

## Oviposition Model of *Scolothrips longicornis* Fed on Two-Spotted Spider Mite

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**Abstract:** Adult longevity, survival and fecundity of the predatory thrips *Scolothrips longicornis* Priesner fed on *Tetranychus urticae* Koch were examined at 15, 20, 26, 30, 35 and 37°C and an oviposition model was developed. The longevity, survival and fecundity of *S. longicornis* were affected by temperature. The longevity ranged from 37.88 days at 15°C to 4.25 days at 37°C. The total fecundity was lowest (11.69 eggs) at 37°C and highest (56.52 eggs) at 26°C. The relationship between total fecundity and temperature was described by a nonlinear equation. The cumulative age-specific oviposition rate was described by the two-parameter Weibull function. The overall adult survival revealed a reverse logistic curve. Three temperature-dependent components, age-specific cumulative oviposition rate, temperature-dependent total fecundity and age-specific survival rate functions, were incorporated into an oviposition model. Oviposition model simulation should be useful for describing the field occurrence patterns of *S. longicornis* egg population.

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**Key words:** Predatory Thrips • Physiological Age • Temperature • Survival • *Tetranychus Urticae*

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### INTRODUCTION

Several species of predatory thrips of the genus *Scolothrips* (Thysanoptera: Thripidae) have been investigated for their potential in the control of spider mites (Acari: Tetranychidae), especially *S. takahashii* Priesner [1-4], *S. sexmaculatus* [5-8], *S. indicus* Priesner [9, 10] and *S. longicornis* [11, 12]. The latter species has been reported from several regions including the Middle East, India and North America [8, 11, 13] and was reported for the first time from Iran in 1996 [14]. *S. longicornis* is common in bean [15], cucumber and eggplant fields [12] and has been demonstrated to be an important predator of several spider mite species [15, 16] with a seasonal abundance correlated with that of the pest [17]. The general biological characteristics of *S. longicornis* (functional response, mutual interference, life table characteristics and feeding activity) have been studied [18-21], but little information is available on the effect of

temperature on *S. longicornis* [11, 12] and no oviposition models of *S. longicornis* has been developed.

Temperature is an important abiotic factor that regulates physiological systems of insects and mites [22, 23]. In biological control, estimation of developmental rates, longevity, survivorship, fecundity and temperature thresholds of target pests and natural enemies is important to understand their population dynamics and to develop sound pest management plans [22, 23].

The purpose of this study was to determine the effects of temperature on *S. longicornis* oviposition and to develop an oviposition model of *S. longicornis*, which can be utilized in predicting egg occurrence patterns and in developing a *S. longicornis* population dynamics model as a means of establishing effective biological control strategies for spider mites. RHO25 is the developmental rate at 25°C and HA, TH and HH represent the parameters of kinetics of the rate-controlling enzymes according to equation (1).

## MATERIALS AND METHODS

**Experimental Design for Oviposition:** The model was established from data published in Pakyari *et al.* [12].

A rearing of the two-spotted spider mite was initiated using individuals originally collected from cucumber fields in Varamin (Tehran province) in 2007. The mites were maintained on detached cucumber leaves each placed upside down on a layer of wet cotton in a Petri dish (150 mm in diameter). The lid of the dish had a 30-mm diameter hole covered with fine nylon mesh to allow ventilation. The Petri dishes were kept in a growth chamber (Binder KBWS 240, Germany) at  $26 \pm 1^\circ\text{C}$ ,  $60 \pm 10\%$  RH and a photoperiod of 16:8 (L:D) h. Similarly, a culture of *S. longicornis* was initiated with adults collected from cucumber (*Cucumis sativa* cv. Sultan) fields. The culture consisted of Petri dishes (180 mm in diameter) each with five thrips maintained on a detached cucumber leaf infested with surplus spider mite eggs (*Tetranychus urticae*) and similarly placed upside down in ventilated Petri dishes. Each Petri dish was sealed with parafilm to prevent escape of the insects. To obtain prey eggs for *S. longicornis*, 40-50 female spider mites from the colony were introduced onto clean cucumber leaves kept in Petri dishes (180 mm in diameter) and allowed to lay eggs (approx. 500-600 eggs) for 48 h in a climate cabinet at  $26 \pm 1^\circ\text{C}$ ,  $60 \pm 10\%$  RH after which the females mites were removed. Adult thrips were transferred onto the cucumber leaves with *T. urticae* eggs every 2 days. After a certain rearing period (2 and 3 months for thrips and spider mites, respectively), the experiments were initiated.

