INTRODUCTION

Peck, caused primarily by stink bugs, is one of the most important quality factors for rice grading and marketability (Yao, 2002; Ito, 2004). Pecky grains are discolored and shriveled, and have poor milling quality. As the amount of pecky rice increases, the quality and value of the crop are reduced. Adequate control of rice stink bugs during heading can improve rice grade, quality and selling price, because kernels fed on by rice stink bugs in the milk or soft dough stages become discolored.

The rice stink bug, *Leptocorisa chinensis* (Dallas), is a major cosmetic pest. *L. chinensis* becomes increasingly important as one of the pests causing pecky rice (Suzuki, 2001). Knowledge of the life history of *L. chinensis*, including the overwintering stage, is an important prerequisite to understanding the population dynamics of the pest in the field. One could predict the fluctuation in population of this pest and then construct an effective control program, if there is detailed knowledge of its development (Yao, 2002). *L. chinensis* invades paddy fields during heading, and as a consequence, pecky rice is caused by *L. chinensis* (Takeuchi et al., 2004). Thus, it is important to predict and control *L. chinensis* invasion during the rice heading stage. In particular, the thermal requirements (d-degrees) for development are often used for estimating developmental periods because temperature has a major influence on the rate at which insects develop (Howe, 1967; Zaslavski, 1988; Gordon, 1998). However, little is known about *L. chinensis* development.

The objectives of this study were to estimate developmental threshold temperatures and heat unit requirements (d-degrees) for the development of the life history stages *L. chinensis*. Such information could provide a means to construct a practical model of the development of *L. chinensis* for establishing integrated management.
MATERIALS AND METHODS

**Insects.** Adults of *L. chinensis* were collected from a paddy field in Hyogo, in September 2002. The insects were kept at 25°C under a 16L–8D photoperiod in a plastic cage (9 cm dia. × 5 cm height) with defrosted rice and distilled water.

**Effect of temperature on development of eggs, nymphs and pre-oviposition.** Developmental periods of *L. chinensis* eggs, nymphs and pre-oviposition were studied at four constant temperatures (±0.5°C): 18, 22, 25 and 30°C (16L–8D). Newly laid eggs (<24 h old) were collected from the adults of the stock culture mentioned above. Newly hatched nymphs (<24 h old) and newly emerged and mated female adults (<24 h old) were placed individually in the plastic cage as mentioned above. The bugs were provided with unhulled rice frozen at the milky stages every 2 d. All eggs and nymphs were checked at 24 h intervals for survival and the presence of exuviae, which was used to determine time of molting. A female and a male that emerged on the same day were confined in the plastic cage as mentioned above. The bugs were provided with unhulled rice frozen at the milky stages every 2 d. All eggs and nymphs were checked at 24 h intervals for survival and the presence of exuviae, which was used to determine time of molting. A female and a male that emerged on the same day were confined in the plastic cage and maintained under the same conditions until the female laid the first egg.

**Estimation of pre-oviposition period after overwintering.** We attempted to estimate the pre-oviposition period after overwintering under two sets of conditions for adults of *L. chinensis*. Thirty-six adult males and 32 adult females were collected from fields just before they were placed in a cage (9 cm dia. × 5 cm height) at a site in a paddy field in Kasai, Hyogo Prefecture from 5 November 2003 to 12 February 2004. The 19 pairs of adults that survived in the field were moved to cages (6 cm dia. × 4 cm height) with one pair in the incubator at 25°C (16L–8D) in the laboratory, and whether females laid eggs was recorded every day.

On 9 November 2001, 27 adults that survived in the field were placed in cages (6 cm dia. × 4 cm height), with one pair of adults in the incubator at 25°C (16L–8D) in the laboratory. Whether *L. chinensis* females laid eggs was also recorded every day.

**RESULTS**

Table 1 shows the developmental period for eggs, nymphs and the pre-oviposition period of *L. chinensis*. The period for each stage decreased as the temperature increased from 18 to 30°C. Table 2 shows the relationship between rearing temperature (*T*) and the rate of development of *L. chinensis*. Developmental rates for eggs, nymphs and pre-oviposition period increased linearly as the rearing temperature rose from 18 to 30°C. The rate

<table>
<thead>
<tr>
<th>Temp. (°C)</th>
<th>Eggs d (mean±SD)</th>
<th>n^a</th>
<th>Nymphs d (mean±SD)</th>
<th>n^a</th>
<th>Pre-oviposition d (mean±SD)</th>
<th>n^a</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>14.9±2.6</td>
<td>89</td>
<td>47.1±1.9</td>
<td>81</td>
<td>29.5±3.6</td>
<td>14</td>
</tr>
<tr>
<td>22</td>
<td>10.4±1.2</td>
<td>34</td>
<td>31.5±1.7</td>
<td>29</td>
<td>21.1±2.3</td>
<td>11</td>
</tr>
<tr>
<td>25</td>
<td>8.7±0.7</td>
<td>250</td>
<td>25.2±2.5</td>
<td>142</td>
<td>17.3±5.3</td>
<td>14</td>
</tr>
<tr>
<td>30</td>
<td>6.7±0.7</td>
<td>197</td>
<td>18.7±2.1</td>
<td>172</td>
<td>12.4±3.2</td>
<td>20</td>
</tr>
</tbody>
</table>

^a Number of individuals tested.

