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Article

Influence of temperature and prey type on life-table parameters and consumption rate of *Stethorus gilvifrons* (Mulsant) (Coleoptera: Coccinellidae) on three tetranychid mites

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ABSTRACT

The two-spotted spider mite *Tetranychus urticae* Koch, the date palm dust mite *Oligonychus afrasiaticus* (McGregor), and the citrus brown mite *Eutetranychus orientalis* (Klein) of family Tetranychidae are key pests of fruit trees, field crops, and ornamentals that cause significant yield losses. The purpose of this research was to assess the effect of three constant temperatures (22, 27, and 32 °C) on the developmental time, life-table parameters, and consumption rate of the predatory beetle *Stethorus gilvifrons* (Mulsant) on maize leaf disks with *T. urticae*, *O. afrasiaticus*, and *E. orientalis* as food. The results indicated a significant difference between the three different temperatures and prey types. The shortest developmental time was recorded on *T. urticae* (9.30 and 10.10 days) at 32 °C, while the longest was on *E. orientalis* (23.34 and 22.50) at 22 °C for females and males, respectively. The shortest female longevity was on *E. orientalis* (21.14 days) at 32 °C, and the longest was 39.12 days on *T. urticae* at 22 °C. The fecundity increased as temperature increased, from 114.6 eggs with a daily rate of 3.81 eggs per female/day at 22 °C to 235.0 eggs with a daily rate of 10.78 eggs per female/day at 32 °C on *T. urticae.* The highest net reproductive rate (R_0), intrinsic rate of natural increase (r_m), and finite rate of increase (λ) were recorded at 32 °C, whereas the lowest values were recorded at 22 °C when predatory beetles *S. gilvifrons were* fed on three prey diets. Gross reproduction rate (*GRR*) recorded the highest value (132.8 offspring/individual) when fed on *T. urticae* at 32 °C and the lowest value (55.30 offspring/individual) when fed on *E. orientalis* at 22 °C. The highest consumption rate of adult males and females was 226.8 and 245.4 individuals when fed on *O. afrasiaticus* at 22 °C, while the lowest was 123.6 and 133.8 individuals on *E. orientalis* at 32 °C. Thus, the results obtained here revealed that temperature and prey diets influence the developmental rate and reproduction of *S. gilvifrons*. Additionally, *T. urticae* is better for mass rearing of *S. gilvifrons* than *O. afrasiaticus* and *E. orientalis* as food.

KEYWORDS: Constant temperatures, *Eutetranychus orientalis*, fecundity, life-table, *Oligonychus afrasiaticus*, predation, *Tetranychus urticae*.

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INTRODUCTION

The citrus brown mite, *Eutetranychus orientalis* (Klein) (Acari: Tetranychidae), is an important pest

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of citrus, deciduous fruit trees, field crops, and ornamentals. The mite feeds on the upper leaves, causing yellow-grey spots and leaves to drop. Heavy infestations may result in fruit drop, top branch mortality, and significant damage to the following year's flowering (Elhalawany 2019; Abdelgayed *et al.* 2017).

Oligonychus afrasiaticus (McGregor) (Acari: Tetranychidae) is a serious economic pest of immature date palm fruits (*Phoenix dactylifera* L.) in the New Valley governorate in Egypt (Elhalawany *et al.* 2020b). In years of dry, dusty, and stormy weather in Iraq, *O. afrasiaticus* caused a 50–80% yield loss of dates (Al-Jboory and Al-Suaide 2010).

Tetranychus urticae Koch (Acari: Tetranychidae) is one of the most important mite pests, feeding on about 1161 host plant species worldwide, including vegetables, fruits, crops, and ornamentals (Migeon and Dorkeld 2023). Spider mite density should not exceed three mobile stages per leaf; they can rapidly grow and cause significant economic damage (yield losses up to 90%) (Warabieda 2015).

Predacious coccinellids, predators of small phytophagous insects and mites, are potential biocontrol agents (Zhang *et al.* 2007). *Stethorus* species, predators of spider mites, have been reported as biocontrol agents of tetranychid pests in agricultural systems (Roy *et al.* 1999). The predatory beetle *Stethorus gilvifrons* (Mulsant) (Coleoptera, Coccinellidae) is a predator with a huge appetite for spider mites in numerous agricultural and horticultural crops both in the open field and in greenhouses (Bayoumy *et al.* 2014; Barbar *et al.* 2016). This species is widely distributed in Africa, Asia, and Europe (Biddinger *et al.* 2009).

The effect of host plants and prey species on the development and life-table parameters of *S. gilvifrons* was rarely studied. Jafari *et al.* (2022) conducted a single study on the effect of host plants and prey species on the development and life-table of *S. gilvifrons*, fed on *T. urticae* on cowpea and maize, and *E. orientalis*, fed on castor bean plants. Many studies on the biology and life-table of *S. gilvifrons* have been published thus far (Aksit *et al.* 2007; Taghizadeh *et al.* 2008a, b; Abdel-Salam *et al.* 2010; Perumalsamy *et al.* 2010; Handoko and Affandi 2012; Latifian 2017; Saleh 2018; Jafari *et al.* 2020, 2022, 2023a, b). However, Ibrahim *et al.* (2010) used *S. gilvifrons* as a biocontrol agent to control dangerous mite pests on apple seedlings, *T. urticae* and *Panonychus ulmi* (Koch). The predatory insect was released at three levels: 5, 10, and 15 adults per seedling. The reduction percentage in *T. urticae* reached 75.69, 89.1, and 92.9%, and for *P. ulmi*, it reached 63.39, 73.57, and 78.33% after 110 days, respectively at three levels.

An effective IPM program for pest control should maximize the effectiveness of natural enemies, but various biotic and abiotic factors can reduce this efficacy. Temperature is a critical abiotic factor that affects both pests and their natural enemies (Zhang *et al.* 2007). Temperature is an important ecological factor that affects the functions and efficacy of natural enemies of spider mites and can be used to predict changes in the population dynamics and phenology of insects and arachnids (Gevrey and Worner 2006).

Therefore, the present study was conducted to evaluate the effects of temperature and prey diet on life-table parameters and prey consumption of *S. gilvifrons* in order to assess the suitability of this predator for mass production for use in biological control programs against tetranychid mites.