Excised bean leaf discs (30 mm in diameter) without major veins served as test arenas. Each disc was placed upside down on a layer of wet cotton in a Petri dish (60 mm in diameter). The lid of the Petri dish had a hole (15 mm in diameter) covered with fine nylon mesh to allow ventilation. Each Petri dish was sealed with parafilm.

To standardize the age of *S. longicornis* eggs used in the experiments, twenty mated adult females were placed on bean leaf discs for 24 h in a climate cabinet at similar conditions as above. Adult thrips were subsequently removed and the leaf discs with the newly laid eggs placed in a climate cabinet at 15, 20, 26, 30, 35 and  $37^\circ\text{C}$ , 60% RH and 16:8 L:D. Sixty eggs were assigned to each temperature. Upon hatching the thrips larvae were reared individually in test arenas and daily fed with a surplus of *T. urticae* eggs (about 100 eggs per thrips larva per day). Immature predators were transferred individually

to fresh leaf discs every second or third day until pupation. Upon adult emergence the sex of the adults was recorded. All emerged females were placed individually together with a male on new leaf discs containing mite eggs for food for two days. The females were subsequently observed daily and, at the onset of reproduction, transferred daily to fresh leaf discs. The number of eggs laid was recorded daily until the female thrips died and longevity (from adult emergence to adult death) was determined. At each temperature, approximately 30 females *S. longicornis* were examined.

**Data Analysis:** Analysis of variance (ANOVA) was conducted to determine statistical differences in longevity and fecundity among the temperatures tested. Proc GLM [24] was used and means were separated by the Duncan's multiple range test ( $P=0.05$ ), [24].

**Oviposition Model:** The model was constructed using the method developed by Kim and Lee [25, 26] and consisted of three temperature dependent functions: Temperature-dependent total fecundity, age-specific oviposition rate and age-specific survival rate.

**Adult Development or Adult Physiological Age:** Adult longevity was regarded as adult development. Adult development rate, the reciprocal of median longevity (in days) was described with the Sharp & DeMichele equation, modified by Schoolfield *et al.* [27], using the equation:

$$r(T) = \frac{RHO25(T/298.15)e^{(HA/A)((1/298.15)-(1/T))}}{1 + e^{(HL/R)((1/TL)-(1/T))} + e^{(HH/R)((1/TH)-(1/T))}} \quad (1)$$

Where  $r(T)$  is the developmental rate at temperature  $T(k)$ ,  $R$  the universal gas constant ( $1.987 \text{ cal degree}^{-1} \text{ mol}^{-1}$ ), RHO25 the developmental rate at  $25^\circ\text{C}$  (298.15 K) assuming no enzyme in activation and HA, TL, HL, TH and HH represent the parameters of kinetics of the rate-controlling enzymes. Parameters were estimated using the SAS program of Wagner *et al.* [28].

The development model was used for calculating the physiological age of adult female *S. longicornis*. The physiological age ( $P_x$ ) of each adult from the starting time to the  $n'$  the time step was defined as in Curry and Feldman [29]:

$$Px = \int_0^n r(Ti) \approx \sum_{i=0}^n r(Ti) \quad (2)$$

Where  $r(T_i)$  is the adult developmental rate at temperature  $T$  (K) of  $i'$  th time step (e. g., day). The developmental rate of female adults in the range of 15-37°C was described by the modified Sharpe and DeMichele model [27] and the estimated parameter were evaluated according to the boundaries given by Wagner *et al.* (1984).

