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# Temperature dependent development and population performance of *Tetranychus fijiensis* Hirst (Acari: Tetranychidae) on Papaya

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**ABSTRACT:** Developmental biology and life table characteristics of *Tetranychus fijiensis* Hirst (Acari: Tetranychidae) on papaya were studied at four distinct constant temperatures (20, 24, 28, and 32°C) and relative humidity (70-85%) conditions. With the increase in rearing temperature conditions, the length of *T. fijiensis* life cycle decreased from 34.46 to 8.58 days. At 20, 24, 28, and 32°C, the Net Reproduction Rate ($R_0$) was 23.48, 39.06, 33.75, and 23.48 and; the intrinsic rate of population increase ($r_m$) was 0.0694, 0.2003, 0.2281, and 0.1902 females/ female/day, respectively. The optimum temperature for mite development was observed to be between 24 and 28°C, while favourable temperature for optimal reproduction capacity of the mite was 28°C. © 2023 Association for Advancement of Entomology

**KEYWORDS:** Life table, reproduction rate, intrinsic rate, optimum temperature

## INTRODUCTION

Papaya (*Carica papaya* L.) is a popular tropical fruit grown in warm climates, primarily for its edible fruit, but also has culinary, medical and industrial benefits. Like most tropical fruits grown in a variety of climates, papaya is attacked by 134 species of arthropods. The Hexapoda accounts for the majority of the species, while the Acarina accounts for 12 of them. Phytophagous mites are frequent secondary pests that cause economic damage, particularly after humans have intervened to control other pests. Spider mites are probably the most persistent arthropod pests and feed more commonly on older leaves, which initially turn yellow on the upper side and silvery on the lower side, followed by necrotic areas and eventually the leaf drops-off. Spider mites do have economic impact on the production of crops in greenhouses and in open fields. There are 1300 species reported so far, with over 100 of them considered as pests and ten are severe pests (Vacante, 2015). The main drivers of a spider mite population growth are their high reproduction potential and rapid development. Among the potential spider mite species, *Tetranychus fijiensis* Hirst is perceived as a serious pest that infests mostly horticultural crops (Anonymous, 2018-20). The major crop plants infested by *T. fijiensis* are coconut palm (Prasad, 1974; Sarkar and Somchoudhury, 1989; Gupta and Gupta, 1994), betel nut palm (Daniel, 1977); papaya (Gupta, 1976; Gupta and Gupta, 1994), white

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mulberry (Bolland *et al*., 1998; Migeon and Dorkeld, 2006-2013), peach and pear (Ehara and Wongsiri, 1975), *Citrus* spp. (Ehara and Wongsiri, 1975; Prasad, 1974 and Gupta, 1992 on *C. aurantium*), sour orange (Gupta and Gupta, 1994), citron, grapefruit, tangerine and calamondin (Othman and Zhang, 2003) and cardamom (Gupta and Gupta, 1994).

Papaya crop is cultivated in varying agroclimatic conditions that would support the development and multiplication of spider mite pests like *T. fijiensis* in a varied manner. The basic information on mite developmental biology and reproduction under ambient temperature conditions has been crucial for understanding the pest population dynamics and for formulating effective management strategies. Temperature is the most crucial environmental factor affecting development and reproduction of poikilothermic organisms like mites, including spider mites. Hence, a study on the mite's biological characteristics at different temperature conditions for the construction of developmental curves were undertaken which can be used for the prediction of developmental time as a function of temperature.

## MATERIALS AND METHODS

***Life history:*** Developmental biology of the spider mite, *T. fijiensis* was studied on papaya leaf discs at four constant temperature and humidity conditions (20±1°C, 80-85% RH; 24±1°C, 75-80% RH; 28°C, 70-75% RH and 32±1°C, 75-80% RH with 14h: 10h L: D conditions in a BOD incubator. Initially, a cohort of 30 to 50 eggs laid on 5cm x 5cm host leaf discs were observed periodically for hatching. Soon after hatching, using a fine camel hairbrush, the larvae were individually transferred to 50 separate 1.5 cm x 1.5 cm fresh host leaf discs kept on wet foam in 9" × 6" polyethylene trays. Further, the larvae were observed every 3 to 6 hours under a stereo binocular microscope and the data in respect of development from larva to adult including the quiescent stages (larvochrysalis, nymphochrysalis and teliochrysalis) were recorded. The sex of the emerging adult was also recorded to compute the data for the developmental time of male and female mite, separately.