MATERIAL AND METHODS

Experiments were conducted at Qaha Agriculture Research Station (30° 2' 47.37" N, 31° 12' 35.13" E), Plant Protection Research Institute, Qalyubia governorate, Egypt, in the summer of 2023. Three prey types for the predatory beetle *S. gilvifrons* were used (i.e., the motile stages of *T. urticae*, *O. afrasiaticus*, and *E. orientalis*). *Tetranychus urticae*, *E. orientalis*, and *S. gilvifrons* were collected from infested castor bean *Ricinus communis* L. (Euphorbaoceae) in Qalyubia governorate, while *O. afrasiaticus* was collected from the fruit of date palm trees *Phoenix dactylifera* L. (Arecaceae) in the New Valley governorate.

Prey culture

Tetranychus urticae was reared on common bean *Phaseolus vulgaris* L., *E. orientalis* was reared on castor bean plants, and *O. afrasiaticus* was reared on maize plants (*Zea mays* L.). The seeds of the three plants were sown at 2 cm depth in 20 pots (15 cm diameter) each. Infested pots were covered under a cage (2 × 2 × 2 m) with a nylon mesh with a 210 µm aperture. The pots were kept for 15 days before being artificially infested with three prey types. After three generations, mites from the stock colony were used in the current experiments, according to Elhalawany *et al.* (2019, 2020a) and Jafari *et al.* (2022). The culture was supplemented with new plants as needed.

Predator culture

Rearing of the predatory beetle *S. gilvifrons* was carried out inside a cage that was 50 × 50 × 100 cm in dimensions and covered by fine nets to prevent the predator from exiting. Each rearing cage contained three maize pots. The predatory beetle *S. gilvifrons* was reared on potted maize plants infested with *T. urticae* under laboratory conditions at 25–27 °C and 60–65% RH for several generations before use in the current experiment.

Experimental cell

Plastic cells (8 × 9 × 4 cm) covered with a fine net to allow ventilation was used in all experiments. Leaf disks of maize (4 cm in diameter) were placed on moistened cotton to maintain the freshness of the leaf inside each cell. The leaf discs were changed with fresh ones. The study was conducted in an incubator at three constant temperatures (22, 27, and 32 ± 1 °C) and 60 ± 5% RH. The motile stages of *T. urticae*, *O. afrasiaticus*, and *E. orientalis* were used for *S. gilvifrons.*

Experimental design

Biological aspects and life-table parameters of *S. gilvifrons*

Stethorus gilvifrons adults were collected from the cage using a mouth aspirator. Thirty male and female *S. gilvifrons* individuals were cultured on maize leaf discs (8 cm in diameter) infested by *T. urticae* inside a plastic container (17 × 11 × 4 cm). After 24 hours, about 100 eggs were individually transferred with a fine brush to a plastic cell and kept at 22, 27, and 32 ± 1 °C for each prey diet. Each treatment was replicated 100 times. After egg hatching, 100 motile stages of three prey diets were added daily for each *S. gilvifrons* until the adult stage. The incubation period, molting, pupation, adult emergence, survival, and number of eggs laid by females were recorded daily. A male was introduced to each plastic cell for mating and removed from the cell after the oviposition of the first egg. Every plastic cell was observed daily to record the number of eggs laid until the female died (Elhalawany *et al.* 2022; Jafari *et al.* 2022).

Life-table parameters were calculated using the immature and adult predators' survival rates. Age-specific survival rate (l_x) and age-specific fecundity (m_x) for each age interval (x) were used to construct a life-table based on the females reared at the three constant temperatures as defined by Birch (1948) and calculated using a BASIC computer program by Abou-Setta *et al.* (1986). Whereas: the net reproductive increase (R_0) = $\Sigma\ l_x m_x$; the mean generation time (T) = $\ln R_0/r_m$; the intrinsic rate of increase (r_m) = $\ln R_0/T$; the doubling time (DT) = $\ln 2/r_m$; $GRR = \Sigma\ m_x$, and the finite rate of increase (λ) = e^{rm}.

The consumption rate of *S. gilvifrons*

Consumption rates were assessed for immature and the adult stages. Every day, 30 fresh adult stages of three prey diets were added to maintain a constant daily food supply, and the number of individuals consumed was recorded. The number of preys consumed by *S. gilvifrons* was examined under a stereo microscope after 24 hours. Each experiment was replicated 10 times.

Statistical analysis

To compare the influence of prey species, developmental time, fecundity, and duration of adult female reproductive stages were analyzed using a two-way ANOVA, and a mean comparison was conducted using Tukey's multiple comparison difference. The significance level was P > 0.05. Analysis was conducted using the SAS program (2003). The relationship between the rate of development (Y) and temperature (X) (at a specific range) can be represented by a straight line resembling the linear equation (Y = a + b$_X$ °C), where *a* is the intercept and *b* is the slope of temperature. The temperature threshold for development (T_0) can be estimated using the equation -a/b (i.e., when Y = 0). The reciprocal of the slope (*b*) of the straight line (i.e., 1/b) is (*K*), which is the number of degree-days (DDUs) above (T_0) required by an animal to complete its development as physiological time (Abou-Setta 2020).

RESULTS

Developmental time and longevity of S. gilvifrons *male reared on different prey species at different temperatures*

This predator successfully developed to adulthood on the tetranychid mites *T. urticae* Koch, *O. afrasiaticus* (McGregor), and *E. orientalis* (Klein) at temperatures from 22 to 32 °C. Data in Table 1 indicated that the developmental time for male immature stages was significantly affected by prey type and temperature. Highly significant differences were obtained between the incubation periods of eggs of *S. gilvifrons* males (F = 354.2, P < 0.0001). The shortest period was 2.10 days at 32 °C on *T. urticae*, while the longest one was 5.64 days at 22 °C on *E. orientalis*. The short life cycle of *S. gilvifrons* male was 10.10 and 10.56 days on *T. urticae* and *O. afrasiaticus* at 32 °C, while the longest period was 22.50 days on *E. orientalis* at 22 °C (F = 430.6, P < 0.0001). The short longevity of *S. gilvifrons* male was 23.90 and 23.62 days on *O. afrasiaticus* and *E. orientalis* at 32 °C, while the longest period was 38.40 days on *T. urticae* at 22 °C (F = 80.1, P < 0.0001). The highest life span was observed at 22 °C while the lowest one was at 32 °C. The decreasing life span of the predator with increasing temperature is mainly due to the decrease in time required for development as the temperature rises (F = 183.3, P < 0.0001).

