Influences of relative humidity on mortality during the pupal stage of *Thrips palmi* (Thysanoptera; Thripidae)

Yoshichika Kakei and Koji Tsuchida*

Laboratory of Entomology, Faculty of Agriculture, Gifu University, Gifu 501-1193, Japan

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Abstract

We examined the effect of relative humidity on mortality during the pupal stage (prepupa and pupa) of *Thrips palmi* (Thysanoptera: Thripidae) under laboratory conditions. Mortality from the prepupal stage to adulthood decreased with increasing relative humidity. We compared the mortalities under 3 experimental treatments (control; upperside treatment, prepupae were released on filter paper; underside treatment, prepupae were covered with filter paper) at various relative humidities (58, 78, 82, 86, 88, 93 and 98%). The mortality under every treatment at 58% relative humidity was 100%. Except at 58 and 93% relative humidities, the mortalities under the underside treatment were lower than the other treatments. Differences in mortality among all three treatments were found at 82 and 86% relative humidities. At 88, 93 and 98% relative humidities, however, no differences in mortality among the three treatments were found. Logistic regression analysis revealed that both humidity and underside treatment had significant negative effects on mortality. Individuals released in the upperside treatment moved at higher rates within a day from the release than those in the underside treatment.

Key words: Relative humidity, mortality, *Thrips palmi*

INTRODUCTION

Although the original distribution of *Thrips palmi* was mainland South-East Asia and India, it has also been recognized in Japan since 1978. When this species infests plants such as eggplant, silvering on the surface of leaves and keloid on the skin of fruits are observed, resulting in a dramatic decrease in their commercial value. Among terebrantia species, *T. palmi* is one of the most serious pests of fruit vegetables in western Japan, because of its high reproductive rate (Kawai, 1985), low sensitivity to insecticides, and wide host range (Ikeda et al., 1984b). The adults, like other terebrantia species, feed on plants and lay eggs singly in the plant tissue. After hatching, the larvae feed on the plant until the II stage, then they drop to the ground and pupate in the soil (Ikeda et al., 1984a). Usually, pupae are concentrated beneath the food plants, like other thrips species (e.g. Lewis, 1973). Schweizer and Morse (1996, 1997) showed that most adults of citrus

thrips, *Scirtothrips citri*, emerge from leaf-litter or shallow soils, and that frequent irrigation and the introduction to soil of decollate snails, *Rumina decollata*, effectively suppress the survival rate of *S. citri*. Tsuchida (1997) reported that the emergence sites of *T. palmi* were restricted to the soil around the stems in an eggplant field with a mulching sheet. Because, from full-grown II stage of larvae to pupal stage, the individuals live in the soil, mortality should be influenced by humidity and soil condition around the pupating site. This paper reports on the relationship between humidity and mortality during the pupal stage (prepupa and pupa) of *T. palmi*.

MATERIALS AND METHODS

Insects. Adults of *T. palmi* were collected from eggplants and cucumbers in a field on the Yanagido Campus of Gifu University, and stock colonies were maintained in the laboratory on cucumber seedlings in a plastic cage (45 × 45 × 60 cm) at 25 ± 1°C, 14L10D. Five to

*To whom correspondence should be addressed at: E-mail: tsuchida@cc.gifu-u.ac.jp

eight adult thrips were transferred to a 7 cm diameter petri dish under the same conditions used for the stock colonies provided with a small cucumber leaf placed on water-soaked filter paper. The dish was incubated and the adult females were allowed to oviposit for three days. After the adults were removed, the leaves containing eggs were kept in the dish, whereas hatched larvae were transferred to another dish with a fresh leaf. The leaves were changed every two days.

Influence of humidity on the mortality of pupal stage (prepupa and pupa). We prepared experimental arenas using Parafilm® and cotton cloth. A square of 3.5×3.5 cm was cut out the center of a 7.6×10.0 cm sheet of Parafilm®, and the resulting space was covered with a 3.7×3.7 cm sheet of cotton cloth. The cloth was dyed purple to make the thrips easily discernable from the background.

We made three experimental treatments with respect to habitat (Fig. 1): prepupae were re-

leased on the arena (control); prepupae were released on a 6.5 cm diameter filter paper within the arena (upperside treatment); prepupae were released on the arena, and they were covered with a 6.5 cm diameter filter paper (underside treatment). We released nine to eleven prepupae per the arena. The arenas were covered with a 7 cm diameter petri dish, which was put into a plastic cage. The arena and petri dish were set horizontally on a 5 cm high stand made from stainless wire that was placed in the plastic cage. A 9.5 cm diameter petri dish filled with supersaturated salt solution was placed underneath the stand in order to control the relative humidity (Winston and Bates, 1960). For our experiments, we used seven relative humidities: 58, 78, 82, 86, 88, 93 and 98%. The plastic cages were sealed and maintained under identical laboratory conditions as the stock colonies. The humidity conditions with three habitat treatments were replicated five times. Daily checks to verify whether insects were dead

Fig. 1. Schematic illustration of humidity controlled rearing arenas.

or alive were made until adulthood. We also checked whether the prepupae had moved from the initial site of release (upperside and underside of filter paper) at 24 h after release. Adults and dead insects were removed from the arenas.