**Temperature-dependent Total Fecundity Function:** Mean total fecundity was estimated by dividing the sum of total eggs laid by all adults by the number of adults examined. Various equations such as nonlinear or polynomial functions have been used to explain the relationship between the fecundity of arthropods and temperature [30-35]. We selected an extreme value function from the library of Table curve [36] to get the temperature-dependent total fecundity curve of *S. longicornis* because of its flexibility and sharp-fitting ability to the collected data as recommended by Kim and Lee [25]:

$$f(T_c) = ae^{-\left[1 + \frac{(b-T_c)/k}{e^{((b-T_c)/k)}}\right]} \quad (3)$$

Where  $f(T_c)$  is the number of total eggs produced by a female adult during her whole life span at temperature  $T_c$  (°C) and  $a$  is the maximum reproductive capacity,  $b$  is the temperature (°C) at which the maximum reproduction occurs and  $k$  is a fitted constant. The values of parameters were calculated using Table curve [36].

**Age-Specific Cumulative Oviposition Rate Function:** The age-specific egg production rate is often described with a gamma distribution or polynomial function [37, 38], which is the proportion of the total life time reproductive potential that elapses during each time period. The two-parameters Weibull function was used to describe the age-specific oviposition rate of *T. urticae* [26]. This equation was chosen for *S. longicornis* in this study because of its relative simplicity. This function is

$$p(P_x) = 1 - e^{-(P_x/\alpha)^\beta} \quad (4)$$

Where  $p^{(px)}$  is the cumulative proportion of stage emergence at physiological age ( $p_x$ ) by a female adult and  $\alpha$  and  $\beta$  are fitted constants. The cumulative egg production rates for each temperature were calculated as

the total cumulative number of eggs up to a physiological age divided by the total number of females alive at a certain age. The mean cumulative oviposition rate for each physiological age was estimated by averaging the cumulative oviposition rates at the same physiological age for the respective temperature regime. The physiological age of adults was calculated using equation (2). Parameter values were estimated using Proc NLIN in SAS [24].

**Age-Specific Survival Rate Function:** The age-specific survival rate is the proportion alive at any given time, which is often described by an exponential [39], Gompertz [40] or Weibull function [41, 42]. In this study, a sigmoid function was used to describe the age-specific survival distribution of *S. longicornis* for its simplicity and shape fitting ability. The survival proportions at physiological age ( $P_x$ ) were fitted to this function:

$$s(P_x) = \frac{1}{1 + e^{((\gamma - P_x)/\delta)}} \quad (5)$$

Where  $s(P_x)$  is the proportion of live females at the physiological age  $P_x$ ,  $\gamma$  is the physiological age at 50% survival and  $\delta$  is the parameter defining steepness of this equation. The parameters were estimated using Table curve [36].

**Egg Production:** The cumulative number of eggs laid by an adult cohort at  $i'$  th time (i.e., physiological age  $P_x$ ) is the product of the temperature-dependent total fecundity [ $f(T_c)$ ], the age-specific cumulative egg production rate [ $P(P_{xi})$ ] and the age-specific survival rate [ $S(P_{xi})$ ]. Therefore the number of egg oviposited by a cohort during the physiological age interval between  $P_{xi}$  and  $P_{xi+1}$  can be estimated as [25]:

$$f(T_c) \left[ p(P_{xi+1}) - p(P_{xi}) \right] \frac{s(P_{xi}) + s(P_{xi+1})}{2} \quad (6)$$

## RESULTS

The longevity ( $P < 0.0001$ ) and total fecundity ( $P < 0.0001$ ) of adult female *S. longicornis* was significantly influenced by temperature (Table 1). Female longevity decreased with increasing temperature. Oviposition occurred at all six temperatures, with the minimum number of total eggs per female at 37°C (11.69)