Table 1. Mean durations (days ± SE) of predator *Stethorus gilvifrons* male reared on different prey diets at different temperatures.

Parameter	*Tetranychus urticae*			*Oligonychus afrasiaticus*			*Eutetranychus orientalis*		
	22 °C	27 °C	32 °C	22 °C	27 °C	32 °C	22 °C	27 °C	32 °C
Incubation period	5.10 ± 0.09b	3.10 ± 0.06c	2.10 ± 0.05e	5.24 ± 0.08b	3.16 ± 0.06c	2.20 ± 0.05e	5.64 ± 0.11a	3.26 ± 0.07c	2.50 ± 0.07d
1st larval instar	2.22 ± 0.07c	1.64 ± 0.06de	1.48 ± 0.06e	2.48 ± 0.09b	1.66 ± 0.06de	1.54 ± 0.07e	2.78 ± 0.09a	1.76 ± 0.07d	1.60 ± 0.06de
2nd larval instar	2.52 ± 0.08b	1.68 ± 0.08c	1.00 ± 0.09e	2.66 ± 0.07b	1.78 ± 0.07c	1.22 ± 0.07d	3.04 ± 0.09a	1.78 ± 0.07c	1.38 ± 0.06d
3rd larval instar	2.48 ± 0.09b	1.24 ± 0.06cde	1.04 ± 0.03e	2.70 ± 0.09a	1.32 ± 0.07cd	1.14 ± 0.05de	2.90 ± 0.08a	1.44 ± 0.08c	1.30 ± 0.08cd
4th larval instar	3.20 ± 0.08b	2.24 ± 0.07de	1.84 ± 0.09g	3.46 ± 0.09a	2.32 ± 0.08cd	1.98 ± 0.08fg	3.56 ± 0.09a	2.46 ± 0.08c	2.08 ± 0.07ef
Pupal stage	3.44 ± 0.08c	2.68 ± 0.06de	2.64 ± 0.05de	3.92 ± 0.13b	2.66 ± 0.07de	2.48 ± 0.10e	4.58 ± 0.15a	2.74 ± 0.08d	2.68 ± 0.08de
Life cycle	18.96 ± 0.17c	12.58 ± 0.15e	10.10 ± 0.14g	20.46 ± 0.27b	12.90 ± 0.21de	10.56 ± 0.18g	22.50 ± 0.4a	13.44 ± 0.19d	11.54 ± 0.14f
Longevity	38.40 ± 0.45a	25.04 ± 0.54de	24.26 ± 0.54de	36.44 ± 0.70b	25.90 ± 0.49d	23.90 ± 0.52e	33.44 ± 1.06c	24.98 ± 0.58de	23.62 ± 0.83e
Life span	57.36 ± 0.51a	37.62 ± 0.6b	34.36 ± 0.59c	56.90 ± 0.88a	38.80 ± 0.53b	34.46 ± 0.50c	55.94 ± 1.33a	38.42 ± 0.62b	35.16 ± 0.87c

Means (± SE) followed by the same letters in the same row are not significantly different by Tukey's HSD (P < 0.05).

Developmental time and longevity of S. gilvifrons *female reared on different prey species at different temperatures*

Similar results were obtained with females; the durations of all developmental stages were longer on *E. orientalis,* followed by *O. afrasiaticus*; however, the shorter periods were when fed on *T. urticae* (Table 2). The developmental period of females' immature stages was significantly affected by all prey types and temperature (F = 692.2, P < 0.0001). There were highly significant differences between different incubation periods of eggs of *S. gilvifrons*; the shortest period was 2.02 days at 32 °C on *T. urticae*, while the longest one was extended to 5.84 days at 22 °C when fed *E. orientalis* (F = 465.0, P < 0.0001). The shortest mean duration of larval stages of *S. gilvifrons* was 1.30, 1.28, 1.10, and 1.80 days for 1st, 2nd, 3rd, and 4th larvae at 32 °C when fed *T. urticae*, while the longer period obtained was 2.98, 3.22, 2.98, and 3.54 days at 22 °C, respectively, when fed on *E. orientalis,* with significant differences (F = 80.20, P < 0.0001; F = 90.86, P < 0.0001; F = 125.8, P < 0.0001; F = 76.54, P < 0.0001).

Table 2. Mean durations (days ± SE) predator *Stethorus gilvifrons* female reared on different prey diets at different temperatures.

