Effect of temperature on development of *Orius strigicollis* (Heteroptera: Anthocoridae) fed on *Frankliniella occidentalis* (Thysanoptera: Thripidae)

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Abstracts

The developments of *Orius strigicollis* eggs and nymphs reared on *Frankliniella occidentalis* were investigated at constant temperatures of 15, 20, 25, 30 and 33°C. Developmental times in the egg and nymphal stages decreased with increasing temperatures although the period of the egg stage at 33°C was almost equal to that at 30°C. The lower developmental thresholds and total effective temperatures were calculated as 11.5°C and 57.5 degree-days for eggs, 11.0°C and 158.7 degree-days for female nymphs, and 10.6°C and 166.7 degree-days for male nymphs, respectively. Hatchabilities were over 90% at 15–30°C, but 80.1% at 33°C. There was no significant difference in the survival rate at the nymphal stage among the temperatures tested. *O. strigicollis* developed from egg to adult at the same developmental rate as *Orius sauteri* and faster than *Orius laevigatus*.

Key words: *Orius strigicollis*, *Frankliniella occidentalis*, developmental time, hatchability, survival rate

INTRODUCTION

The western flower thrips, *Frankliniella occidentalis* (Pergande) is a serious worldwide pest of various crops (van Dijken et al., 1994; Lewis, 1997). *F. occidentalis* was accidentally introduced to Japan approximately ten years ago (Hayase and Fukuda, 1991) and quickly spread almost throughout the country (Katayama, 1997). *F. occidentalis* exhibits thigmotactic behavior to hide in the flowers and buds where insecticide spray can not reach (Brødsgaard, 1994). Furthermore, many populations of *F. occidentalis* have developed resistance to various conventional insecticides (Immaraju et al., 1992; Brødsgaard, 1994). Therefore, alternative techniques to regulate *F. occidentalis* such as biological controls are required in Japan as well as other countries.

The anthocorid *Orius* spp. preferably attack small agricultural pests: thrips, aphids and mites (Barber, 1936). Some *Orius* bugs are already used as biological control agents against *F. occidentalis* on vegetable and ornamental crops under greenhouse conditions in Europe (van Lenteren et al., 1997). In Japan, *O. sauteri* has been most often investigated as a predatory enemy to be applied in the biological controls of *F. occidentalis* and *Thrips palmi* Karny (e.g. Kohno and Kashio, 1998; Nagai and Yano, 1999) because of its common distribution and high effectiveness (Kawai, 1995; Yasunaga, 1997). Since 1998, *O. sauteri* has been commercially available against *F. occidentalis* and *T. palmi* on cucumbers, eggplants and sweet peppers. However, Kohno (1997, 1998) and Ito and Nakata (2000) showed that *O. sauteri* females entered reproductive diapause under short-day conditions although the diapause rates varied somewhat among the populations and exposed temperatures. Therefore, *O. sauteri* may not be effective during the winter season in Japan due to its reproductive diapause induction at short photoperiods. An application of *O. sauteri* in December resulted in failure to control *F. occidentalis* on sweet peppers in greenhouses (Narai, unpubl.).

Insects distributed in the lower latitudes often show no diapause even under short-day. *Orius strigicollis* (Poppius) is mainly found in more temperate regions (lower latitudes) than *O. sauteri*, including southwest Japan, Taiwan and the southern part of China (Yasunaga and Kashio, 1993; Yasunaga,
1997). Shimizu and Kawasaki (2001) indicated that Orius spp. distributed in the lower latitudes of Japan possessed a lower diapause incidence and a shorter critical day length. Practically, F. occidentalis on eggplants or sweet peppers in greenhouses were effectively suppressed by the introduction of O. strigicollis not only in the long-day season (Shibao and Tanaka, 2000) but also in the short-day season of December and January (Narai, unpubl.; Takai, unpubl.). These results suggest that O. strigicollis can be useful as a year-round biological control agent against F. occidentalis in domestic greenhouses.

It is important to determine the biological characteristics of O. strigicollis and compare them with those of other commercialized Orius bugs because they provide useful information to establish an effective biological control strategy with O. strigicollis against F. occidentalis (Nakata, 1995). Kim et al. (1997, 1999) determined the development, fecundity and longevity of O. strigicollis. But their O. strigicollis were reared on cotton aphids (Aphis gossypii Glover), two spotted spider mites (Tetranychus urticae Koch) or mold mites (Tyrophagus putrescentiae Schrank), not F. occidentalis. The life history parameters of development, fecundity and longevity may change with different food sources.

This paper reports the effects of temperature on the development of O. strigicollis eggs and nymphs provided F. occidentalis as a preliminary step to evaluating its biological characteristics.

