Effect of temperature on development and reproduction of the onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), on pollen and honey solution

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(Received 11 June 1999; Accepted 28 June 2000)

Abstract

The effects of five constant temperatures (15°C, 20°C, 23°C, 25°C and 30°C) under 16L8D photoperiod on development, reproduction and population growth of *Thrips tabaci* reared on a diet of pollen and honey solution were studied. Although hatchability was more than 80% at temperatures between 15 and 25°C, it was low at 30°C. Survival rates from hatch to adult were higher than 65% at all temperatures. Developmental rates increased linearly as rearing temperature increased. It was estimated that 232.6 degree-days, above a developmental zero of 10.8°C, were required to complete development from egg to adult oviposition. These data were related to records of field temperatures in Kurashiki, western Japan, to estimate the potential number of generations per year that could complete development under outdoor conditions. Using this data, a maximum of between seven and 11 generations could have developed annually between 1990 and 1998. Mean adult longevity decreased with increasing temperature, from a maximum of 86.6 days at 15°C to a minimum of 12.8 days at 30°C. The mean fecundity on pollen and honey solution was the highest at 23°C and 270 eggs per female. The intrinsic rate of natural increase (*r*ₚ) was highest at 25°C and 0.1709.

Key words: *Thrips tabaci*, developmental zero, thermal constant, population growth, pollen

INTRODUCTION

The onion thrips, *Thrips tabaci*, is an important pest of vegetables and ornamentals all over the world and is well known as a vector of tomato spotted wilt virus (TSWV) (Sakimura, 1940; Wijkamp et al., 1995), tobacco streak virus (TSV) (Séodoree and Teakle, 1987) and sowbane mosaic sobemovirus (SoMV) (Hardy and Teakle, 1992). *T. tabaci* is polyphagous and is found not only in leaves, but in the flowers of its many host plants, where it feeds on pollen, an essential component of the diet of flower living thrips such as *Frankliniella intonsa*, *T. obscurus* and *T. imaginis* (Murai and Ishii, 1982; Kirk, 1985; Trichilo and Leigh, 1988; Teulon and Penman, 1991). Several life history studies of *T. tabaci* have been published (Sakimura, 1937; Gawaad and El-Shazli, 1969; Edelson and Magaro, 1988; Van Rijn et al., 1995), but the effect of a wide range of temperatures on development and reproduction remains little-known (Kirk, 1997). Moreover, several of the reports center on the effects of host plant on life cycle and lack the age-specific data needed for an accurate estimation of the intrinsic rate of natural increase (*r*ₚ). The intrinsic rate is used to evaluate reproductive potential of insects and the population consequences of host plant resistance and pesticide application measured at the individual level (Trichilo and Leigh, 1988; Romanow et al., 1991). Furthermore, it is an important parameter for evaluating the effect of natural enemies to which biological control will be introduced (Van Driesche and Bellows, 1996).

Determination of the response of development and reproduction to different temperatures is vital to an understanding of the life history and population dynamics of this pest. For example, in order to simulate population dynamics of *T. tabaci* and understand virus epidemiology, the life history parameters of the vector must be considered.

*T. tabaci* is a cosmopolitan species that has a wide variety of host plants and host flexibility and completes its life cycle both on leaf and flower (Imai et al., 1988). Leaf living thrips such as *Scirtothrips dorsalis* and *T. setosus* complete their life cycle only on leaves of the host plant; flower living thrips such as *F. intonsa* and *T. hawaiiensis* depend on the flower (Cheng, 1985; Murai, 1988). There are no studies that evaluate *T. tabaci* as a flower liv-
ing thrips.

This study investigates the relationship between temperature and development and reproduction of *T. tabaci* on pollen and honey solution, and determines the basic thermal requirements for development. These data are related to temperature records for western Japan, and can be used to estimate the maximum number of generations per year that could potentially complete development in this region.

The status of *T. tabaci* as a major pest of ornamentals, especially in greenhouses, was replaced by *F. occidentalis* and *T. palmi* (Jacobson, 1997). The reasons for this replacement are discussed.

