EFFECT OF TEMPERATURE ON THE DEVELOPMENT, LONGEVITY AND OVIPOSITION OF GREENHOUSE THRIPS (*HELIOTHRIPS HAEMORRHOIDALIS*) ON LEMON FRUIT

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ABSTRACT

Greenhouse thrips (*Heliothrips haemorrhoidalis*) is a major pest of horticultural crops worldwide, and in New Zealand it is particularly damaging on citrus, avocados and ornamentals. *Heliothrips haemorrhoidalis* development, oviposition and longevity were determined at five constant temperatures (16, 18, 20, 23 and 25ºC) on unripe Yenben lemon fruit. Total developmental time (egg to adult) ranged from 72.9 days at 16ºC to 28.4 days at 25ºC. The rate of *H. haemorrhoidalis* oviposition was highest at 25ºC, with an average of 1.4 eggs laid per day. Mean adult longevity ranged from 89.9 days at 25ºC to 124 days at 16ºC. It was estimated that 419.8 degree-days, above a lower threshold temperature of 10.1ºC, were required to complete development from egg to adult. The developmental time predictions obtained from the degree-day model were validated under variable field conditions. Actual developmental times were generally within one day of times predicted by the model.

Keywords: greenhouse thrips, *Heliothrips haemorrhoidalis*, degree-day model, unripe lemon fruit.

INTRODUCTION

Heliothrips haemorrhoidalis Bouché (Thysanoptera: Thripidae) is a polyphagous pest of a number of fruit crops and ornamentals worldwide. Commonly referred to as "greenhouse thrips", it is widely distributed throughout the North Island of New Zealand, but is found outdoors only as far south as Nelson (Mound & Walker 1982). The species is uniparental and reproduces by thelytokous parthenogenesis. Greenhouse thrips damage plants by feeding on the mesophyll tissue of fruit and mature leaves. Larval and adult stages feed by a "piercing-sucking" process whereby the plant surface is pierced and chlorophyll and other cell contents are extracted from the plant tissue. Greenhouse thrips feeding causes fruit and leaves to take on a silver or bronze appearance, and is often associated with the presence of dark faecal droplets causing further discolouration on both fruit and foliage. Scars and blemishes on fruit is caused by greenhouse thrips feeding are an economic problem, as the fresh fruit is unattractive and may be considered unsuitable for premium quality grades. It has been estimated that greenhouse thrips costs the New Zealand citrus industry around $6,000,000 annually (K. Pyle, pers. comm.). There are very few natural enemies of greenhouse thrips in New Zealand and control is primarily dependent on insecticide applications. Greenhouse thrips have many overlapping generations per year in New Zealand, but populations generally peak in late summer/autumn (Blank & Gill 1997). Temperature is a key driver of insect development rates and this relationship underpins the understanding of population dynamics (Bernal & Gonzalez 1993). The ability to predict seasonal population changes via a temperature-development rate model could lead to better targeting of control measures.

Insect development rate models are generally built by observing development over a range of constant temperatures. One of the best-known models is the degree-day model, which uses the linear portion of the temperature-developmental plot to predict developmental rates under any fluctuating temperature regime. This model has been widely used in insect pest management and has proven important as a forecasting tool and for predicting egg hatch and seasonal occurrence of a number of insect populations. Models have been developed to predict onion thrips development (Edelson & Magaro 1988), estimate generations of *Thrips hawaiiensis* (Murai 2001), and predict different levels of attack by slash pine flower thrips (Fatzinger & Dixon 1996) in the field. One of the criticisms of degree-day models is that the constant temperatures used to generate them do not take into account the natural variations in temperature found in natural conditions.

The objectives of the study were (1) to determine the influence of temperature on *H. haemorrhoidalis* development, longevity and oviposition as a basis for population modelling; (2) to estimate lower developmental threshold temperatures for each life stage and the thermal requirements to complete development; and (3) to validate the degree-day model derived from constant temperature experiments under variable temperature conditions.

MATERIALS AND METHODS

Rearing

Greenhouse thrips were reared on unripe Yenben lemons in ventilated plastic containers (30 cm x 20 cm x 10 cm). Field-collected leaves infested with *H. haemorrhoidalis* were placed into the containers on the lemons. As the leaves dried, the thrips moved on to the lemons and began to feed and oviposit on the fruit. The leaves were removed from the containers once dry. Fresh lemons were added to the colony every three weeks and any deteriorated fruit were removed. Colonies were maintained at 23ºC (± 2ºC) and a 16 h photoperiod.

Each of the following experiments was conducted at five different temperature regimes: 16, 18, 20, 23 and 25ºC (± 2ºC).