Table 2. Regression equations of developmental rate (*Y*) to rearing temperature (*T*) in *Leptocorisa chinensis* developmental zero and total effective heat units calculated from the regression equation.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Regression equation</th>
<th>r^2</th>
<th>Developmental zero (°C)</th>
<th>Total effective heat units (d-degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egg</td>
<td>Y=0.00687T−0.0552</td>
<td>0.99**</td>
<td>8.1</td>
<td>147</td>
</tr>
<tr>
<td>Nymph</td>
<td>Y=0.00277T−0.0274</td>
<td>0.99**</td>
<td>10.1</td>
<td>370</td>
</tr>
<tr>
<td>Pre-oviposition period</td>
<td>Y=0.00397T−0.0374</td>
<td>0.99**</td>
<td>9.6</td>
<td>256</td>
</tr>
</tbody>
</table>

**p<0.01.**
of development of the different life history stages in relation to temperature is expressed by the linear regression equation ($Y = a + bT$), where $Y$ is the reciprocal of the number of days (=development rate) and $T$ is temperature (°C) (Patel and Schuster, 1983). There was a significant linear relationship between temperature and development rates of eggs, nymphs and pre-oviposition. The developmental zeros in eggs and nymphs were at 8.1 and 10.1°C, respectively, and the effective heat units were 147 d-degrees and 370 d-degrees, respectively. The developmental zero and effective heat unit for the pre-oviposition period of nondiapause females were 9.6°C and 256 d-degrees, respectively.

The cumulative percentage of ovipositing females collected on 9 November 2001 and 12 February 2004 gradually increased (Fig. 1). All females had laid their eggs by 41 d after incubation. There was no significant difference in the days when egg laying started after incubation between the populations collected on 9 November 2001 (28.6 d±5.7 SD) and 12 February 2004 (33.3 d±4.9 SD) ($p>0.05$, $t$-test). From these results, an effective heat unit of 469.7 d-degrees above 9.6°C, which is the threshold for females of non-reproductive diapause, was assumed to be equal to that of reproductive diapause, and was estimated to be required for the pre-oviposition period of overwintering females.

**DISCUSSION**

In *L. chinensis*, Hasegawa et al. (1976) reported that this bug overwinters as adults. In the present study, we recognized that all the adult females collected in winter gradually began to lay eggs after incubation (Fig. 1). An effective heat unit of 469.7 d-degrees was required for the pre-oviposition period of overwintering females, although the effective heat unit for the pre-oviposition period of un-diapaused females was 256 d-degrees. We have never observed the level of egg maturation in overwintering females, but Hasegawa et al. (1976) observed that the females have no mature eggs in the winter. The same genus, *Leptocorisa oratorius* Fabricius is known to have reproductive diapause (Ito and Nik Mohd. Noor, 1993). It is considered that adult *L. chinensis* would undergo reproductive diapause in the winter. There was no significant difference in the timing of egg laying after incubation between the populations collected on 9 November 2001 and 12 February 2004. It is thought that the level of ovary maturity between both of the populations is the same. Since there was not much difference, the effective heat unit for the pre-oviposition period of *L. chinensis* females in the meteorological data for November to February from 2001 to 2004 was recorded with the AMeDAS system in Kasai City, Hyogo Prefecture. A more intensive experiment should be conducted for assessing the termination of reproductive diapause.

Here, the number of annual generations of *L. chinensis* was estimated based on these data and the meteorological data from 2001 to 2003.
recorded by the AMeDAS system in Kasai City, Hyogo Prefecture. The starting point for the calculation was 1 January. The results indicated that adults of the first generation and second generation emerged in mid-July and late August, respectively (Fig. 2). The possibility also showed that adults of the third generation would appear depending on temperature. In the earlier study, two peaks were observed in July and September in Shiga Prefecture (Hasegawa et al., 1976), and also in Hyogo Prefecture (Yamashita, unpublished) in the Kinki region. The present results are consistent with these reports, in that the number of annual generations of *L. chinensis* was two.

Earlier studies investigated the effects of constant temperature on the rate of development of *L. chinensis* reared on unhulled rice in milky stages every 7 d (Ishizaki et al., 2002). Developmental thresholds of 13.5, 12.0 and 18.0°C, and thermal constants of 92.4, 316.2 and 247.7 d-degrees were estimated for the eggs, nymphs and pre-oviposition period, respectively. Developmental rates obtained from those results did not provide a good estimate of the developmental times of populations in the field. A direct extrapolation of the results to the field did not fit the field fluctuation of *L. chinensis*. The development of *L. chinensis* reported by Ishizaki et al. (2002) was longer than that in the present results. The estimated lower developmental threshold temperatures recorded in the present study differed slightly from those estimated using the results of Ishizaki et al. (2002). These differences may be due to differences in the quality and quantity of food materials the tested insects consumed or/and differences in developmental thresholds between the geographic populations of *L. chinensis* from Hyogo and Ibaraki prefectures.

These results would be useful to estimate the occurrence of each stage of *L. chinensis*. However, to apply the developmental simulation to *L. chinensis*, further studies are needed for the measurement of another developmental parameter as well as different geographical populations in various climatic regions.

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**REFERENCES**