***Reproduction:*** Female teliochrysalis stages, selected from the mite culture maintained in the laboratory were individually transferred onto 50 (1.5 cm × 1.5 cm) fresh leaf bits. Two male adults were released on to each leaf disc to ensure mating subsequent to the emergence of adult female from the teliochrysalis stage. Further, observations were made every 24 hours to record the pre-oviposition period, the number of eggs laid every day, duration of oviposition (oviposition period), post-oviposition period, fecundity and sex ratio (♂: ♀, as proportion of male and female off-springs) were recorded across different temperature conditions and were compared to know the influence of temperature on these biological attributes.

***Population performance and demography*:** Temperature-wise age specific life table of the mite *T. fijiensis* was constructed separately. Demographic/Life table parameters such as, Mean Generation Time (T), Net Reproduction Rate (Ro), Gross Reproduction Rate (GRR), Finite Rate of Increase (λ), Intrinsic Rate of Natural Increase ($r_m$) and Doubling Time (DT) were computed following the procedure suggested by Birch (1948) and Atwal and Bains (1974) and the data were analysed (Chidananda, 2016; Pooja, 2018).

Net Reproductive Rate ($R_o$) = $\sum l_x m_x$

Mean Generation Time (T) = $\frac{\Sigma\ xlxmx}{Ro}$

Finite Rate of Increase in number (λ) = anti ln[$\frac{logeRo}{T}$]

Intrinsic Rate of Natural Increase ($r_m$) = ln (λ)

Doubling time, DT = $\frac{\ln 2}{rm}$ where,

$l_x$ = proportion of females alive at age interval x

$m_x$ = number of female off-springs produced by the surviving female at age interval x

$l_x m_x$ = product of the proportion of females live at age interval x and the number of female off-springs per original female produced at the age interval x

Data in respect of development and reproduction parameters were expressed as mean ± SE and the mean data were analysed using one-way ANOVA followed by Tukey's HSD test (P=<0.05) in statistical software SPSS 23 to compare the mean values across different rearing temperature conditions. Demographic parameters were computed using the relevant formulae and expressed as mean±SE determined by bootstrapping method and subjected to Post Hoc analysis to compare them across different constant temperature conditions.

***Determination of thermal constant:*** Thermal constant of an organism is the temperature heat units required to complete its life cycle. Thermal constant for each stage of development and total development from egg to adult of *T. fijiensis* was determined by making use of the data of duration of corresponding developmental stage in different constant rearing temperature conditions using simple linear regression analysis. Simple linear regression analysis, $\hat{Y}$ = a ± b X was performed as the relationship between temperature (ºC) and rate of development (1/developmental time in days) to determine the lower developmental threshold or temperature threshold (ºC) (= - a (intercept) / b (regression coefficient) and thermal constant (K) (=1/regression coefficient) according to the rule of constant sum of effective temperature as Thermal constant (b) = (Temperature - Development threshold) X Duration of development (Dent, 1997; Price, 1984).

## RESULTS AND DISCUSSION

### Temperature threshold and thermal constant

Data in respect of duration of development of *T. fijiensis* at four different constant temperatures were used to determine the mite's temperature threshold (°C) and thermal constant (day-degrees) values. The regression analysis between rearing temperature and rate of development at each stage of development (egg to adult) was carried out. The relationship between rate of development and temperature was expressed in the form of an equation, $\hat{Y}$ = 0.0065X-0.0859 ($R^2$ = 0.8895) for female and $\hat{Y}$ = 0.0073X-0.101 ($R^2$ = 0.8626) for male (Table 1). Temperature threshold was 13.22 and 13.84ºC for female and male, respectively. The thermal constant value for female was 153.85 degree-days and 136.99 degree-days for male. The temperature showed profound influence on both survival and development of *T. fijiensis*. For survival, male mite required relatively marginally higher temperature of 13.84ºC against 13.22ºC required for female. But male required lower accumulated heat units of 136.99 degree-days compared to 153.85 degree-days necessary for female.

