DEVELOPMENT RATES, LONGEVITY AND FECUNDITY OF SIX-SPOTTED MITE (*EOTETRANYCHUS SEXMACULATUS*) AT CONSTANT TEMPERATURES

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ABSTRACT

Six-spotted mite (*Eotetranychus sexmaculatus*) is a key pest of avocados in New Zealand. Six-spotted mite feeding on leaves can cause excessive leaf drop and a subsequent reduction in tree productivity and yield. Six-spotted mite development, longevity and fecundity were determined at six constant temperatures (10, 13, 18, 21, 25, 30ºC) on avocado leaf discs. No larvae hatched from eggs at 10°C. The number of days to complete egg development ranged from 5.3 days at 30°C to 23.9 days at 13°C. Total developmental time (egg to adult) ranged from 29.6 days at 18°C to 11 days at 30°C. Mean adult longevity ranged from 18.8 days at 30°C to 41.4 days at 18°C. The number of eggs laid per female ranged from 6.9 to 20.9. Degree-day models were developed for eggs, larvae and nymphs. It was estimated that 202.8 degree-days, above a threshold temperature of 12.2ºC, were required to complete development from egg to adult.

Keywords: six-spotted mite, *Eotetranychus sexmaculatus*, temperature, development rate, longevity, fecundity.

INTRODUCTION

Six-spotted mite, *Eotetranychus sexmaculatus* (Riley) (Acari: Tetranychidae), is a serious pest of avocados in New Zealand. Six-spotted mite feeding causes a purple discolouration along the veins on the underside of avocado leaves (Stevens et al. 2001). High populations can cause severe defoliation of trees and subsequent decrease in tree productivity, especially prior to flowering. In Californian avocados, feeding damage by only 5-10 adult mites per leaf is said to cause leaf drop (Bailey & Olsen 1990). Similar mite populations have been observed to cause leaf drop in New Zealand avocados, but this is not always the case and higher populations can show no leaf drop effect (D. Steven, pers. comm.), therefore the relationship between mite numbers and leaf drop is not simple.

Although this species has been in New Zealand since at least 1953 (Lamb 1953), the mite was first observed to cause serious defoliation to avocado trees during the late 1990s, first in Northland and later in other avocado growing regions (Tomkins 2002). Six-spotted mite populations generally increase in spring and decline from January to March (Froud et al. 2002, Steven 2003). Control in New Zealand avocado orchards is dependent on the use of a small number of pesticides and the potential for development of resistance to miticides by six-spotted mite is a concern (Charles & Allan 2002). It is not known why the pest status of six-spotted mite has increased. In California, biological control of six-spotted mite has generally been sufficient to keep populations below economically injurious levels (Fleschner 1953), but there is no evidence of such control in New Zealand. However, six-spotted mites can become a pest in Californian avocado orchards when pesticides applied against other pests (e.g. *Scirthothrips perseae*) disrupt biological control (Hoddle 2002). In New Zealand orchards, high levels of natural enemy (ladybirds and predatory mites) mortality following the application of broad spectrum pesticides used for controlling pests, such as leafrollers, armoured scale and greenhouse thrips, may possibly cause six-spotted mite outbreaks (Tomkins 2002). However, the evidence for this is not clear cut, as high mite populations have also been observed in orchards that have not received any insecticides. Other factors that may predispose avocado trees to six-spotted mite population outbreaks include nutrient deficiency, drought, heavy flowering, high nitrogen levels or abundance of alternative hosts (Brookbanks 2001).

Although six-spotted mite is a cosmopolitan species, there is no published summary of basic reproductive and temperature-developmental parameters. These data can assist with timing of control measures and add to understanding of the impact of climate and geographic distribution on population development.

METHODS

Adult mites were collected from an avocado orchard in Whangarei. Eggs of a known age were obtained from three adult females placed for 24 h on an arena consisting of a 15 mm diameter disc cut from an unsprayed mature avocado leaf, placed with the lower surface facing up on moist filter paper in a Petri dish. Ten groups of adults were established and 31-36 eggs from these females were placed at each of 6 temperatures (10, 13, 18, 21, 25 and 30°C) and 16:8 h light:dark. Eggs were checked daily for larval emergence and newly emerged larvae were transferred individually to a new leaf arena. Thereafter each mite was checked daily and life stage, mortality and number of eggs laid was recorded until death. The sex was determined once each mite reached adulthood. When leaf discs degraded (dried up or fungal growths appeared) mites were transferred to new leaf disc arenas. Eggs stored at 10°C did not emerge after 42 days; these were transferred to 18°C for 2 weeks to determine their viability.