Oviposition and egg hatch

Five adult *H. haemorrhoidalis* were enclosed within each of four cages on unsprayed lemons. The cages consisted of clear plastic tubes (21 mm diameter, 30 mm height) with fine wire mesh covering one end. The other end was attached to the lemon with Blutak™. Ten lemons were placed into each of the temperature regimes. Adults were removed from cages after a period of 24 h. On day 14, once eggs had developed and were easily visible, each caged arena was examined using a binocular microscope and the number of eggs was recorded. The number of eggs laid per adult per day was estimated by dividing the number of eggs laid in each cage by five (the number of adults). Egg hatch was also recorded by checking each cage daily for emergence and calculating the mean percentage of egg hatch within each temperature regime. Eggs of adults that died during the experiment were not included in the analyses.

Egg-larval development

To obtain eggs of a known age, five adult greenhouse thrips were enclosed per cage with 4 cages per lemon as described above. Five lemons were placed into each of the temperature regimes. The adults were removed after 24 h and the lemons placed back in the incubators. Each lemon was inspected daily for larval thrips emergence. Newly emerged larvae were placed individually into new cages on fresh lemons to measure larval and pupal development times. The duration of the pre-pupal and pupal stages were not recorded separately as the pre-pupal stage often lasted for less than a day. Recording ceased once all thrips became adults. This experiment was repeated three times.

Adult longevity

Fifty newly emerged *H. haemorrhoidalis* adults were caged singly on individual lemons as described above. Ten lemons were placed into each constant temperature regime. Cages were checked daily for adult mortality. Every 20 days, each adult was transferred to a new cage on a new lemon. Longevity was recorded until all thrips were dead. This experiment was repeated twice.

Degree-day model development

Development of the degree-day model initially required calculation of the developmental threshold (*t*) and the thermal constant, *K*. The developmental threshold is defined as the temperature at which an insect or developmental stage ceases to develop. The thermal constant is the amount of heat required to complete development and is expressed as degree-days. The developmental threshold and the thermal constant required for each *H. haemorrhoidalis* life stage were derived from the linear regression equation: y = a + bx, where y is the developmental rate at temperature x, a is the y-intercept and b is the slope (Sokal & Rohlf 1981). The developmental threshold and thermal constant values were calculated using the following formulae:

Developmental threshold $t = (y-a) / b$,
$t = (0-a) / b$

y was set at 0 as we were attempting to determine the temperature at which development ceases (where the developmental rate is zero).

Thermal constant $K = 1 / b$.

The predicted developmental rate under any fluctuating temperature regime can be determined by summing the degree-days above *t* until the *K* value for the life stage was reached. This was achieved by accumulating the mean daily temperature minus the lower developmental threshold.

Degree-day model validation

A degree-day model derived from constant temperature developmental studies for all stages was tested under variable field conditions. To obtain eggs of a known age, five adult greenhouse thrips were placed into each of four cages on unsprayed lemons. A total of 300 greenhouse thrips were established on 15 lemons. Five lemons were placed into each of three plastic ventilated containers and maintained at 18ºC. The adults were removed after 24 h and the three containers placed outside in different localities around the Mt Albert Research Centre. Gemini Tinytalk® data loggers were also placed into each of the containers to obtain the mean daily temperature to which the thrips were exposed. The lemons were checked daily for larval emergence. Newly emerged larvae were placed into separate cages to measure larval and pupal developmental times. The life stage of each thrips in each cage was recorded daily until all thrips had become adults. This experiment was repeated four times over a 12-month period to validate the degree-day model under varying temperatures. The number of days required for development in the field was compared with those predicted using the degree-day model calculated from the constant temperature data.

Data analysis

Statistical analysis of the data was conducted using the computer programme SAS. The effect of temperature on development, oviposition and adult longevity were determined by Analysis of Variance (ANOVA). A Least Significant Difference (LSD) test was performed on the data if a significant difference was indicated by the ANOVA ($P<0.05$).

The relationship between temperature and developmental rate for each life stage (egg, larval and pupal) was calculated by linear regression using SAS.

RESULTS

Oviposition and egg hatch

The rate of *H. haemorrhoidalis* oviposition increased with increasing temperature (Table 1). The regression of oviposition rate to temperature was significant ($y = 0.09807x - 1.20623$; $r^2 = 0.98$; $P<0.05$) and the threshold temperature for *H. haemorrhoidalis* oviposition was estimated to be 12°C. Egg hatch was variable within all treatments. Mean percentage egg hatch across temperature treatments was between

56.8% at 26°C and 83.0% at 20°C. There was no significant difference in egg hatch between the different temperature regimes (P>0.05).

TABLE 1: Mean number of *Heliothrips haemorrhoidalis* eggs laid per adult per day (± SE).

Temperature (°C)	Eggs laid per adult per day
16	0.4 ± 0.1
18	0.5 ± 0.1
20	0.8 ± 0.1
23	1.0 ± 0.1
25	1.4 ± 0.1

Egg-larval development and adult longevity

Only individuals that completed development to adulthood were included in the analyses. Developmental times for all life stages were inversely related to temperature (Table 2). Developmental rate (reciprocal of developmental time) increased linearly with temperature for all life stages ($r^2 > 0.98$). The regression equations describing these relationships were $y = 0.004447x - 0.0458$, $y = 0.00728x – 0.00728$ and $y = 0.0017354x – 0.18997$ for egg, larval and pupal development respectively.