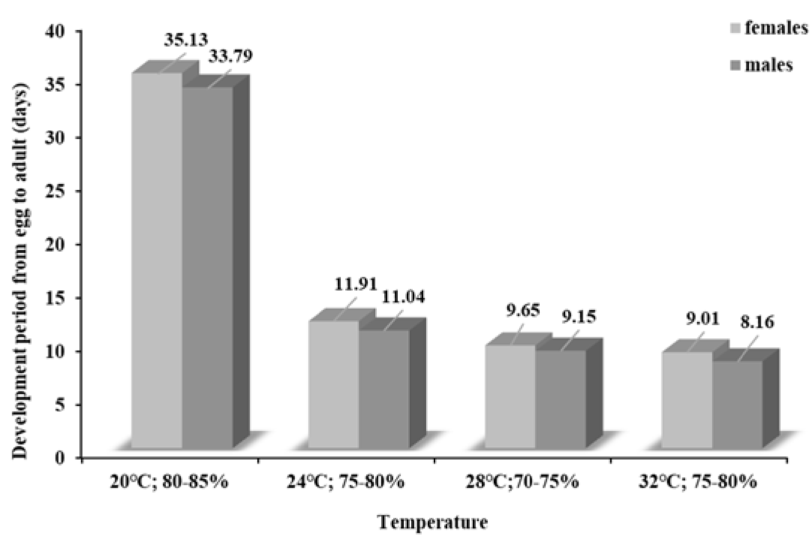


Fig. 1 Development of mite *Tetranychus fijiensis* on papaya at different constant temperature conditions in the laboratory

As the rearing temperature conditions increased from 20 to 32ºC (at the incremental rate of 4ºC), the duration of development for each stage recorded a gradual decrease (Fig. 2). Also, total development of both female and male decreased reasonably (35.13 to 9.01 days for female, 33.79 to 8.16 days for male). Mean developmental duration (female + male) was lowest, 8.58 days at 32ºC. Comparatively higher developmental duration of 34.46 days was recorded at 20ºC.

Data with respect to longevity of mated females at constant temperatures (20, 24, 28 and 32ºC) revealed that the female survived for 19.84, 13.48, 10.96 and 13.50 days. Each mated female laid an average of 25.34, 43.91, 39.43 and 26.62 eggs over 14.06, 11.85, 8.93 and 10.06 days. The fecundity was significantly high at 24ºC i.e. 43.91 eggs, laid over a lower period for 11.85 days (Table 2). The pre-oviposition period, oviposition period, post-oviposition period, female longevity, fecundity respectivelty, and daily egg laying by each female were found significantly affected by temperature factor. *T. fijiensis* had a comparatively longer pre-oviposition period of 4.25 days at 20ºC. The Post-oviposition period was not statistically significant at 20º and 24ºC, while it was only 0.53 days at 28ºC, but it was longer, 1.59 days at 32ºC. The oviposition period was longer, 14.06 days at 20ºC while, it was shorter, 8.93 days at 28ºC. Even though oviposition period was long at 20ºC, but the eggs per female was high, 43.91 at 24ºC. All the egg laying related periods, (pre-oviposition, oviposition and post-oviposition periods), and female longevity were found decreased as the rearing temperature increased; except in respect of total number of eggs/female, which increased up to only certain level of temperature, which further declined at higher temperatures. Fecundity was high at 24°C compared to other temperature levels (Table 2 and Fig. 2).