Table 1: Adult longevity and total number of eggs laid per female of *S. longicornis* at different constant temperatures

Temperature (°C)	No. adults examined	Longevity in days (mean ±SE)	Total eggs/female (mean ±SE)
15	32	37.88±0.33 <sup>a</sup>	33.25±0.58 <sup>c</sup>
20	33	28.70±0.35 <sup>b</sup>	43.06±1.39 <sup>b</sup>
26	31	21.16±0.44 <sup>c</sup>	56.52±1.66 <sup>a</sup>
30	39	12.67±0.19 <sup>d</sup>	44.87±1.13 <sup>b</sup>
35	30	8.23±0.15 <sup>e</sup>	32.8±0.89 <sup>c</sup>
37	13	4.25±0.18 <sup>f</sup>	11.69±0.87 <sup>d</sup>

Means followed by the same letter within a column are not significantly different ( $P < 0.05$ , Duncan's multiple range test).

Table 2: Estimated parameters for adult developmental rate curve (1/median longevity) of female *S. longicornis*

Parameters*	Estimated values	S.E.M	r <sup>2</sup>
RHO25	0.0624	0.003	0.99
HA	15056.288	2165.026	
TH	310.861	0.605	
HH	93245.746	36022.444	

Table 3: Estimated parameters for oviposition model components of *S. longicornis*

Models	Parameters	Estimated values	S.E.M	r <sup>2</sup>
Temperature-dependent total fecundity model	$\alpha$	54.373	7.613	0.77
	$b$	23.004	1.267	
	$k$	8.44	1.739	
Age-specific cumulative oviposition model	$\alpha$	0.563	0.009	0.99
	$\beta$	1.975	0.095	
Age-specific survival rate model	$\gamma$	1.148	0.025	0.96
	$\delta$	-0.161	0.022	

and the maximum value at 26°C (56.52) (Table 1). The developmental rate of female adults in the range of 15-37°C is shown in (Fig. 1) and the estimated parameter values, which were within the boundaries given by Wagner *et al.* (1984) is shown in (Table 2).

**Oviposition Model:** The estimated curves and parameters for the oviposition model of *S. longicornis* are presented in Table 3 and Fig 2a. The estimated highest fecundity was ~54 eggs (parameter  $a$ ) at ~23°C (parameter  $b$ ).

The age-specific cumulative oviposition rate curve and the estimated parameters is shown in Fig. 2b and Tale 3, respectively. The survival curve showed low initial mortality, then a steep linear decrease in survival and a slowing in the mortality rate towards the end of adult life span. Fifty percent of the total eggs were laid at the physiological age of 0.56 in this model. The relationship between survival and adult physiological age was presented by a sigmoid function (Fig. 2c, Table 3). Fifty percent mortality occurred at the physiological age of 1.15.

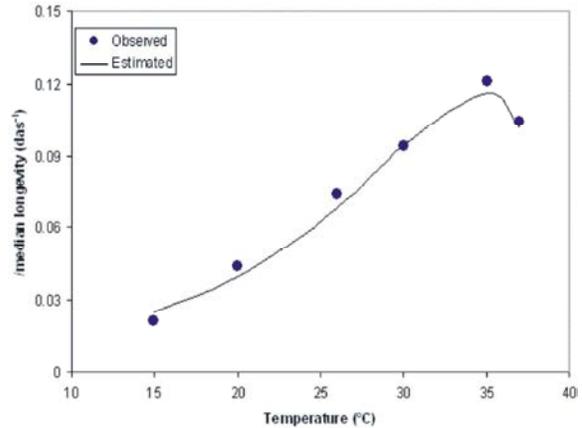


Fig. 1: Adult developmental rate curve (1/median longevity) of female *S. longicornis*. Four-parameter poikliothermic model of Schoolfield *et al.* (1981) was applied with high temperature inhibition.