Heliothrips haemorrhoidalis adult longevity increased with decreasing temperature (Table 2).

TABLE 2: Mean developmental times of *Heliothrips haemorrhoidalis* life stages and adult longevity (days ± SE).

Temperature (°C)	Egg	Larvae	Pupae	Total (egg–adult)	Adult longevity
16	38.1 ± 0.2	23.3 ± 0.4	11.5 ± 0.2	72.9	124.0 ± 3.5
18	29.3 ± 0.3	17.1 ± 0.2	8.3 ± 0.1	54.7	120. 4 ± 5.2
20	23.0 ± 0.2	14.1 ± 0.2	6.2 ± 0.2	43.3	116.5 ± 5.4
23	18.1 ± 0.2	11.0 ± 0.2	4.9 ± 0.2	33.5	111.2 ± 2.7
25	15.1 ± 0.2	9.2 ± 0.1	4.1 ± 0.3	28.4	89.9 ± 5.0

Degree-day model development

The estimated developmental thresholds for all life stages ranged between 10.1 and 10.9ºC (Table 3). It was estimated that 419.8 degree-days, above a lower threshold temperature of 10.1ºC, were required to complete development from egg to adult.

TABLE 3: The developmental threshold (*t*) and thermal constant (*K*) estimated for the life stages of *Heliothrips haemorrhoidalis*

	Egg	Larvae	Pupae	Total (egg–adult)
Developmental zero (ºC)	10.3	10.1	10.9	10.1
Thermal constant (degree days)	224.9	137.3	57.6	419.8

Degree-day model validation

Heliothrips haemorrhoidalis development was predicted and observed to be most rapid during summer for all life stages (Table 4). Egg development was predicted within one day of the observed time for the summer and winter replicates. Larval and pupal development times were predicted within two days of the observed time for all four seasons.

TABLE 4: Observed and predicted developmental times of *Heliothrips haemorrhoidalis* (days ± SE).

Life stage	Season	Observed	Predicted	Mean temperature during development (ºC)
Egg	Summer	22.3 ± 0.3	23.4	19.9
Egg	Autumn	155.6± 0.4	158.4	11.7
Egg	Winter	76.0 ± 0.2	75.9	13.3
Egg	Spring	37.4 ± 0.2	39.2	15.4
Larvae	Summer	12.2 ± 0.2	12.0	21.6
Larvae	Autumn	22.7 ± 0.5	24.4	15.7
Larvae	Winter	20.4 ± 1.1	22.5	16.3
Larvae	Spring	18.5 ± 0.3	18.9	17.3
Pupae	Summer	4.1 ± 0.2	5.9	20.8
Pupae	Autumn	12.0 ± 0.3	11.5	15.9
Pupae	Winter	11.6 ± 0.2	11.3	16.0
Pupae	Spring	7.7 ± 0.3	7.4	18.7

DISCUSSION

The developmental time of *H. haemorrhoidalis* from egg to adult was found to be relatively similar to those reported in previous studies. For example, the mean total developmental time (egg to adult) at 23ºC has been previously reported as 36 days (Rivnay 1935), 37.3 days (Froud & Stevens 1997) and 37.5 days (Del Bene et al. 1998) on citrus twigs, unripe lemons and *Viburnum* leaves, respectively. The slight differences may be attributed to a number of variables, including host plant species and/or host plant nutritional status, humidity and genetic variation in populations.

The number of eggs laid per adult per day increased from 0.4 at 16°C to 1.4 at 26°C. This is consistent with the values given by Rivnay (1935) and Lewis (1973) within the same temperature regimes. However, Del Bene et al. (1998) found much higher oviposition rates, with values increasing from 0.5 at 15°C to 2.1 at 25°C, and they estimated the threshold temperature for *H. haemorrhoidalis* oviposition to be 7°C. This threshold, which assumes a linear relationship between oviposition and temperature, was lower than those estimated by other authors. The present study estimated the threshold temperature for *H. haemorrhoidalis* oviposition to be 12.3°C, which is similar to the estimates given by Lewis (1973) of 12.5°C and Rivnay (1935) of 12.4°C.

Del Bene et al. (1998) recorded *H. haemorrhoidalis* longevity from 72.5 days at 15ºC to 36.0 days at 25ºC when reared on *Viburnum* leaves. This is shorter than that found in the present study where the thrips were reared on unripe lemons.

The degree-day model developed accurately predicted *H. haemorrhoidalis* developmental times under field conditions with a good level of accuracy and shows potential for estimating the seasonal occurrence and abundance of greenhouse thrips under different climatic conditions. It may also be valuable in determining the optimum time for initiating greenhouse thrips monitoring programmes or for applying control measures against *H. haemorrhoidalis*. This includes both spray applications and augmentative releases of biological agents into *H. haemorrhoidalis* populations. In practice, applying a degree-day model requires a starting point, which could be an arbitrary date, or a 'biofix' based on a tangible biological event (e.g. capture of adult in trap, plant phenology event).

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