Demographic parameters

Survivorship data, fecundity and the ratio of female progeny reared at each temperature were used to construct life tables from which demographic growth parameters were calculated. Net reproductive rate (R_o), mean generation time (T_c) and the intrinsic rate of natural increase (r_m) were calculated using the methods described by Carey (1993), where:

$$R_o = \sum l_x m_x$$

$$T_c = \sum x l_x m_x / R_o$$

$$r_m = \log_e(R_o)/T_c$$

where l_x is proportion of females alive at age x and m_x is the number of female progeny born to surviving females at age x.

Temperature thresholds and degree-day calculations

The degree-day model was calculated from the developmental threshold (t) (the temperature at which the developmental stage ceased to develop), and the thermal constant (K) (the amount of heat required to complete development expressed as degree-days). The developmental threshold and the thermal constant required for each life stage were derived from the regression equation: y= a + bx, where y is the developmental rate at temperature x, a is the y-intercept and b is the slope. The developmental threshold and thermal constant values were calculated using the following formulae:

Developmental threshold: $t = -a / b$
Thermal constant: $K = 1 / b$

Developmental thresholds and thermal constants were used to model the development times of eggs using average daily temperature data in 2006 from Kerikeri (Northland), Mt Albert (Auckland) and Te Puke (Bay of Plenty).

Statistical analysis

The rate of development (defined as 1/time) for the different life stages (egg, larva and nymph) was compared between temperatures and sex (including their interaction) using generalised linear models (GLM) in Genstat (Release 9.2, (PC/Windows XP; Copyright 2007, Lawes Agricultural Trust, Rothamsted Experimental Station) with normal errors, to determine which factors were significant. Sex and its interaction with temperature were found to be insignificant for each response. The relationship between temperature and developmental rate for each life stage was then calculated. Only individuals that completed a life stage were included in the analysis for that respective life stage.

RESULTS

No larvae hatched from eggs at 10°C even after being transferred to 18°C for 2 weeks. Larvae that emerged from eggs at 13°C did not survive to protonymph stage. At temperatures from 18-30ºC, an average of 70.1% of mites survived to adult stage. The development times for each life stage of six-spotted mite at constant temperatures are shown in Table 1. There were no significant differences between the development rates of female and male mites (P>0.05) at any temperature, so development times of sexes were combined. Developmental times for all life stages were inversely related to temperature. Total developmental time (egg to adult) ranged from 11 days at 30°C to 29.6 days at 18°C.

TABLE 1: Mean development times (days ± SEM) for six-spotted mite life stages and survival to adult at constant temperatures.

Temperature (°C)	no. of eggs	Egg	Larva	Nymph	Egg-Adult
13	31	23.9 ± 0.4	–	–	–
18	31	13.0 ± 0.1	6.0 ± 0.2	10.7 ± 0.5	29.6 ± 0.5
21	36	10.7 ± 0.3	5.5 ± 0.1	9.7 ± 0.4	25.6 ± 0.6
25	42	5.9 ± 0.1	3.5 ± 0.2	8.2 ± 0.4	17.3 ± 0.5
30	34	5.3 ± 0.3	2.2 ± 0.2	3.9 ± 0.1	11.0 ± 0.3

Percent survival to adults was highest at 18 and 30°C (Table 2). Female adult longevity decreased from 48.3 days to 19.4 days with increasing temperature from 18-30°C, but male longevity was greatest at 21°C. Mean adult longevity ranged from 18.8 days at 30°C to 41.4 days at 18°C. Female pre-oviposition period decreased from 9.5 days to 2.6 days as temperature increased from 18 to 30°C. Mites laid the most eggs at 21°C and the fewest at 25°C (Table 2).

TABLE 2: Percentage of six-spotted mites surviving to adult, mean adult longevity (days), pre-oviposition period (days), number of eggs laid and percentage of mites as females at constant temperatures.

Temp. (°C)	Survival to adult (%)	Female adult longevity	Male adult longevity	Pre-oviposition period	No. eggs/ female	Mites as females (%)
18	77.4	48.3 ± 4.1	29.3 ± 6.2	9.5 ± 0.8	14.2 ± 1.5	71.4
21	63.4	33.0 ± 5.6	40.1 ± 3.0	4.8 ± 0.4	20.9 ± 3.6	52.2
25	69.0	21.1 ± 1.1	17.8 ± 3.4	4.5 ± 0.7	6.9 ± 0.7	75.0
30	73.5	19.4 ± 2.0	17.9 ± 2.6	2.6 ± 0.5	15.4 ± 1.8	60.0

There was a significant linear trend of increasing developmental rate with increasing temperature for all life stages (P<0.001) (Table 3). Lower developmental thresholds ranged from 9.8°C for eggs to 13.9°C for larvae, and thermal constants ranged from 32 for larvae to 97.5 for eggs. It was estimated that 202.8 degree-days, above a lower threshold temperature of 12.2°C, were required to complete development from egg to adult.