MATERIALS AND METHODS

Laboratory rearing of F. occidentalis and O. strigicollis. F. occidentalis and O. strigicollis stock cultures were performed in a laboratory under the condition of 25±1°C, 60±10% R.H. and 16L–8D photoperiod. F. occidentalis adults were collected from chrysanthemum flowers in the Kurahashi-jima Island of Hiroshima Prefecture in 1996. The population was reared as described by Loomans and Murai (1997) although soaked broad beans without seed coats were supplied as food instead of flower pollens. The diets were replaced every two days in principle.

A laboratory colony of O. strigicollis was started with insects which had been reared at Kochi Agricultural Research Center since 1996 (Field origin: Nangoku City in Kochi Pref.). UV-sterilized eggs of Ephestia kuehniella Zeller or Plutella xylostera L. were supplied as food to the nymphs and adults. The adults were reared in a plastic container (15 cm length, 10 cm width and 5.5 cm height), the lid of which had a ventilation hole (2.5 cm dia.) covered with a fine-mesh nylon screen. Five or six soybean sprouts and moistened cotton in a small acrylic petri dish (3.2 cm dia., 1.1 cm depth) were provided in each container as oviposition substrates and water source, respectively. The lepidopterous eggs and soybeans were replaced every two or three days. The soybean sprouts containing O. strigicollis eggs were placed in a transparent acrylic container (9.2 cm dia. and 5.5 cm height) with a ventilation hole (2.5 cm dia.) in its lid. One day before the expected date of hatching of O. strigicollis eggs, the lepidopterous eggs were provided near the soybeans as a food source for newly eclosing nymphs. Soaked broad beans and a few pieces of paper towel were placed inside the container as a moisture source and shelter for the young nymphs. The diets and broad beans were replaced every two or three days.

Hatchability and development of O. strigicollis eggs. This test was carried out at five constant temperatures, 15, 20, 25, 30 and 33°C with a 16L–8D photoperiod. Eggs were obtained by exposing chrysanthemum stems (ca. 5 cm length) to about 20 females of O. strigicollis for 12 h in a plastic petri dish (9.5 cm dia., 2.2 cm height) at 25°C. The numbers of O. strigicollis eggs deposited in the stems were counted. The stems were placed individually in other petri dishes with a moistened filter paper (7 cm dia.). The petri dishes were introduced in incubators controlled at each test temperature. Egg development was checked at 24 h intervals and hatchabilities were calculated by dividing the numbers of eggs hatched into the numbers of eggs deposited.

Development and survival of O. strigicollis nymphs. This experiment was carried out at four constant temperatures, 15, 20, 25 and 30°C with a 16L–8D photoperiod. Each newly hatching nymph (age within 12 h) was confined in a small glass cylinder (2.5 cm dia., 1.5 cm height) containing a chrysanthemum leaf disk (1.6 cm dia.) and second stadium larvae of F. occidentalis as prey. Both edges of the glass cylinder were sealed with filter paper disks (2.5 cm dia.) and Sealon Films (Fuji

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Photo Film Co., Ltd.). The numbers of *F. occidentalis* larvae provided for the first, second, third, fourth and fifth stadium nymphs were 5, 7, 10, 15 and 25 per day, respectively, and all of them were replaced daily. Natural mortality of *F. occidentalis* larvae was neglected because it was almost zero in a preliminary test. Observation was done daily to monitor survival and exuviation of *O. strigicollis* nymphs.

**Statistical analyses.** Hatchabilities and survival rates at the rearing temperatures tested were statistically analyzed with a chi-square test for independence. When significant differences were indicated, the data were subjected to arcsine transformation and then compared by a Tukey-type multiple comparison test (Zar, 1999).

The relationship between insect developmental rates (reciprocals of developmental times) and rearing temperatures is described by a straight line, except at the extremely low or high temperatures that are deleterious to its growth (Campbell et al., 1974). From the experimental data obtained, I calculated the following linear regression equations for the developmental rates of *O. strigicollis* eggs, female and male nymphs against rearing temperatures:

$$Y = a + bX$$

where *Y* is the developmental rate, *X* is the rearing temperature, and *a* and *b* are parameters. The lower developmental thresholds (*T*<sub>0</sub>) and total effective temperatures (*K*) were computed as follows:

$$T_0 = -a/b \quad K = 1/b$$

**RESULTS AND DISCUSSION**

Developmental times and hatchabilities of *O. strigicollis* eggs are presented in Table 1. Developmental times decreased with increasing rearing temperatures, although the period at 33°C was almost equal to that at 30°C. Hatchabilities were higher than 90% from 15 to 30°C and there were no significant differences among the rates (Tukey-type multiple comparison test, *q*=1.353 (15°C vs. 20°C), 0.411 (15°C vs. 25°C), 0.783 (15°C vs. 30°C), 0.978 (20°C vs. 25°C), 0.816 (20°C vs. 30°C), 0.287 (25°C vs. 30°C), *k*=4, *p* > 0.05). On the other hand, the rate at 33°C was less than 90% and significantly lower than that at 30°C (chi-square test, $X^2=13.44$, d.f.=4, 0.005 < *p* < 0.01 and Tukey-type multiple comparison test, *q*=3.846, *k*=4, 0.01 < *p* < 0.05). This result means that high temperatures of 33°C and above might be unsuitable for the development of *O. strigicollis* eggs.