Bonato *et al*. (1999) studied the effect of mating status on the fecundity and longevity of *T. fijiensis* on *Disoxylum bijugum* (Meliaceae) at a constant temperature of 25±1°C. The median longevity of inseminated females was 16.5 days, more than the longevity on papaya at 24°C in the present study. But fecundity of inseminated females was 49.6 eggs, which is near to the fecundity (43.91 eggs) on papaya at 24°C in the present study. Vatana *et al*. (2001) studied the reproduction of *T. fijiensis* on passion fruit leaf; fecundity of mated female was 20 eggs with male to female sex ratio of 1:8, near similar to the fecundity of 25.34 eggs at 20ºC and sex ratio of 1: 7.47 at 32ºC in our present study. Moro *et al*. (2012) investigated on *T. urticae*

Table 1. Thermal constant and temperature threshold for the development of *T. fijiensis* on papaya

| Stage | Sex | Regression equation | $R^2$ | (k=1/b) | ($T_0$=a/b) |
|---|---|---|---|---|---|
| Egg | Female | Ŷ=0.0215X-0.289 | 0.9108 | 46.51 | 13.44 |
| | Male | Ŷ=0.0215X-0.289 | 0.9108 | 46.51 | 13.44 |
| Larva | Female | Ŷ=0.068X-1.153 | 0.9794 | 14.71 | 16.96 |
| | Male | Ŷ=0.076X-1.261 | 0.9657 | 13.16 | 16.59 |
| Protonymph | Female | Ŷ=0.0583X-0.917 | 0.8125 | 17.15 | 15.73 |
| | Male | Ŷ=0.092X-1.692 | 0.9316 | 10.87 | 18.39 |
| Deutonymph | Female | Ŷ=0.0547X-0.781 | 0.5792 | 18.28 | 14.28 |
| | Male | Ŷ=0.082X-1.352 | 0.9514 | 12.20 | 16.49 |
| Total (egg to adult) | Female | Ŷ=0.0065X-0.0859 | 0.8895 | 153.85 | 13.22 |
| | Male | Ŷ=0.0073X-0.101 | 0.8626 | 136.99 | 13.84 |

Table 2. Reproduction parameters of *Tetranychus fijiensis* on papaya at different constant temperatures in the laboratory

| Reproduction attributes | 20°C; 80-85% (n=30) | 24°C; 75-80% (n=32) | 28°C; 70-75% (n=35) | 32°C;75-80% (n=30) |
|---|---|---|---|---|
| Pre-oviposition period (days) | 4.25 ± 0.35$^{c}$ | 0.71 ± 0.19$^{a}$ | 1.50 ± 0.16$^{ab}$ | 1.84 ± 0.13$^{b}$ |
| Oviposition period (days) | 14.06 ± 0.98$^{b}$ | 11.85 ± 0.79$^{ab}$ | 8.93 ± 0.70$^{a}$ | 10.06 ± 0.84$^{a}$ |
| Post-oviposition period (days) | 1.53 ± 0.28$^{ab}$ | 0.91 ± 0.19$^{ab}$ | 0.53 ± 0.13$^{a}$ | 1.59 ± 0.44$^{b}$ |
| Longevity of mated females (days) | 19.84 ± 1.03$^{b}$ | 13.48 ± 0.80$^{a}$ | 10.96 ± 0.72$^{a}$ | 13.50 ± 0.86$^{a}$ |
| Mean no. of eggs/ female | 25.34 ± 2.37$^{a}$ | 43.91 ± 3.84$^{b}$ | 39.43 ± 4.01$^{b}$ | 26.62 ± 2.49$^{a}$ |
| Mean no. of female offsprings | 23 | 38.65 | 33.96 | 23.34 |
| Mean no. of male offsprings | 2.06 | 4.94 | 5.06 | 3.12 |
| Sex ratio of progeny (@&: B&) | 11.15:1 | 7.18:1 | 6.70:1 | 7.47:1 |