**MATERIALS AND METHODS**

**Insect.** A stock culture of *T. tabaci* was collected from a field population on onion at Izumo, Shimane, in western Japan. All *T. tabaci* tested were produced asexually, resulting in an all-female sample, i.e. thelytokous reproduction. Thrips were reared on tea pollen (*Camellia sinensis*) and 10% honey solution (Murai and Ishii, 1982), and cultures were kept in a thermostatic cabinet set (SANYO Co. MIR-151) of 20±1°C and 16L:8D photoperiod.

**Developmental times at different constant temperatures.** *T. tabaci* can lay eggs into water through a thin membrane such as Sealonfilm® (Fuji Photo Film Co.) or Parafilm® (American National Can Co.) (Murai and Ishii, 1982). In order to collect eggs, 20 adult females were placed in each of several glass tubes (36 mm diameter, 40 mm length) with 10 mg of tea pollen. Both ends of the tube were covered by that Sealonfilm®. At one end, a drop of water (approx. 1 ml) was deposited and covered with a further layer of Sealonfilm®.

To investigate egg development, eggs that had been laid within a 6-h period at 20°C were individually placed with a fine brush on slack Sealonfilm® floating on water in a petri dish and held at either 15, 20, 23, 25 or 30±1°C in controlled thermostatic cabinets (described above), 16L:8D photoperiod. Four petri dishes containing more than 50 eggs were set at each temperature.

To investigate larval and pupal development, each newly hatched larva was reared individually as for the egg collecting method described above. In this case, a rearing glass tube of 16 mm diameter and 30 mm length was used and approx. 0.5 mg of tea pollen and 0.1 ml of 10% honey solution were provided. Food sources were not changed until adult emergence. When thrips larvae pupated, mold grew on the pollen. This mold had no negative effect on the development of thrips.

Developmental periods of eggs, first and second stadium larvae, prepupa and pupa were determined by observation at 12-h intervals. More than 20 individuals were tested at each temperature.

Linear regression of the mean temperatures experienced by individual insects and their developmental rate (1/day) was carried out to estimate the threshold temperature of development and the thermal constants necessary for development between stages and to adulthood, as described by McDonald et al. (1998).

**Reproduction.** Newly emerged females were individually reared using the same method as for larval rearing, but foods were replenished every two days. The number of eggs laid into the honey solution through that Sealonfilm® was determined daily at five constant temperatures: 15, 20, 23, 25 and 30°C, 16L:8D photoperiod. Oviposition and survival were recorded daily throughout the life time of the female.

Life table parameters including net reproductive rate (*R*<sub>n</sub>) and mean generation time (*T*) were calculated with the standard formula below (Birch, 1948).

\[
R_n = \sum_{x=1}^{\infty} l_x m_x, \quad T = \ln R_n / r_m
\]

The intrinsic rate of natural increase (*r*<sub>m</sub>) was derived by iterative substitution of values of *r*<sub>m</sub> into the following equation,

\[
\sum_{x=1}^{\infty} e^{-rx} l_x m_x = 1
\]

where *e* is the base of natural logarithms, *x* is individual age, *l*<sub>x</sub> is the probability of an individual surviving to age *x* and *m*<sub>x</sub> is fecundity at age *x*. Sex ratio was 1.0, because of thelytokous reproduction.

**RESULTS**

**Development**

The mean developmental times of each stage, hatchabilities, survival rate and preoviposition pe-
Table 1. Developmental duration of *T. tabaci* at different temperatures

<table>
<thead>
<tr>
<th>Temp. (°C)</th>
<th>Hatchability (%)</th>
<th>Developmental duration in days</th>
<th>Survival rate from hatch to adult (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>94.4</td>
<td>7.15±1.46 9.56±1.89 3.53±0.69 7.89±0.56 8.64±0.56</td>
<td>95.0</td>
</tr>
<tr>
<td>20</td>
<td>83.6</td>
<td>6.53±0.59 3.26±0.55 3.92±0.54 1.89±0.39 3.95±0.27 4.37±0.56</td>
<td>95.0</td>
</tr>
<tr>
<td>23</td>
<td>83.5</td>
<td>5.03±0.51 2.80±0.41 3.26±0.45 1.17±0.37 3.22±0.55 3.41±0.71</td>
<td>90.0</td>
</tr>
<tr>
<td>25</td>
<td>82.4</td>
<td>4.99±0.51 2.38±0.54 2.87±0.57 1.11±0.31 2.63±0.56 2.35±0.56</td>
<td>67.5</td>
</tr>
<tr>
<td>30</td>
<td>10.5</td>
<td>3.76±0.44 1.85±0.17 1.89±0.46 0.80±0.25 2.33±0.48 1.96±0.64</td>
<td>67.5</td>
</tr>
</tbody>
</table>