Kim et al. (1999) reported that developmental times and hatchabilities of *O. strigicollis* eggs were 18.9 days and 70.6% at 15°C, 8.6 days and 81.8% at 20°C, 6.1 days and 80.0% at 25°C and 3.4 days and 91.8% at 30°C, respectively. Their *O. strigicollis* eggs have longer developmental times and slightly lower hatchabilities from 15 to 25°C than our *O. strigicollis* eggs. The development of *Orius* eggs can be little affected by the rearing methods and host plants selected in each study since the eggs are usually oviposited into plant tissues. Thus, a precise explanation for the differences among the results described above can not be obtained.

Compared to the eggs of *O. sauteri* and *Orius laevigatus* (Fieber), which is commonly used as a biological control agent for the thrips pests in Europe, *O. strigicollis* eggs take longer (16.3 days) to complete development at 15°C (13.7 days in *O. sauteri*: Nagai and Yano, 1999; 11.7 days in *O. laevigatus*: Alauzet et al., 1994). However, the developmental periods at 20, 25 and 30°C do not differ much from those of *O. sauteri* and *O. laevigatus*. The hatchabilities of *O. strigicollis* eggs are as high as those of *O. sauteri* (92.9–100%: Nagai and Yano, 1999) and *O. laevigatus* (73–87%: Alauzet et al., 1994) at temperatures from 15 to 30°C.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Hatchability (%)&lt;sup&gt;a&lt;/sup&gt;&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Developmental time (days)&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>90.3 (93) ab</td>
<td>16.3±0.15 (84)</td>
</tr>
<tr>
<td>20</td>
<td>96.6 (29) ab</td>
<td>6.5±0.10 (28)</td>
</tr>
<tr>
<td>25</td>
<td>91.9 (62) ab</td>
<td>4.6±0.07 (57)</td>
</tr>
<tr>
<td>30</td>
<td>92.6 (95) a</td>
<td>3.1±0.03 (88)</td>
</tr>
<tr>
<td>33</td>
<td>80.1 (136) b</td>
<td>3.0±0.02 (109)</td>
</tr>
</tbody>
</table>

<sup>a</sup>Figures in parentheses indicate numbers of eggs tested.

<sup>b</sup>Percentages in column followed by same letter are not significantly different at 5% level by Tukey-type multiple comparison test following chi-square test. Data ($X$) were transformed to 0.5[arcsine($X/(n+1)\times$ arcsine($X/(n+1)\times(n+1)$)] ($n$=No. tested) before the multiple comparison tests.
Table 2 shows the developmental times and survival rates in the nymphal stage of *O. strigicollis*. At all the temperatures tested, fifth stadium nymphs had the longest developmental times of any stages. This age-related developmental pattern is considered to be a common characteristics of the Orius predatory bugs because it has been observed in other Orius species: *Orius insidiosus* (Say) (Isenhour and Yeargan, 1981), *O. laevigatus* (Alauzet et al., 1994; Cocuzza et al., 1997), *O. minutus* (L.) (Kohno and Kashio, 1998) and *O. sauteri* (Nakata, 1995; Kohno and Kashio, 1998; Nagai and Yano, 1999).

The developmental periods of *O. strigicollis* nymphs are longer on diets of cotton aphids (45.6 days at 15°C, 21.3 days at 20°C and 9.4 days at 30°C: Kim et al., 1999) than on diets of *F. occidentalis* larvae (estimated in this study). Moreover, Kiman and Yeargan (1985) and Vacante et al. (1997) showed that the developmental times and survival rates of *Orius albipennis* (Reuter), *O. insidiosus* and *O. laevigatus* nymphs differed among the different foods supplied. Therefore, *O. strigicollis* nymphs provided *F. occidentalis* larvae as their prey in this study should at least be compared with the nymphs of other *Orius* species reared on thrips. The developmental times of *O. sauteri* nymphs fed on *T. palmi* were 40.9, 18.9, 11.5 and 9.5 days at rearing temperatures of 15, 20, 25 and 30°C, respectively (Nagai and Yano, 1999). *O. laevigatus* reared on *F. occidentalis* completed nymphal development at 15°C in 48.2 days and at 25°C in 14.1 days (Cocuzza et al., 1997). These results indicate that *O. strigicollis* nymphs, in contrast to the egg stage, can develop faster than *O. sauteri* nymphs at 15°C and *O. laevigatus* nymphs at 15°C and 25°C.