*n: number of mites observed; Mean values (± SE obtained by bootstrapping method) with same alphabetical superscript within the row are not significantly different as per Tukey's HSD test (p<0.05)*

Table 3. Demography parameters of *Tetranychus fijiensis* on papaya at different constant temperatures in the laboratory

| Demographic parameters | 20°C; 80-85% | 24°C; 75-80% | 28°C; 70-75% | 32°C; 75-80% |
|---|---|---|---|---|
| Mean Generation Time (days) | 47.30 ± 0.28$^{d}$ | 19.09 ± 0.12$^{c}$ | 16.56 ± 0.14$^{a}$ | 17.93 ± 0.15$^{b}$ |
| Doubling Time (DT) | 10.49 ± 0.07$^{d}$ | 3.65 ± 0.02$^{b}$ | 3.33 ± 0.03$^{a}$ | 4.03 ± 0.04$^{c}$ |
| Net Reproduction Rate (No. of female offsprings/ female/generation) | 29.23 ± 0.09$^{a}$ | 58.55 ± 0.14$^{c}$ | 61.94 ± 0.22$^{d}$ | 37.36 ± 0.14$^{b}$ |
| Gross Reproduction Rate (GRR) | 23.48 ± 0.09$^{a}$ | 39.06 ± 0.17$^{c}$ | 33.75 ± 0.20$^{b}$ | 23.48 ± 0.14$^{a}$ |
| Finite Rate of Increase (No. of female offsprings/ female/ day) | 1.0720 ± 0.000$^{a}$ | 1.2231 ± 0.001$^{c}$ | 1.2592 ± 0.002$^{d}$ | 1.2119 ± 0.002$^{b}$ |
| Intrinsic Rate of Natural Increase (No. of female off-springs/female/day) | 0.0694 ± 0.000$^{a}$ | 0.2003 ± 0.001$^{c}$ | 0.2281 ± 0.002$^{d}$ | 0.1902 ± 0.001$^{b}$ |

*Mean values (± SE obtained by bootstrapping method) with same alphabetical superscript within the row are not significantly different as per Tukey's HSD test (p<0.05)*