Parameter	*Tetranychus urticae*			*Oligonychus afrasiaticus*			*Eutetranychus orientalis*		
	22 °C	27 °C	32 °C	22 °C	27 °C	32 °C	22 °C	27 °C	32 °C
Incubation period	5.18 ± 0.08c	3.06 ± 0.06e	2.02 ± 0.05g	5.44 ± 0.07b	3.32 ± 0.07d	2.14 ± 0.05g	5.84 ±0.06a	3.48 ± 0.08d	2.50 ± 0.08f
1st larval instar	2.40 ± 0.08c	1.66 ± 0.06ef	1.30 ± 0.05g	2.64 ± 0.07b	1.80 ± 0.05e	1.50 ±0.07f	2.98 ± 0.05a	2.00 ± 0.06d	1.56 ± 0.08f
2nd larval instar	2.52 ± 0.08c	1.72 ± 0.07e	1.28 ± 0.08g	2.72 ± 0.07b	1.90 ± 0.07de	1.40 ±0.08fg	3.22 ± 0.07a	2.00 ± 0.08d	1.50 ± 0.03f
3rd larval instar	2.56 ± 0.09b	1.20 ± 0.05de	1.10 ± 0.04e	2.82 ± 0.08a	1.36 ± 0.07d	1.20±0.06de	2.98 ± 0.05a	1.56 ± 0.07c	1.36 ± 0.08d
4th larval instar	3.26 ± 0.08b	2.16 ± 0.06de	1.80 ± 0.08f	3.42 ± 0.09ab	2.36 ± 0.09cd	1.86 ±0.07f	3.54 ± 0.05a	2.54 ± 0.09c	1.94 ± 0.06ef
Pupal stage	3.50 ± 0.08c	2.58 ± 0.06e	1.80 ± 0.09g	4.22 ± 0.12b	2.74 ± 0.09e	2.30 ±0.08f	4.78 ± 0.13a	3.02 ± 0.07d	2.50 ± 0.08ef
Life cycle	19.30 ± 0.17c	12.38 ± 0.16f	9.30 ± 0.2i	21.26 ± 0.21b	13.48 ± 0.23e	10.40±0.17h	23.34± 0.20a	14.60 ± 0.2d	11.36 ± 0.18g
Pre-oviposition	4.08 ± 0.11c	2.20 ± f0.05	2.54 ± 0.08e	4.46 ± 0.12b	2.54 ± 0.09d	2.90 ±0.09e	4.90 ± 0.10a	3.00 ± 0.06d	2.90 ± 0.09d
Oviposition	30.08 ± 0.33a	23.48 ± 0.44d	22.04± 0.45e	28.60 ± 0.42b	20.76 ± 0.35f	20.60 ±0.37f	26.40± 0.37c	19.32 ± 0.4g	15.40 ± 0.21h
Post-oviposition	4.96 ± 0.20c	3.20 ± 0.10ef	2.96 ± 0.11f	5.70 ± 0.15b	3.50 ± 0.1de	2.84 ±0.09f	6.36 ± 0.17a	3.68 ± 0.1d	2.84 ± 0.09f
Longevity	39.12 ± 0.39a	28.88 ± 0.49c	27.54 ± 0.46d	38.7± 0.45ab	26.8± 0.38de	26.34±0.44e	37.66± 0.45b	26.0 ± 0.39e	21.14 ± 0.24f
Mean fecundity (eggs/ ♀)	114.6 ± 1.8f	145.2 ± 2.28d	235.0 ± 2.04a	101.4 ± 2.0g	123.9 ± 1.95e	200.4±2.78b	90.80 ±1.4h	115.2 ±1.46f	152.0 ± 1.04c
Daily fecundity (eggs/ ♀/day)	3.81 ± 0.06d	6.24 ± 0.16c	10.78 ± 0.26a	3.55 ± 0.07d	6.03 ± 0.17c	9.84 ±0.28b	3.46 ±0.07d	6.02 ± 0.15c	9.89 ± 0.07b
Life span	58.42 ± 0.45b	41.26 ± 0.49c	36.84 ± 0.5d	60.02 ± 0.56a	40.28 ± 0.5c	36.74±0.49d	61.0 ±0.50a	40.60 ± 0.5c	32.50 ± 0.27e

Means (± SE) followed by the same letters in the same row are not significantly different by Tukey's HSD (P < 0.05).

The adult female longevities were also different significantly between both temperature and prey types. The *T. urticae* was more favored to the *S. gilvifrons*, followed by *O. afrasiaticus* and *E. orientalis*. In addition, significant differences occurred between the three prey diets on female fecundity; the highest one was observed on *T. urticae* (235.0 eggs/♀) with a daily rate of 10.78 eggs/♀/day at 32 °C, and the lowest rate was on *E. orientalis* (90.80 eggs/♀) with a daily rate of 3.46 eggs/♀/day at 22 °C (F = 614.9, P < 0.0001). Also, the life span of *S. gilvifrons* females was affected by temperature, with the longest periods at 22 °C and the shortest periods at 32 °C (F = 545.1, P < 0.0001) (Table 2).

Food consumption

Data in Table 3 indicated that temperature and prey diets have a significant effect on *S. gilvifrons* predacious capacity. At 22 °C, the consumed food was higher than that at 27 and 32 °C. The consumption rate decreased as the temperature increased. The number of mites consumed by *S. gilvifrons* larvae increased from the first to the fourth instar. At all tested temperatures, the fourth instar larvae of the predator recorded the highest predacious capacity among immature stages of the predator. *S. gilvifrons* significantly consumed more prey (158.0) on *O. afrasiaticus* at 22 °C than on *E. orientalis* at 22 °C (127.1) during the oviposition period. The higher number of preys consumed during the adult stage was recorded for *S. gilvifrons* females and males on *O. afrasiaticus* at 22 °C (245.4 and 26.8 prey), whereas the lowest was 133.8 and 123.6 prey when fed on *E. orientalis* at 32 °C, respectively. Also, *S. gilvifrons* adults consumed a greater number of prey diets than larval instars at different temperatures. That can be because the adult predator has grown larger and more active, which results in a greater need for food to complete laying eggs.

Thermal requirements of S. gilvifrons

Data in Table 4 indicated that the thermal factor had a negative relationship with the duration of each stage, as increasing temperature rapped development and shortened the duration from egg to adult. To describe the relationship between developmental rate and temperature, the lower thermal thresholds and degree-day requirements were assessed for *S. gilvifrons* from the linear regression equation developed. The lower temperature threshold (T_0) for different stages of the predatory coccinellid, *S. gilvifrons*, ranged between 8.16 and 15.80 °C from egg to adult. The accumulated day degrees (*K*) ranged between 19.29 and 301.72 DDUs from egg to adult. The values of the coefficient of determination (the proportion of variation in the dependent variable that can be explained by the independent variable) R^2 of *S. gilvifrons* ranged between 0.85 and 1.0.

Table 3. The consumption rate of *Stethorus gilvifrons* reared on adult stages of different prey diets at different temperatures.