TABLE 3: Relationship between temperature and developmental rates of six-spotted mites and calculated lower development thresholds and thermal constants.

Life stage	n	t (lower temperature development threshold) (°C)	K (thermal constant) (degree-days)	Regression equation
Egg	177	9.81	97.48	y = -0.10063 + 0.010258x
Larva	119	13.92	31.96	y = -0.4355 + 0.03129x
Nymph	106	11.93	76.16	y = -0.1566 + 0.01313x
Egg-adult	101	12.15	202.80	y = -0.05991 + 0.004931x

Estimated demographic parameters of six-spotted mite are shown in Table 4. The reproductive rate (R_o) for six-spotted mite was highest at 18 and 30°C. This reflected the higher rate of survival at these temperatures. The reproductive potential (R_o, calculated from female survival and number of females produced) was lowest at 25°C and corresponded with the lowest number of eggs laid per female and a lower survival rate than seen at 18 and 30°C. The longest generation time (T_c) for six-spotted mite occurred at 18°C. The intrinsic rate of increase (R_o) was the same at 18, 21 and 25°C and greatest at 30°C.

TABLE 4: Demographic parameters of six-spotted mite on avocados at four constant temperatures.

Temperature (°C)	R_o (reproductive potential)[1]	T_c (generation time) (days)	R_m (intrinsic rate of increase)
18	6.63	50.81	0.04
21	5.59	42.14	0.04
25	2.81	26.98	0.04
30	6.93	19.77	0.10

[1]$R_o > 1$, the population increases in size.

The predicted egg development times in three regions in the North Island during 2006 are illustrated in Figure 1. Eggs laid on the first day of each month were predicted to take 9-10 days to hatch in February, depending on the region. In June, it was predicted that eggs would take 60 days to hatch in Northland and 91 days to hatch in the Bay of Plenty. Using the egg to adult degree day model and the pre-oviposition period at each temperature, the number of generations in Northland, Auckland and Bay of Plenty was estimated to be 4.27, 4.48 and 3.53 respectively.

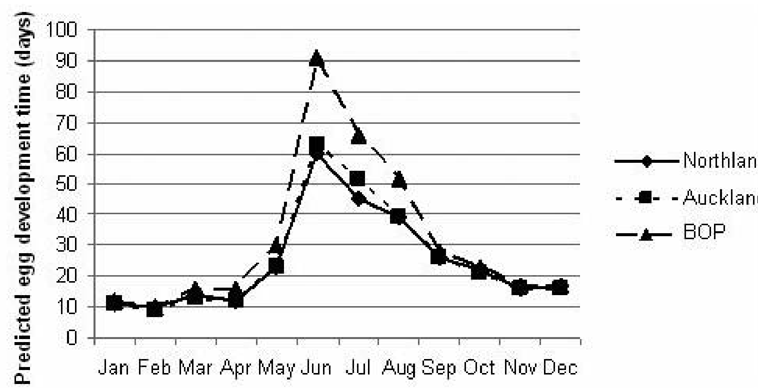

FIGURE 1: Predicted six-spotted mite egg development time (days) in the three major avocado growing regions of New Zealand during 2006.

DISCUSSION

This is the first study investigating the effects of temperature on development rates, longevity and fecundity of six-spotted mite. The degree-day model developed in this study can be used for predicting egg hatch and seasonal abundance and is useful for determining the optimum time to apply repeat control measures or for predicting the efficacy of natural enemies. These laboratory data suggest that six-spotted mite population growth would be greatest in the warmer, northern growing regions, which matches observations of pest status. Failure of eggs to survive lower temperatures would also be expected to limit population development in cooler parts of New Zealand.

