 2). Also, an analysis of the Butler & Dickerson (1972) data resulted in values different from the current assessment of H. convergens from Tucson. Differences in the determination of temperature-dependent developmental requirements for H. convergens from the Butler & Dickerson (1972) data may be attributed to at least four conditions: (1) the lower temperatures tested did not represent the low range at which H. convergens may develop; (2) the higher temperatures tested, while appropriate for assessing developmental dynamics, should not be included in the linear regression because these temperatures were beyond the point of maximum growth rate; (3) development at one of the midrange temperatures (25°C) does not fit a linear pattern and thus appears to be inaccurate; and (4) rearing conditions pertaining to diet, photoperiod, and relative humidity were different. Each of these points is considered in the following discussion.

Only three temperature treatments from the Butler & Dickerson (1972) data set were appro-
The major conclusion from a comparison of the development of *H. convergens* from Corvallis, Ithaca, and Tucson is that the species exhibits a constancy across geographically separated populations in the traits of developmental threshold and degree-day requirements (Fig. 1). Similar observations were made for *Chrysopa oculata Say* (Tauber et al. 1987) and the European corn borer, *Ostrinia nubilalis* Hubner (Calvin et al. 1991).

A generalized estimation of the developmental threshold and degree-day requirements for *H. convergens* is presented in Table 3. Degree-day requirements above respective thresholds for each life stage and for all life stages combined produced an average estimate of the temperature-dependent development of *H. convergens*. The data for *H. convergens* development from Texas (Michels & Behle 1991) provided an independent set of values for testing the accuracy of the generalized model. A reanalysis of the data presented by Michels & Behle (1991), which incorporated only those values in the linear section of the growth rate function, demonstrated a developmental threshold of 12.0°C and developmental requirements from egg to adult of 239 degree-days. Thus, data from four distinct regions of North America suggest that temperature-dependent growth of *H. convergens* is relatively uniform and may be characterized by a lower developmental threshold of 12.5°C with 228 degree-days required for egg-adult development.

Table 3. Values of the lower developmental threshold and degree-day requirements for predicting mean days and range ± SE for temperature-dependent development of *H. convergens*, based on populations from Corvallis, Oreg.; Ithaca, N.Y.; and Tucson, Ariz.

<table>
<thead>
<tr>
<th>Life stage</th>
<th>Developmental parameter</th>
<th>Predicted vs observed development</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( D_{th} )</td>
<td>DD</td>
</tr>
<tr>
<td>Egg</td>
<td>11.1 ± 1.0</td>
<td>41 ± 2.5</td>
</tr>
<tr>
<td>Larva</td>
<td>12.9 ± 0.7</td>
<td>125 ± 5.8</td>
</tr>
<tr>
<td>Pupa</td>
<td>13.2 ± 0.7</td>
<td>53 ± 2.6</td>
</tr>
<tr>
<td>Egg–Adult</td>
<td>12.5 ± 0.7</td>
<td>228 ± 9.4</td>
</tr>
</tbody>
</table>

Observed data obtained from Michels & Behle (1991) for a population from Bushland, Tex. \( n = 3 \). \( D_{th} \), Developmental threshold. DD, Degree-days.
Acknowledgment

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