Parameter	*Tetranychus urticae*			*Oligonychus afrasiaticus*			*Eutetranychus orientalis*		
	22 °C	27 °C	32 °C	22 °C	27 °C	32 °C	22 °C	27 °C	32 °C
1st larval instar	23.5 ± 1.14 b	16.4 ± 1.38	16.1 ± 0.90 de	27.6 ± 1.51a	21.9 ± 1.26 bc	18.9 ± 0.67 cd	22.10 ±1.23 b	15.5 ± 0.89 e	14.4 ± 0.43 e
2nd larval	29.0 ± 0.97 bc	28.1 ± 1.64 c	26.6 ± 0.99 c	31.6 ± 1.05b	36.8 ± 1.95 a	27.6 ± 1.14 c	26.20 ± 1.27 c	25.8 ± 1.01 c	21.1 ± 0.53 d
3rd larval instar	54.8 ± 3.07 ab	43.5 ± 2.56 d	41.8 ± 1.29 d	58.9 ± 2.31 a	49.5 ± 2.83 bc	45.9 ± 1.35 dc	50.0 ± 1.85 bc	34.4 ± 1.75 e	34.6 ± 0.65 e
4th larval instar	91.1 ± 3.45 ab	67.7 ± 2.79 e	66.2 ± 3.62 e	95.6 ± 1.99 a	77.4 ± 3.55 cd	73.5 ± 3.88 de	84.6 ± 2.60 bc	57.8 ± 1.99 f	43.2 ± 1.12 g
Total	198.4 ± 7.77	155.7 ± 7.30	150.7 ± 5.62 d	213.7 ± 4.45 a	185.6 ± 9.28 b	165.9 ± 6.40 cd	182.9 ± 4.80	133.5 ± 4.25 e	113.3 ± 1.31 f
Pre-oviposition	50.2 ± 1.74 a	43.0 ± 1.83 b	36.30 ± 1.10 c	51.9 ± 1.26 a	47.8 ± 1.96 a	37.7 ± 1.07 c	47.8 ± 1.96 a	36.8 ± 1.40 c	30.4 ± 0.76 d
Oviposition	147.0 ± 7.0 ab	126.0 ± 5.26	108.4 ± 4.09 e	158.0 ± 4.36 a	139.2 ± 5.62	115.8 ± 3.82 de	127.1 ± 5.01	104.9 ± 3.0 e	86.2 ± 1.48 f
Post-	32.0 ± 2.17 a	23.10 ± 1.20	19.0 ± 0.63 de	35.50 ± 1.12 a	27.6 ± 1.05 b	21.9 ± 0.92 dc	28.1 ± 2.15 b	22.7 ± 0.84 dc	17.2 ± 0.73 e
Adult female	229.2 ± 9.30	192.1 ± 7.27	163.7 ± 4.95f	245.4 ± 5.88 a	214.6 ±7.97 bc	175.4 ± 5.46 ef	203.0 ± 6.23	164.4 ± 3.68 f	133.8 ± 1.70 g
Adult male	206.7 ± 7.50 b	184.4 ± 7.22	149.8 ± 4.84 d	226.8 ± 6.56 a	204.9 ± 7.89 b	160.4 ± 5.56 d	184.4 ± 6.30 c	151.9 ± 3.80 d	123.6 ± 1.92 e

Means (± SE) followed by the same letters in the same row are not significantly different by Tukey's HSD ($P < 0.05$).

Table 4. Linear regression model for temperature-dependent developmental rates of immature stages of *Stethorus gilvifrons* female reared on different prey types.

Stages	prey	*a*	*b*	T_0	*K*	R^2
Egg	*T. urticae*	−0.48	0.03	15.80	33.11	0.99
	O. afrasiaticus	−0.45	0.03	15.80	35.28	0.99
	E. orientalis	−0.33	0.02	14.49	43.71	1.00
1st larval instar	*T. urticae*	−0.36	0.04	10.09	28.36	0.99
	O. afrasiaticus	−0.24	0.03	8.46	34.74	0.98
	E. orientalis	−0.33	0.03	10.89	32.74	0.99
2nd larval instar	*T. urticae*	−0.45	0.04	11.74	26.01	0.99
	O. afrasiaticus	−0.40	0.03	11.53	28.85	0.99
	E. orientalis	−0.47	0.04	13.17	28.08	0.99
3rd larval instar	*T. urticae*	−0.69	0.05	13.29	19.29	0.85
	O. afrasiaticus	−0.65	0.05	13.61	20.89	0.89
	E. orientalis	−0.51	0.04	12.72	25.02	0.91
4th larval instar	*T. urticae*	−0.23	0.02	9.25	40.19	0.97
	O. afrasiaticus	−0.24	0.02	9.96	40.78	0.99
	E. orientalis	−0.23	0.02	9.95	42.92	0.99
Total immature	*T. urticae*	−0.32	0.03	11.82	37.06	0.98
	O. afrasiaticus	−0.19	0.02	9.53	50.55	0.97
	E. orientalis	−0.20	0.02	10.57	52.41	0.97
Life cycle	*T. urticae*	−0.06	0.01	11.53	197.45	0.99
	O. afrasiaticus	−0.04	0.00	10.49	234.91	0.97
	E. orientalis	−0.03	0.00	8.16	301.72	0.90

a = intercept, *b* = slope of temperature, $T_0 = -a/b$, *K* (DDUs) = 1/b, R^2 = coefficient of determination

Life-table parameters of S. gilvifrons

Life-table parameters of *S. gilvifrons* at three constant temperatures and three prey diets are presented in Table 5. The life-table parameters *T*, r_m, λ, and R_0 differed between the three constant temperatures and three prey diets. The shortest mean generation time (*T*) at 32 °C was 16.15, 17.02, and 17.14 days, and the longest at 22 °C was 29.42, 30.61, and 32.67 days on *T. urticae*, *O. afrasiaticus*, and *E. orientalis*, respectively. The highest intrinsic rate of increase (r_m) value was 0.280♀/♀/day on *T. urticae* at 32 °C, while the lowest one was 0.106♀/♀/day on *E. orientalis* at 22 °C. The highest net reproductive rate (R_0) value was 93.53♀/♀ on *T. urticae* at 32°C. The gross reproductive rate (*GRR*) increased from 52.47 on *O. afrasiaticus* at 22 °C to 132.8 offspring/ individuals on *T. urticae* at 32 °C. The shortest doubling time (*DT*) was 2.48 days on *T. urticae* at 32 °C, and the longest on *E. orientalis* at 22 °C was 6.49 days. The finite rate of increase (λ) was 1.32, 1.29, and 1.26 individuals/female/day at 32 °C on *T. urticae*, *O. afrasiaticus*, and *E. orientalis*, respectively, indicating that the population could multiply 1.32, 1.29, and 1.26 times per female per day.

Table 5. Life-table parameters of *Stethorus gilvifrons* reared on different prey types and different temperatures.