Mites can generally be very effectively controlled by natural enemies, and the use of these demographic parameters can provide insights into the potential for biological control. In theory, a predator that has an intrinsic rate of increase equal or greater than its prey should efficiently regulate the population of its prey (Sabelis 1992). Modelling population growth rates can predict temperature regimes for which a predator can develop and reproduce at least as fast as its prey. However, an intrinsic rate of increase of a predator that is less than its prey does not necessarily mean that it will not suppress prey populations (Richardson 1977; McMurtry et al. 1974). Other factors, such as predation rates that could eliminate prey more rapidly than they can reproduce, must be taken into account to predict the outcome of pest and natural enemy interactions. In addition, different strains of predators can exhibit different growth rates (Roy et al. 2003; Shen et al. 1999) and strains with a faster intrinsic rate of increase at temperatures of interest can be introduced to enhance biological control. Several species of predators are commonly observed to be associated with six-spotted mites in avocado orchards. However, they do not appear to be able to prevent unacceptable outbreaks. The poor control of populations of six-spotted mite may be because the predators are highly susceptible to insecticides used in the orchards, or because the biological parameters (e.g. reproductive ability, prey consumption rate, food preferences) of the predators are not sufficient to provide control. The main predators seen in association with six-spotted mites in New Zealand include several types of mites (unidentified Phytoseiidae), *Agistemis longisetus* (Stigmaeidae), the whirlygig mite *Anystis baccarum* (Anystidae) and the predatory ladybirds *Stethorus* spp. Most of these predators feed predominantly on mites. The ladybirds, *Stethorus* spp., are obligate predators of spider mites. The reproductive parameters of *Stethorus* spp. present in New Zealand are not well known.

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REFERENCES

Bailey JB, Olsen KN 1990. Control of two avocado mite species. California Agriculture, March-April: 31-32.

Brookbanks P 2001. Six-spotted mite control strategy. AvoScene December: 15-21.

Carey JR 1993. Applied demography for biologists with special emphasis on insects. Oxford University, Oxford, UK. 206 pp.

Charles JG, Allan DJ 2002. Dose-mortality response of "susceptible" *Eotetranychus sexmaculatus* (sixspotted mite) to Avid and Malathion. A pre-emptive strategy for detecting future resistance. NZ Avocado Growers' Association Annual Research Report 2: 32-34.

Fleschner CA 1953. Biological control of avocado pests. California Avocado Society yearbook 81:81-90.

Froud KJ, Stevens PS, Machin T, Jamieson LE 2002. Efficacy of New Pesticides against sixspotted mite *Eotetranychus sexmaculatus* (Riley) (Acari: Tetranychidae) on avocados. NZ Avocado Growers' Association Annual Research Report 2: 17-21.

Hoddle MS 2002. Developmental and reproductive biology of *Scirtothrips perseae* (Thysanoptera: Thripidae): a new avocado pest in California. Bulletin of Entomological Research 92: 279-285.

Lamb KP 1953. Survey of red spider mites (Acarina: Teteranychidae) on grape vines. New Zealand Journal of Science and Technology 35: 65-66.

McMurtry JA, Scriven GT, Malone RS 1974. Factors affecting oviposition of *Stethorus picipes* (Coleoptera: Coccinellidae) with special reference to photoperiod. Environmental Entomology 3: 123-127.

Richardson NA 1977. The biology of *Stethorus loxtoni* Britton and Lee (Coleoptera: Coccinellidae) and its potential as a predator of *Tetranychus urticae* Koch (Acarina: Tetranycidae) in California. Ph.D. Thesis, University of California, Berkeley, California, USA. 184 pp.

Roy M, Brodeur J, Clouteir C 2003. Effect of temperature on intrinsic rates of natural increase (r_m) of a coccinellid and its spider mite prey. Biocontrol 48: 57-72.

Sabelis MW 1992. Predatory arthropods. In: Crawley MJ ed. Natural enemies. The population biology of predators, parasites and disease. Blackwell, Oxford, UK. Pp. 225-264.

Shen M, Guo Z, Xiong J 1999. Influence of temperature on the experimental population of *Stethorus punctillum*. Acta Ecology Sinica 18: 181-187.

Steven D 2003. Novel chemicals to control six-spotted mite, *Eotetranychus sexmaculatus*. NZ Avocado Growers' Association Annual Research Report 3: 1-8.

Stevens PS, Jamieson LE, Cave J 2001. Comparative toxicity of pesticides to the sixspotted mite *Eoteranychus sexmaculatus* (Riley) (Acari: Tetranychidae) on avocados. NZ Avocado Growers' Association Annual Research Report 1: 7-11.

Tomkins AR 2002. Sustainable management of sixspotted spider mite (*Eotetranychus sexmaculatus* (Riley)) on avocados. NZ Avocado Growers' Association Annual Research Report 2: 22-27.