*Means±SD. Numbers in parenthesis indicate sample size.*

Table 2. Regression equation, developmental zero and thermal constants for *T. tabaci*

<table>
<thead>
<tr>
<th>Stage</th>
<th>Regression equation</th>
<th>( r^2 )</th>
<th>Developmental zero (°C)</th>
<th>Thermal constant (K) (degree-days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egg</td>
<td>( y = -0.0840 + 0.0117x )</td>
<td>0.98</td>
<td>7.2</td>
<td>85.5</td>
</tr>
<tr>
<td>Larva+pupa</td>
<td>( y = -0.0726 + 0.0074x )</td>
<td>0.99</td>
<td>9.8</td>
<td>135.1</td>
</tr>
<tr>
<td>Preoviposition period</td>
<td>( y = -0.3062 + 0.0275x )</td>
<td>0.96</td>
<td>11.1</td>
<td>36.4</td>
</tr>
<tr>
<td>Total</td>
<td>( y = -0.0463 + 0.0043x )</td>
<td>0.93</td>
<td>10.8</td>
<td>232.6</td>
</tr>
</tbody>
</table>

Period at each of five constant temperatures are given in Table 1. More than 80% of eggs hatched at temperatures lower than 25°C, though development of the egg to the eye-spot stage was impaired at 30°C, and only 10% of eggs gave rise to larvae. Thus, high temperature appeared to inhibit egg development. Egg duration at 15°C was 11.4 days, about three times as long as that at 30°C.

Adult emergence from larvae reared on pollen and honey solution was higher than 65% at all temperatures and was higher than 90% at temperatures lower than 23°C. The developmental periods from hatch to adult emergence were 28.1, 13.0, 10.5, 9.0 and 6.9 days at 15, 20, 23, 25 and 30°C, respectively. Preoviposition period at 15°C was 8.6 days, about four times as long as that at 30°C.

There was a significant linear relationship between developmental rates and mean temperatures (between 15 and 30°C inclusive) for all developmental stages. The developmental zero and the thermal constants are given in Table 2. The developmental zero for egg, combined larval and pupal stages, preoviposition period and egg to adult oviposition period were 7.2, 9.8, 11.1 and 10.8°C, respectively, with thermal constants of 85.5, 135.1, 36.4 and 232.6 degree-days, respectively.

The number of degree-days derived from an automated meteorological data acquisition system (AMeDAS) at Kurashiki operated by the Japanese Meteorological Agency between 1990 and 1998, and the corresponding estimate of the number of generations that could complete development each year, are presented in Table 3. On the basis of temperature data alone, a maximum of between seven and 10 generations could complete development annually under field conditions in Kurashiki, western Japan.

### Reproduction

Adult longevity and fecundity of *T. tabaci* at five constant temperatures are shown in Table 4. Adult longevity decreased with increasing temperature (\( F = 10.95; \text{d.f.} = 4; p < 0.0001 \)). Adult longevity at 15°C was 86.6 days, about seven times as long as
Table 3. Estimated maximum number of generations that could complete development in the field, for each year between 1990 and 1998 in Kurashiki

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total effective temperature (degree-days)</td>
<td>2.020</td>
<td>1.895</td>
<td>1.848</td>
<td>1.654</td>
<td>2.145</td>
<td>1.860</td>
<td>1.855</td>
<td>2.360</td>
<td>2.499</td>
</tr>
<tr>
<td>Estimated maximum number of generations</td>
<td>8.7</td>
<td>8.1</td>
<td>7.9</td>
<td>7.1</td>
<td>9.2</td>
<td>8.0</td>
<td>8.0</td>
<td>10.1</td>
<td>10.7</td>
</tr>
</tbody>
</table>

Table 4. Fecundity and longevity of T. tabaci on tea pollen and honey solution at different constant temperatures