Parameter	*Tetranychus urticae*			*Oligonychus afrasiaticus*			*Eutetranychus orientalis*		
	22 °C	27 °C	32 °C	22 °C	27 °C	32 °C	22 °C	27 °C	32 °C
Mean generation time (T_C)[a]	29.42 b	19.85 d	16.15 e	30.61 b	20.48 cd	17.02 e	32.67 a	21.43 c	17.14 e
Survival rate (%)	70.0 d	90.0 a	80.0 bc	72.0 cd	89.0 a	80.0 bc	68.0 d	85.0 ab	75.0 cd
Sex ratio (females/total)	0.50 a	0.50 a	0.50 a	0.52 a	0.51 a	0.50 a	0.53 a	0.50 a	0.50 a
Net reproductive rate (R_0)[b]	40.12 e	65.34 c	93.53 a	36.33 e	56.26 d	80.31 b	32.81 e	49.19 d	57.0 cd
Intrinsic rate of increase (r_m)[c]	0.125 g	0.210 d	0.280 a	0.117 h	0.196 e	0.257 b	0.106 i	0.181 f	0.235 c
Finite rate of increase (λ)[c]	1.13 a	1.23 a	1.32 a	1.12 a	1.21 a	1.29 a	1.11 a	1.19 a	1.26 a
Doubling generation (*DT*)[a]	5.53 a	3.29 b	2.48 b	5.91 a	3.53 b	2.69 b	6.49 a	3.81 b	2.95 b
Gross reproduction rate (*GRR*)[d]	59.60 def	80.81 c	132.8 a	52.47 f	68.14 d	109.28 b	55.30 f	65.63 de	81.08 c

[a] Day, [b] females/female/generation, [c] individuals/female/day, [d] offspring/individual
Means followed by the same letters in the same row are not significantly different by Tukey's HSD (P < 0.05).

The age-specific survival rate of S. gilvifrons *reared on different prey and at different temperatures*

Age-specific survival rate (l_x) and age-specific fecundity (m_x) curves for *S. gilvifrons* are illustrated in (Fig. 1). The daily age-specific survival rate was highest at 27 °C and decreased at 22 °C and 32 °C for the three prey species. The maximum number of eggs produced (day 16: 6.02 egg/♀/day) when fed on *T. urticae* at 32 °C was the lowest (day 27: 2.37 egg/♀/day) when fed on *E. orientalis* at 22 °C. The highest survival rate of females was 90% when fed on *T. urticae* at 27°C, while the lowest value was 68.0% when fed on *E. orientalis* at 22 °C.

DISCUSSION

Mass production of predators requires large numbers at low costs for biological control programs. It should be selected by predators with short developmental time, high survival rates, and high reproduction rates. To design an effective Integrated Pest Management (IPM) program, it is important to comprehend the four elements of an interacting biological control system: the environment, natural enemies, host plants, and prey (Duffey *et al*. 1986).

An effective IPM program for pest control should maximize the effectiveness of natural enemies, but various biotic and abiotic factors can reduce this efficacy. Temperature is a critical abiotic factor that affects both pests and their natural enemies. Predacious coccinellids, predators of small phytophagous insects and mites, are potential biocontrol agents (Zhang *et al.* 2007). *Stethorus* species, predators of spider mites, have been reported as biocontrol agents of tetranychid pests in agricultural systems (Roy *et al.* 1999).