The predicted reproductive density curve in relation to the adult cohort ages and temperatures is shown in Fig. 3. The egg production curve showed a higher and wider shape at low temperatures (approx. 15-24°C) and the peak fecundity and oviposition period sharply decreased with increasing temperature.

## DISCUSSION

The total fecundity of *S. longicornis* at 26°C in this study (56.52 eggs) was less than that reported by Sengonca and Weigand [19] at similar temperatures (285.2 eggs). It was also lower compared with other species in the same genus at the comparable temperature: *S. takahashii* (90.5 eggs in Gotoh *et al.* [4] and *S. sexmaculatus* (153.8 eggs in Coville and Allen [43]. These noticeable differences might be related to the host plant and prey used in the different studies, perhaps indicating that cotton and/or *T. cinnabarinus* is more superior to *S. longicornis* than the cucumber-bean combination and/or *T. urticae* used in this study.

In the present laboratory study, the total fecundity per female ranged from 11.69 to 56.52 eggs depending on temperatures, which is in contrast to a total fecundity of 285.2 eggs found in a greenhouse experiment by Sengonca and Weigand [19]. The lower fecundity exhibited in laboratory conditions might be physiological, such as decreased ovary development or behavioral, such as inactive oviposition behavior [44]. Nutritional deficiency caused by incorrect diet conditions, reduced light intensity and restricted ventilation, etc. are potential