<table>
<thead>
<tr>
<th>Temp. (°C)</th>
<th>n</th>
<th>Longevity (days)</th>
<th>Fecundity</th>
<th>(total egg no./female)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>34</td>
<td>86.6±36.6c</td>
<td>169.6±94.2 (349)b</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>38</td>
<td>46.8±21.4b</td>
<td>210.0±148.9 (548)bc</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>17</td>
<td>41.7±14.5b</td>
<td>270.4±111.6 (433)c</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>26</td>
<td>25.0±10.2ab</td>
<td>165.0±84.8 (293)b</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>23</td>
<td>12.8±4.6a</td>
<td>62.6±35.9 (124)a</td>
<td></td>
</tr>
</tbody>
</table>

*Means ± SD. Means followed by the same letter in the same column were not significantly different at \( p=0.05 \) (Scheffé's multiple comparison test).

That at 30°C, Most ovipositing females continued oviposition until the day before death at all temperatures. The total fecundity per female at 30°C was significantly smaller than that at other temperatures (\( F=46.8; \) d.f. =4; \( p<0.0001 \)). The largest mean fecundity per female was 270 eggs at 23°C (Table 4). The highest oviposition rate of more than 8 eggs per day per female was observed at 25°C.

Parameters of population growth of T. tabaci at five constant temperatures are given in Table 5. The intrinsic rate of natural increase (\( r_m \)) increased with temperature to a peak of 0.1709 at 25°C, however, this value at 30°C was very small. Net reproductive rate was the greatest at 23°C.

### DISCUSSION

Although at 30°C low mortality was observed between larva and adulthood, egg mortality was 89.5%. High temperature appeared to inhibit egg development of T. tabaci. A low hatchability (around 50%) at 35°C has also been recorded for F. occidentalis (Katayama, 1997) and T. kawaiensis (Murai unpublished). These low hatchabilities were observed by the same method using a film. This suggests that high temperature is likely to have a direct effect on egg development. McDonald et al. (1998) described that the England strain of F. occidentalis hatched successfully at 35°C in chrysanthemum leaf. Eggs of T. palmi deposited in cucumber leaves are able to hatch at 30°C (Kawai, 1985). Therefore, T. tabaci has a lesser capacity to develop at high temperatures. Sakimura (1937) described a summer decline in the numbers of a Japanese population of T. tabaci, a trend which may be explained by the inability of eggs to hatch at high temperatures and the low density of preferred host stages i.e. flowers.

The developmental zero for the egg stage of T. tabaci was lower than those of F. intonsa (12.0°C, Murai, 1988), T. palmi (11.3°C, Kawai, 1985) and F. occidentalis (9.2°C, Katayama, 1997; 9.9°C, McDonald et al., 1998). Adult F. intonsa can overwinter in a state of reproductive diapause, and larval stages are not observed in winter (Murai, 1988). Adult and larval stages of F. occidentalis can overwinter outdoors in Shizuoka (Katayama and Ikeda, 1995), diapause patterns of F. occidentalis and T. tabaci are not known. The lower development zero for egg stage may enable larvae of T. tabaci to appear in winter as Sakimura (1937) ob-
served overwintering immature stages of *T. tabaci* in onion fields in Japan. The developmental zero for development from hatching to adult emergence of *T. tabaci* was lower than those of *T. palmi* (11.5–11.7°C, Kawai, 1985) and *F. intonsa* (11.0°C, Murai, 1988) and higher than those of *T. imaginis* (7.0°C, Andrewartha, 1936), *F. occidentalis* (8.9°C, Katayama, 1997; 6.1°C, McDonald et al., 1998) and *S. dorsalis* (9.3°C, Tatar, 1994). Edelson and Magaro (1988) stated that the developmental zero of the Texas population of *T. tabaci* was 10.2°C when reared on onion leaf. There is no notable difference in developmental zero of *T. tabaci* among rearing diets.