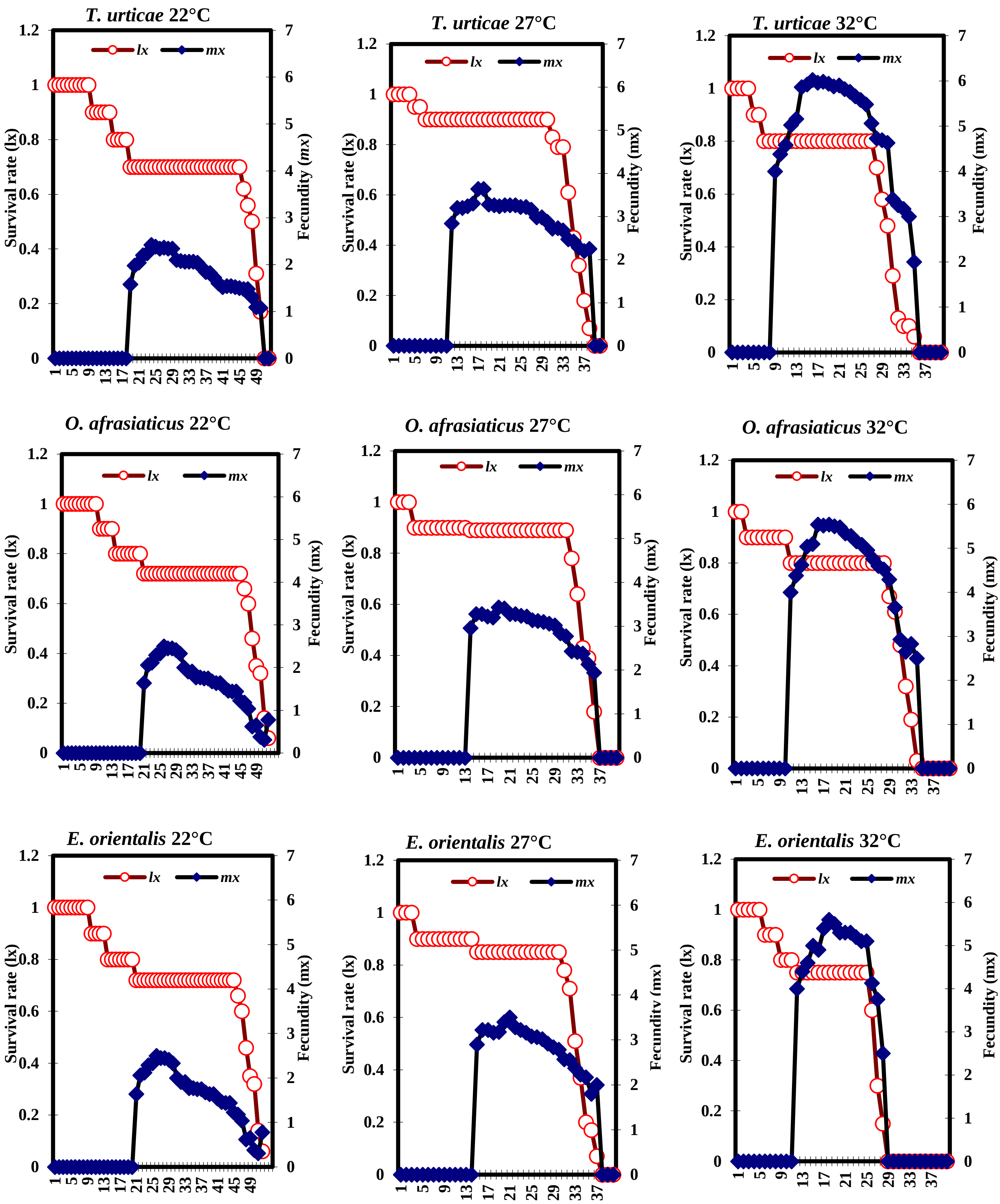

Figure 1. Age-stage-specific survival rate (*lx*) and age-specific fecundity (m_x) curves of *Stethorus gilvifrons* on different prey types and different temperatures.

To study more on these facts, we focused here on evaluating the effects of temperature and prey diet on life-table parameters of *S. gilvifrons* to assess the suitability of this predator for mass production for use in biological control programs against tetranychid mites. As expected, significant differences between the life history of *S. gilvifrons* feeding on *E. orientalis*, *T. urticae* and *O. afrasiaticus* at different temperatures were observed.

The predatory coccinellids, *S. gilvifrons*, were able to survive and reproduce on *E. orientalis*, *O. afrasiaticus*, and *T. urticae*. The shortest developmental time was recorded on *T. urticae*. The results of this study indicated that the development time (from egg to adult) of *S. gilvifrons*, female and male, ranged from 12.58 to 14.60 days at 27 °C on three prey diets. The findings agree with those of Jafari *et al.* (2022), who found *S. gilvifrons* female life cycle of about 13.00 days on both *T. urticae* and *E. orientalis*; *T. urticae* is a preferable food for *S. gilvifrons*. Conversely, a longer developmental period (19.2 days) was reported by Perumalsamy *et al.* (2010) for *S. gilvifrons* preying on *Oligonychus coffeae* (Nietner), infesting tea leaves. Moreover, according to Saleh (2018), the developmental time of *S. gilvifrons* was reported to be 15.3 days at 25 °C after feeding on *T. urticae* on the leaves of cowpea bean plants. Also, Jafari *et al.* (2020) showed that the developmental time of *S. gilvifrons* decreased with increasing temperatures, with the lowest and highest intrinsic rate of increase at 15 °C and 34 °C, respectively. Jafari *et al.* (2023b) indicated that the total development time for females was estimated to be 61.4, 31.6, 14.4, 13.3, 12.5, and 11.7 days at 15, 20, 25, 27, 30, and 42 °C for *S. gilvifrons* fed on *T. urticae*.

The results showed a significant decrease in male and female longevity with increasing temperatures from 22 °C to 32 °C. In our study, *S. gilvifrons* female's longevity was 39.12, 28.88, and 27.54 days on *T. urticae* at 22, 27, and 32 °C. Similar results were obtained at 37.06 days and 47.91 days at 27 °C for *S. gilvifrons* on maize and castor bean, respectively, by Jafari *et al.* (2022). Also, Taghizadeh *et al*. (2008a) indicated that the longevity of *S. gilvifrons* was 14.50 days at 27 °C, preying on *T. urticae* reared on bean leaves (*P. vulgaris* L.).

The fecundity of female predators was affected by temperature and prey type. The highest fecundity was observed on *T. urticae* (235.0 eggs/♀) with a daily rate of 10.78 eggs/♀/day at 32 °C. Similar results obtained by Jafari *et al.* (2022) showed that the total fecundity of *S. gilvifrons* was 158.67, 151, and 107.65 eggs per female on maize, cowpea, and castor bean, respectively. Furthermore, Imani *et al*. (2009) indicated that the mean fecundity was 175 eggs per female on *Tetranychus turkestani* Ugarov & Nikolskii and 318 eggs per female on *E. orientalis* at 30 °C.

In the current study, *S. gilvifrons* fed better on *T. urticae* than other prey species. The optimum temperature for its development was 32 °C, as it developed faster than 22 and 27 °C. While the survival rate was highest at 27 °C, it decreased as the temperature increased for all prey species. The lower temperature threshold (T_0) for different stages of the predatory mite, *S. gilvifrons*, ranged between 8.16 and 15.80 °C from egg to adult. The present results almost agree with the findings of Jafari *et al.* (2023b), who indicated that lower developmental thresholds were 11.96 and 12.47 °C for *S. gilvifrons*, as reported by Taghizadeh *et al*. (2008b). The thermal constant (K) in the current study ranged between 197.45 and 234.91 degree-days for the life cycle. Similar results were obtained by Taghizadeh *et al*. (2008b), who found the thermal constant (K) was 222.72 degree-days. The optimal temperature for the development of *S. gilvifrons* was about 33 °C for total development, and the thermal constant was 187.87 degree-days, as reported for *S. gilvifrons* by Jafari *et al.* (2023b).

In our study, temperature and prey diets had a significant effect on *S. gilvifrons* predacious capacity. The consumption rate decreased as the temperature increased. This could be because the larvae of the predator spent more time in each instar at such a low temperature, which enabled them to consume more prey to satisfy their needs and pass to the next instar. Adult females consumed more prey than larval stages and males. At all temperatures, the highest consumption rate was when the predators had been reared on *O. afrasiaticus.* Similar findings were also reported by Perumalsamy *et al.* (2010) for *S. gilvifrons* preying on *O. coffeae* and Ragkou *et al.* (2004) for *Stethorus punctillum* Weise fed on *T. urticae*. Barbar *et al.* (2016) found that *S. gilvifrons* consumed an average of 886.6 adults of *Panonychus citri* (McGregor).