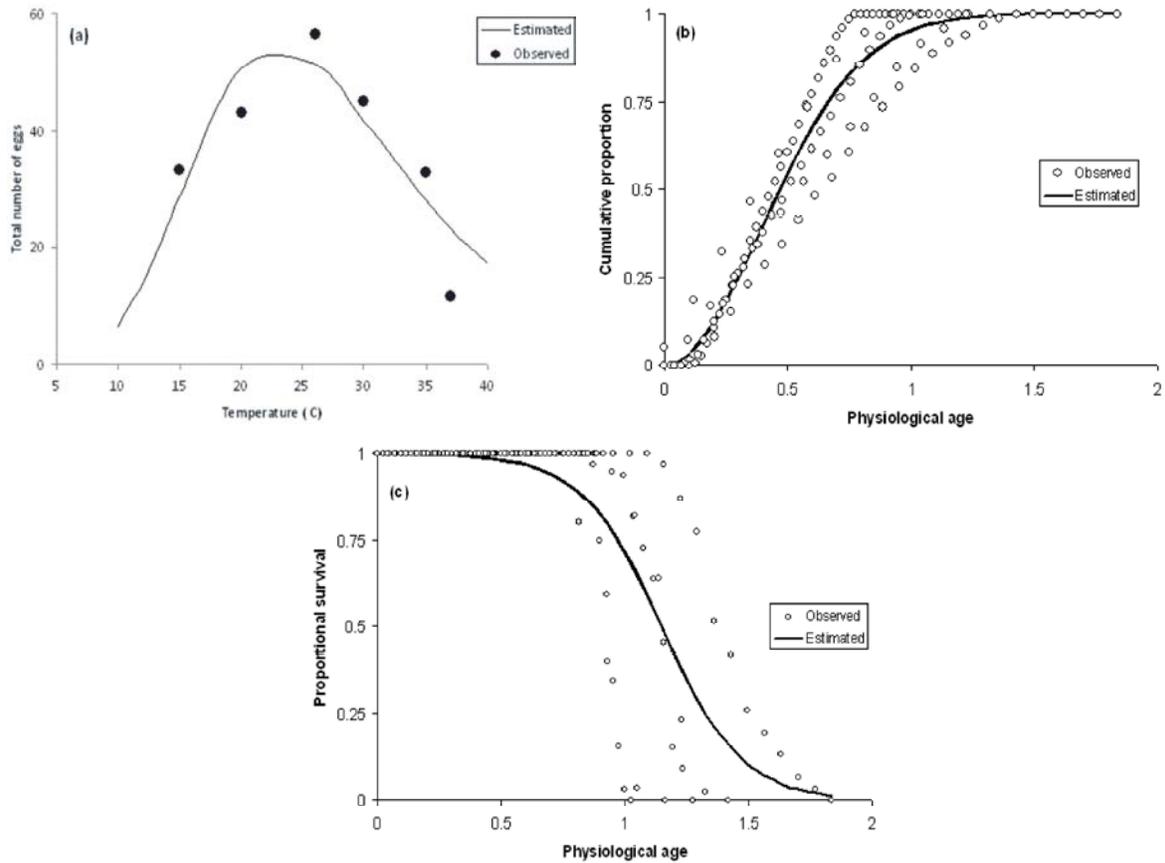


Fig. 2: Major components of the oviposition model of *S. longicornis* (a) Temperature-dependent total fecundity curve, (b) age-specific cumulative oviposition rate curve, (c) age-specific survival rate curve.

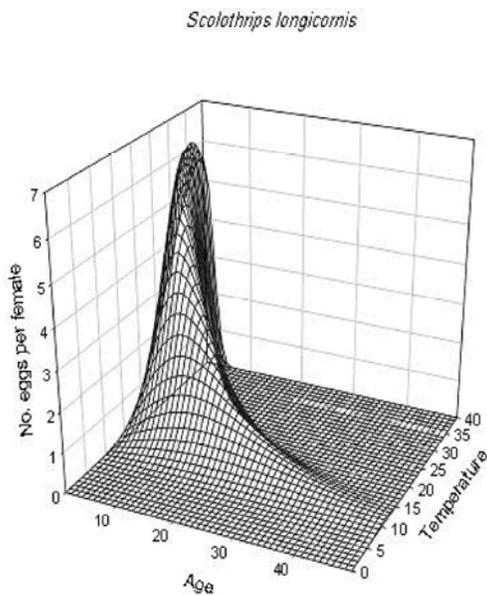


Fig. 3: Predicted oviposition density curves of *S. longicornis* in relation to cohort age and temperature.

causes of physiological and/or behavioral alternation in the oviposition of arthropods [25] and may have resulted in reduced fecundity of *S. longicornis* as observed in the laboratory experiment.

In many stochastic phenology models of arthropods, an independent variable such as time scale is often based on degree days. A model based on degree days can produce significant errors in phenology prediction of arthropods during a cool or hot season because the relation between developmental rate and temperature is not linear [45]. To avoid this problem, we used the rate summation method [29] in which physiological age is based on the summation of the developmental rate using a nonlinear developmental rate function, similar to the methodology employed by Shaffer and Gold [33], Wagner *et al.* [28] and Berry *et al.* [34].

The oviposition models can be used to simulate daily egg production of *S. longicornis* under variable temperature conditions similar to the method reported by Kim and Lee [25]. The cumulative number of eggs laid by a female adult at the  $i$ 'th time (i.e., at physiological age

$Px_t$ ) can be calculated from the product of the temperature-dependent total fecundity, the age-specific cumulative oviposition rate and the age-specific survival rate. Consequently, we expect that the corresponding equations are realistic and adequately describe the underlying biological processes of *S. longicornis*. Little information is available on the oviposition models for natural enemies of spider mites [46], although there has been recent work in this area. Such models are needed for realistic population models for application in the planning and implementation of integrated pest programs.

*S. longicornis* has potential for controlling spider mites in both greenhouse and field. *S. longicornis* is also able to develop at relatively low temperatures (15°C, Pakyari *et al.* [11] and therefore it may be suitable for use during the early season. Our oviposition model could be used to determine the optimal temperature conditions for its mass rearing, to predict its seasonal population dynamics in fields and greenhouse crop and to develop a population dynamics model of *S. longicornis*. In the future, further field and greenhouse data will be needed to substantiate and validate our model.

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