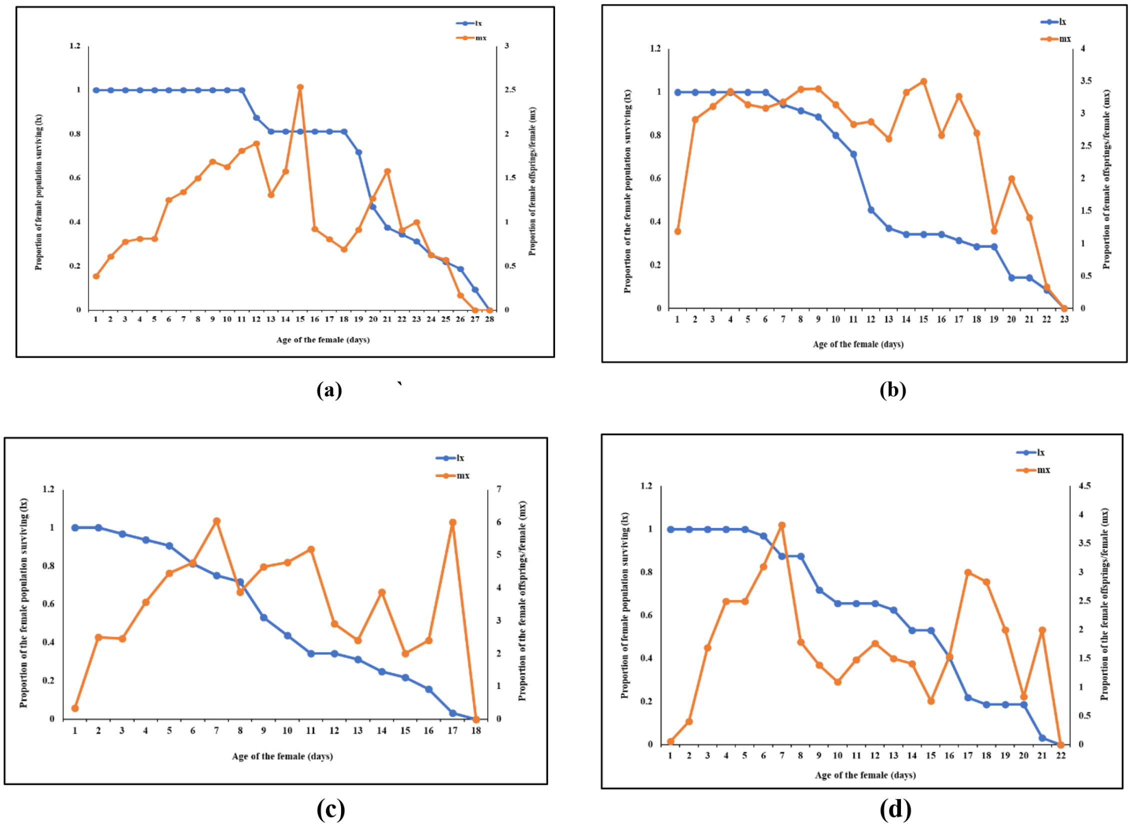


Fig. 2 Age specific survival and fecundity of *Tetranychus fijiensis* on Papaya at different temperature and humidity conditions: (a) 20°C; 80-85% RH, (b) 24°C; 75-80% RH, (c) 28°C; 70-75% RH and (d) 32°C; 75-80% RH

reproduction parameters on commercial papaya cultivars, pre-oviposition duration of females on papaya cultivars ranged from 1.4 to 1.6 days and on cultivar Sunrise, the highest number of eggs (33.9 eggs/female) was recorded, while in the present study, preoviposition of *T. fijiensis* ranged from 0.71-4.25 days and the maximum fecundity of 43.91 eggs/female was recorded. According to Puspitarini *et al*. (2021), *T. urticae* female longevity on papaya was 16.10-17.70 days, while in the present study with *T. fijiensis* it was shorter, 10.96 to 13.48 days (at 24 and 28°C). However, total fecundity was 41.30-43.80 eggs in their study, comparable to the fecundity of 39.43 to 43.91 eggs by *T. fijiensis* in the present study.

As the rearing temperature increased from 20 to 32ºC, the mean generation time and doubling time were found to decrease from 47.30 to 16.56 days. On the contrary, it decreased up to 28ºC and marginally increased thereafter. The higher GRR (61.94) was recorded at 28ºC. The higher $R_0$, 39.06 females/female/ generation was recorded at 28ºC. The chief demography factor $r_m$ was found increased as the rearing temperature increased and it was highest, 0.2281 at 28ºC indicating favourable population progression of *T. fijiensis* on papaya. Also, this chief demographic parameter, ($r_m$) (number of female offsprings/female/day) values of the mite differed significantly across the temperatures. Moro *et al*. (2012) studied the population characteristics of *T. urticae* on leaves of four papaya cultivars and the net reproduction rate was highest (106.7 females/female/ generation) on cultivar Sunrise. It was the highest of 39.06 for *T. fijiensis* in the present study on a popular variety of papaya. Puspitarini *et al*. (2021) recorded the intrinsic rate of natural increase of *T. urticae* as 0.1856 to 0.2220 on papaya cultivars under laboratory conditions (26 ± 2°C; RH 72 ± 2% and photoperiod of L12: D12 h) similar to the $r_m$ values of *T. fijiensis* (0.2003 to 0.2281) at 24 and 28°C.

The biological data of spider mite, *T. fijiensis* generated across various constant rearing temperature and humidity conditions on papaya leaf discs indicated that the optimum temperature range for mite development was 24 to 28°C, while temperature and humidity conditions more favourable for its reproduction and population progression was 28°C and 70 to 75 per cent relative humidity. It may be inferred that this mite species might emerge as an economically important pest of papaya in the event of favourable ambient temperature conditions, necessitating timely control measures or management strategies.

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