The relationship between temperature and rate of development in insects and mites is typically estimated as linear, whereas it is really curved (Birch 1948). According to the effect of temperature and prey diet on life-table parameters of *S. gilvifrons* in the current study, the highest (r_m), finite rate of increase (λ), gross reproduction rate, and net reproductive rate (R_0) were obtained on *T. urticae* at 32 °C. These results are in coincidence with those of Taghizadeh *et al.* (2008a) who found that the highest values of r_m and R_0 were recorded at 35 °C. The intrinsic rate of natural increase and net reproductive rate increased linearly with temperature, while mean generation time and doubling time decreased linearly. Abdel-Salam *et al.* (2010) indicated that the fecundity rate was higher at 30 °C and that mean generation time and doubling time were shorter at 30 °C. Gross reproductive rate, net reproduction rate, intrinsic rate of increase, and finite rate of increase were higher at 30 °C. Also, Saleh (2018) found that the fecundity rate was higher at 35 °C than at 15°C and 25 °C, and the gross reproductive rate, net reproduction rate, intrinsic rate of increase, and finite rate of increase were higher at 35 °C than at 15 and 25 °C. Moreover, Jafari *et al.* (2020) showed the lowest and highest intrinsic rate of increase at 15 °C and 34 °C, respectively. Jafari *et al.* (2022) found that the intrinsic rate of increase (r_m) and net reproductive rate (R_0) of *S. gilvifrons* vary with temperature, with the lowest values at 15 °C and the highest at 34 °C. Total fecundity is highest at 30 °C, and female longevity is the shortest at 34 °C. Mean generation time decreases with temperature, with the least at 34 °C.

CONCLUSIONS

The results obtained here revealed that temperature and prey diets influence the developmental rate and reproduction of *S. gilvifrons*. However, at all temperatures, the highest consumption rate was when the predators had been reared on *O. afrasiaticus*, *T. urticae* is better for mass rearing of *S. gilvifrons* than *O. afrasiaticus* and *E. orientalis*, because it has shortened duration and highest fecundity when fed on *T. urticae*. Also, it can be concluded that 32 °C is a more satisfactory temperature than 22 and 27 °C for the population increase of *S. gilvifrons* when reared on *T. urticae*. These findings can be used to forecast population dynamics, as well as to guide mass rearing and the use of *S. gilvifrons* predator to reduce tetranychid pests in biological control programs.

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تأثیر دما و نوع طعمه بر آماره‌های جدول زندگی و میزان مصرف *Stethorus gilvifrons* (Mulsant) (Coleoptera: Coccinellidae) روی سه کنۀ تارتن

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چکیده

کنۀ تارتن دولکه‌ای *Tetranychus urticae* Koch، کنۀ تارتن خرما *Oligonychus afrasiaticus* (McGregor) و کنۀ قهوه‌ای مرکبات *Eutetranychus orientalis* (Klein) از خانوادۀ Tetranychidae از آفات کلیدی درختان میوه، محصولات زراعی و گیاهان زینتی هستند که باعث خسارات مهمی به محصول می‌شوند. هدف از این پژوهش بررسی تأثیر سه دمای ثابت (۲۲، ۲۷ و ۳۲ درجۀ سلسیوس) بر زمان نمو، آماره‌های جدول زندگی و میزان مصرف کفشدوزک شکارگر *Stethorus gilvifrons* (Mulsant) روی دیسک‌های برگ ذرت با *T. urticae*، *O. afrasiaticus* و *E. orientalis* به عنوان غذا است. نتایج حاکی از تفاوت معنی‌دار بین سه دمای مختلف و نوع طعمه بود. کوتاه‌ترین زمان نمو با تغذیه از *T. urticae* (۹/۳۰ و ۱۰/۱۰ روز) در دمای ۳۲ درجۀ سلسیوس، در حالی که طولانی‌ترین زمان در *E. orientalis* (۲۳/۳٤ و ۲۲/۵۰) در ۲۲ درجۀ سلسیوس برای ماده ها و نرها ثبت شد. کوتاه‌ترین طول عمر ماده با تغذیه از *E. orientalis* (۲۱/۱٤ روز) در دمای ۳۲ درجۀ سلسیوس و بیشترین طول عمر با تغذیه از *T. urticae* در دمای ۲۲ درجۀ سلسیوس ۳۹/۱۲ روز بود. باروری با افزایش دما افزایش یافت، از ۱۱٤/٦ تخم با نرخ روزانه ۳/۸۱ تخم در روز در ۲۲ درجۀ سلسیوس به ۲۳۵ تخم با نرخ روزانه ۱۰/۷۸ تخم در روز در ۳۲ درجۀ سلسیوس با تغذیه از *T. urticae* افزایش یافت. بیشترین میزان خالص تولیدمثل (R_0)، نرخ ذاتی افزایش طبیعی (rm) و میزان متناهی افزایش (λ) در دمای ۳۲ درجۀ سلسیوس ثبت شد، در حالی‌که کمترین مقادیر در دمای ۲۲ درجۀ سلسیوس ثبت شد که کفشدوزک‌های شکارگر *S. gilvifrons* با سه رژیم غذایی تغذیه شدند. میزان تولیدمثل ناخالص (*GRR*) بیشترین مقدار (۱۳۲/۸ فرزند/فرد) را هنگام تغذیه با *T. urticae* در دمای ۳۲ درجۀ سلسیوس و کمترین مقدار (۵۵/۳۰ فرزند/فرد) هنگام تغذیه با *E. orientalis* در دمای ۲۲ درجۀ سلسیوس ثبت شد. بیشترین میزان مصرف نر و ماده بالغ ۲۲٦/۸ و ۲٤۵/٤ نفر بود که با *O. afrasiaticus* در دمای ۲۲ درجۀ سلسیوس تغذیه شدند، در حالی‌که کمترین میزان مصرف ۱۲۳/٦ و ۱۳۳/۸ نفر با تغذیه از *E. orientalis* در دمای ۳۲ درجۀ سلسیوس بود. بنابراین، نتایج به‌دست‌آمده در این پژوهش نشان می‌دهد که دما و رژیم غذایی بر سرعت رشد و تولید مثل *S. gilvifrons* تأثیر می‌گذارد. افزون بر این، *T. urticae* برای پرورش انبوه *S. gilvifrons* بهتر از *O. afrasiaticus* و *E. orientalis* به عنوان غذا است.

واژگان کلیدی: دمای ثابت، *Eutetranychus orientalis*، باروری، جدول زندگی، *Oligonychus afrasiaticus*، شکارگری، *Tetranychus urticae*.

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