Statistical methods. All statistical analyses except for a Marquart-fitting procedure were performed using StatView 5.0 for the Macintosh (SAS Institute Inc., 1992–98).

RESULTS AND DISCUSSION

We analyzed the relationship between the cumulative mortality in control treatments and relative humidity using the logistic model (Fig. 2): $F(h) = m / (1 + e^y)$, with $y = (h - h_c) / \beta$. Here, h represents the humidity level, m is the maximum survival, h_c is the critical humidity, and β is a measure of variance equal to standard deviation $\times \sqrt{3} / \pi$ (Mood and Graybill, 1974). The parameter values were obtained by a Marquart-fitting procedure, minimizing the squared deviations between model predictions and data points (see also Van Houten et al., 1995). The mortality decreased with increasing humidity.

None of the inoculated individuals at 58% humidity could survive to adulthood, irrespective of the habitat treatment. Except at 58 and 93% humidities, the mortalities under the underside treatment were lower than the other treatments, and the differences in the mortalities were statistically significant at 82 and 86% humidities (Table 1, Chi square test, $p < 0.05$). At 88, 93 and 98% relative humidities, however, no differences in mortalities between each of the treatments were found. We analyzed the effects

Table 2. Logistic regression analysis for mortality of pupal stages (prepupa and pupa) under each treatment at each humidity

Independent variables	Coefficient	Wald test
Humidity	−0.306	< 0.0001
Upperside treatment ^a	−0.102	0.643
Underside treatment ^a	−0.837	0.0001

^aEach value was calculated comparing to the control treatment.

of treatment and humidity on mortality using a logistic regression analysis (Table 2): two independent variables (humidity and treatment) were used to test their influence on the probability of an insect being dead or alive, and the effect of the treatment was evaluated by comparison to the control (upperside vs. control and underside vs. control). The upperside treatment did not significantly influence mortality compared to the control. The underside treatment, however, significantly decreased mortality compared to the control. Humidity also had a significant negative effect on mortality.

From two days after release, the number of individuals found to have moved did not increase, but decreased only due to the death of individuals or adult emergence in this study. We compared, therefore, the frequencies of individuals which had moved from the initial site of release within a day of release between the upperside and underside treatments, irrespective of whether they were dead or alive. No individuals could survive to adulthood under the control treatment at 58 and 78% humidities.

Table 1. Differences in mortalities among each treatment under each relative humidity during the pupal (prepupa and pupa) stage

Relative humidity (%)	Mortality (%)			Chi square ^a
	Control	Upperside	Underside	
58	100	100	100	—
78	100	100	79.2	—
82	96.2	92	79.2	8.16*
86	86.3	74	60.4	8.81*
88	51.9	52	44	0.85
93	11.3	17	13.2	0.33
98	15.1	17	3.8	4.55

^aThe mortalities at 58 and 78% relative humidity under each treatment could not be tested using Chi square because of low frequencies of some columns. * $p < 0.05$.

Table 3. Comparison of the numbers of moved prepupae at 24 h after the release between upperside and underside treatments at three humidity conditions

Relative humidity (%)	Treatment	No. of prepupae		
		Moved	Did not move	
58–78	Upperside	33	70	$p < 0.001^a$
	Underside	1	102	
82–88	Upperside	31	119	$p < 0.001$
	Underside	7	149	
93–98	Upperside	20	87	$p < 0.001$
	Underside	1	105	

^aThe differences of the frequencies were tested using Fisher's exact probability test.

The mortalities of individuals under the control at relatively higher humidities (93 and 98%) were less than 20%, and the mortalities from 82 to 88% humidities were intermediate between these two humidity classes (Table 1). Therefore, we combined the data for frequencies of relocated individuals into three humidity classes: lower (58–78%), middle (82–88%), higher (93–98%). Individuals released in the upperside treatment moved at higher rates than those in the underside one (Table 3), showing that the individuals in the upperside treatment had a greater propensity to move from the site of initial release within a day of the release.

During the pupal stage (prepupae and pupae) of *T. palmi*, higher relative humidity was a more favorable condition for survival (Fig. 2). The effect of position on mortality in the arena was apparent at 82 and 86% humidities (Table 1). The logistic regression analysis revealed that the underside treatment had a significant effect on decreasing mortality compared to the control. These results suggest that the mortalities of prepupa and pupa of this species could be influenced not only by relative humidity, but also by differences in the space surrounding the individuals. In the underside treatment, the area to which the individuals attached is thought to be largest among the 3 treatments. Such an effect might help to decrease the mortalities during the pupal stage in the middle range humidity conditions. Thrips are in the habit of crawling into dark corners, with the maximum of their body surface in contact with the surroundings (Mound, 1994). This trait is considered to be selectively adaptive, because it might

Fig. 2. The relationship between the cumulative mortality and the relative humidity fitted using the logistic model. See text for the explanation of the calculation. Here, m represents maximum survival, h_c is critical humidity, and β is a measure of variance equal to the standard deviation $\times \sqrt{3}/\pi$.

lower the mortality during the pupal stage at some humidity conditions.

After thrips crawl into the soil, their survivorship should be influenced not only by the soil water content, but also by the physical structure of the soil. Further studies on the effects of environment around the pupation site are needed to understand the population regulation system of thrips in the field.

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