The mean durations from egg to adult emergence were estimated at 53.7 days (15°C), 24.7 days (20°C), 15.9 days (25°C) and 11.4 days (30°C) for *O. strigicollis* (females: this study), 54.6 days (15°C), 26.4 days (20°C), 16.0 days (25°C) and 12.7 days (30°C) for *O. sauteri* (Nagai and Yano, 1999), 59.2 days (15°C) and 18.1 days (25°C) for *O. laevigatus* (Cocuzza et al., 1997). Comparison of these *Orius* species demonstrates that *O. strigicollis* develop from egg to adult at the same rate as *O. sauteri* at 15–30°C and faster than *O. laevigatus* at 15°C and 25°C.

Table 3 shows the linear regression equations for developmental rates against temperatures, the lower developmental thresholds (T₀) and the total effective temperatures (K) of *O. strigicollis* eggs and nymphs. The data at 33°C in the egg stage were not included in the equation because they did not fit to the regression line. The K of *O. strigicollis* eggs and nymphs are smaller than those of *O. sauteri* which require 62.1 degree-days for the egg stage and 180.8 degree-days for the nymphal stage (Nagai and Yano, 1999), although the T₀ of *O. stri-
gicollis are quite similar to *O. sauteri* (11.1°C: egg, 10.3°C: nymph).

Night temperature in domestic greenhouses where eggplants are cultivated during the winter should be kept at a minimum of 12°C (Ishibashi, 2000). This temperature is higher than the *T₀* of *O. strigicollis* eggs and nymphs estimated in the current study (Table 3). Therefore, *O. strigicollis* eggs and nymphs produced by the adults released in eggplant greenhouses can develop throughout the winter.

The survival rates of *O. strigicollis* nymphs are shown in Table 2. The rate was approximately 60% at temperatures of 15, 20 and 25°C, but it decreased to 37.3% at 30°C, although there was no significant difference among the rates at 15–30°C (chi-square test, $\chi^2$ = 7.641, d.f. = 3, $p$ > 0.05). The survival rates of *O. sauteri* were estimated to be 51.4, 78.3, 77.8 and 76.0% at 15, 20, 25 and 30°C, respectively (Nagai and Yano, 1999). These rates are all higher than those of *O. strigicollis*. It is difficult to consider that sufficient prey were not supplied to *O. strigicollis* nymphs during this experiment because no *O. strigicollis* nymphs that had killed and exhausted the *F. occidentalis* larvae supply were observed in the test. We kept *O. strigicollis* nymphs in sealed glass cylinders with no ventilation holes, and thus the inside humidity was probably very high. Nagai and Yano (1999) stated that the nymphal survival could be affected by the rearing methods used. Therefore, the lower survival rates of *O. strigicollis* nymphs shown in Table 2, especially at 30°C, might be caused by the rearing condition of too high humidity.

The current laboratory study shows that *O. strigicollis* fed on *F. occidentalis* develop from egg to adult at the same rate as or faster than the congeneric predatory bugs produced commercially, i.e. *O. sauteri* and *O. laevigatus*. However, its survival rates in the nymphal stage are lower than the other bugs. It may be necessary to review the rearing system of *O. strigicollis* when life history parameters of the adult stage are examined in the next study.

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**REFERENCES**


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<table>
<thead>
<tr>
<th>Stage</th>
<th>Regression equation</th>
<th>$r^2$</th>
<th>Lower developmental threshold ($T₀$: °C)</th>
<th>Total effective temperature ($K$: degree-days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egg</td>
<td>$Y = 0.0174X - 0.2003* $</td>
<td>0.967</td>
<td>11.5</td>
<td>57.5</td>
</tr>
<tr>
<td>Female nymph</td>
<td>$Y = 0.0063X - 0.0693* $</td>
<td>0.981</td>
<td>11.0</td>
<td>158.7</td>
</tr>
<tr>
<td>Male nymph</td>
<td>$Y = 0.0060X - 0.0636* $</td>
<td>0.975</td>
<td>10.6</td>
<td>166.7</td>
</tr>
</tbody>
</table>

* $X$ and $Y$ indicate temperature (°C) and developmental rate (day$^{-1}$). An equation of the egg stage was calculated with data of 15, 20, 25 and 30°C. Asterisks (*) mean significant at 0.1% level.