Validation of lower thresholds derived from laboratory studies should be attempted with some references to field data but the continuous and overlapping generations of thrips throughout the season makes this difficult. It should be treated as an estimate of maximum potential volatinism. Effective accumulative temperatures of four species, *T. palmi* (Kawai, 1985), *F. intonsa* (Murai, 1988), *S. dorsalis* (Tatar, 1994) and *F. occidentalis* (Katayama, 1997) have been studied. The estimation of possible generation number of *T. tabaci* was lower than that of *F. intonsa* and *F. occidentalis*, and is similar to that of *T. palmi*, and greater than that of *S. dorsalis*.

Most females produced eggs throughout their adult lives, similar to the case of *F. intonsa* and *T. hawaiiensis* (Murai and Ishii, 1982). Van Rijn et al. (1995) reported a mean adult longevity of 11.9 days and peak oviposition rate of 5.5 eggs per day on *T. tabaci* reared on cucumber at 25°C. In this study, mean adult longevity was 25.0 days and peak oviposition rate was more than 8 eggs per day on pollen and honey solution at 25°C. Thus, pollen and honey solution appear to enhance egg production and adult longevity of *T. tabaci*; this pattern was also found in *T. imaginis* (Andrewartha, 1935), *F. intonsa* (Murai and Ishii, 1982), and *T. obscurus* (Teulon and Penman, 1991). Adult females of *T. tabaci*, reared on only honey solution without pollen, did not produce any eggs (Murai, unpublished). Honey solution may not affect egg production of *T. tabaci*, as Murai and Ishii (1982) described for *F. intonsa*. However, the difference in enhancing egg production of *T. tabaci* among different kinds of pollens remains unknown.

A pollen born virus, SoMV can be transmitted leaf to leaf by *T. tabaci* in the absence of infected pollen (Hardy and Teakle, 1992). As adult thrips that have fed on pollen have a higher fecundity and longer life span than those that feed solely on leaves, they may have a correspondingly greater capacity to act as vectors of these viruses.

Van Rijn et al. (1995) reported population growth parameters of *T. tabaci* at 25°C on cucumber. Net reproductive rate (*R*$_n$) of *T. tabaci* on pollen and honey solution was six times higher than on cucumber leaf and the intrinsic rate of increase (*r*$_m$) was similar on both food sources. This is due to the fact that adult longevity of *T. tabaci* on pollen and honey solution was twice as long as that on cucumber leaf reported by Van Rijn et al. (1995). Pollen is clearly a significant factor in determining the net reproductive rate of *T. tabaci*. This pattern was also detected in *F. occidentalis*, *F. intonsa* and *T. obscurus* (Murai and Ishii, 1982; Trichilo and Leigh, 1988; Teulon and Penman, 1991). In addition to being able to complete its life cycle on the leaf tissue of its many host plants (Imai et al., 1988), *T. tabaci* is clearly also able to exploit pollen, an ephemeral and high-quality food resource that enhances its generative potential. *T. tabaci* therefore has a flexible host range in terms of species and growth stage of plant, a factor which may contribute to its cosmopolitan status.

The intrinsic rate of natural increase (*r*$_m$) of *T. tabaci* in this study is higher than that of *T. palmi* (0.134, Kawai, 1985), *F. intonsa* (0.158, Murai, 1988) and *F. occidentalis* (0.141, Katayama, 1997; 0.166, Van Rijn et al., 1995) at 25°C. However, at 30°C, it was lower than that of *F. occidentalis* and *T. palmi* and *F. intonsa*. At 30°C, the fecundity of each female was less than at other temperatures, a fact which may be at least partially due to a reduced adult longevity. It was suggested that this higher intrinsic rate of natural increase of *T. tabaci* at the temperatures lower than 25°C is due to the advantage of thelytokous reproduction, and the opposite result at 30°C is due to low hatchability of *T. tabaci*.

*F. occidentalis* and *T. palmi* have replaced for *T. tabaci* as a pest thrips of Japanese ornamental plants as well as *F. occidentalis* in Europe. Although this replacement is mainly due to higher resistance of *F. occidentalis* and *T. palmi* against many chemicals (Matsuzaki et al., 1986; Robb, 1989), the low hatchability and lower survival rate
of *T. tabaci* at higher temperatures may have a supplemental effect on it.

**ACKNOWLEDGEMENTS**

The author thanks Dr. J. R. McDonald, Central Science Laboratory, Sand Hutton, York, UK for his critical reading of this manuscript.

**REFERENCES**


