Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Biology of the red spider mite, Oligonychus coffeae Nietner in tea under field and laboratory conditions

Aditi Sharma
CSKHPKV, PALAMPUR
Akshita Akshita
akshitasharmasml@gmail.com

CSKHPKV, PALAMPUR
Ajay kumar Sood
CSKHPKV, PALAMPUR

Research Article

Keywords: Oligonychus coffeae, tea, morphometrics, developmental biology, life cycle, laboratory and semi-field conditions

Posted Date: September 21st, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10921799/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Biology of the red spider mite, *Oligonychus coffeae* Nietner in tea under field and laboratory conditions

Aditi Sharma, Ajay K. Sood, Akshita*, Ishani Sharma and Sakshi Sharma
Department of Entomology, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur–176062, Himachal Pradesh, India

*Corresponding author: Akshita
akshitasharmasml@gmail.com

Abstract

The present investigation were conducted to study the morphometrics, developmental biology and annual life cycle of the red spider mite (RSM), *Oligonychus coffeae* a key pest of tea under controlled laboratory (25±1°C, 70±5% RH) and semi-field (near-natural, shaded) conditions at Palampur, Himachal Pradesh. The studies on morphometrics and development biology of red spider mite, *O. coffeae* at 25°C revealed that adults were orange to red, with females being larger (0.32-0.38 mm length and 0.21-0.25 mm breadth) than males (0.23-0.25 mm length and 0.14-0.19 mm breadth). Females had a longer life span (20.9 days) than males (11.1 days) and laid 57-77 eggs. The mite completed 24 generations under laboratory conditions and 22 generations under semi-field conditions annually, with the generation time ranging from 9.0-23.0 days and 11.0-23.0 days, respectively. On the basis of survival and duration, total growth index and immature growth index was the highest during generation 18 (G_{18}) and generation 12 (G_{12}) under laboratory conditions and generation 16 (G_{16}) and generation 21 (G_{21}) under semi-field conditions. The generation period was negatively correlated with temperature (max. and min.) and minimum relative humidity under both laboratory as well as semi field conditions, while stepwise regression model revealed that maximum relative humidity under laboratory (R^2= 0.78) and minimum temperature under semi-field conditions (R^2= 0.91) significantly influenced the generation time of red spider mite.

Keywords *Oligonychus coffeae*, tea, morphometrics, developmental biology, life cycle, laboratory and semi-field conditions

Introduction

Tea is one of the oldest beverages, native to China and is an important plantation crop in the world (Ahmed et al. 2014). The global tea consumption expanded by 2.0 per cent in 2022 in

comparison to 2021 and the world intake of tea increased annually by 3.3 per cent (FAO, 2024). Tea is well known for its stimulant and health benefit properties. India is the second largest tea producer in the world with Assam region being the single largest tea- growing area having a production of 0.75 million tons from 0.32 million hactare area (Bora et al. 2022). The country's tea exports increased from USD 0.83 billion in 2023-24 to USD 0.92 billion in 2024-25 (PIB, Ministry of commerce and industry 2025). There are four types of special teas produced in India *viz.* Assam, Darjeeling, Kangra and Nilgiris, which are exported all over the world (Kachhawa and Kumawat 2018). 'Kangra Tea' has been granted 'Geographical Indication' in 2005 because of its unique aroma and flavour and is second product of India to receive a GI registration with the European Union (EU) during 2023. Kangra tea is exported to foreign countries including France, Germany, Russia and United Kingdom.

Tea crop is infested by a total of 1062 species of insect and mite pests all over the world (Das 1965; Chen and Luo 2025). Forty-nine insect and mite species which are associated with tea belonging to order Hemiptera (18), Lepidoptera (15), Coleoptera (4), Isoptera (4), Diptera (1), Orthoptera (1) and six mite species namely, red spider mite (*Oligonychuscoffeae*Nietner), scarlet mite (*Brevipalpus californicus* Banks), pink mite (*Acaphylla theae* Watt), purple mite (*Calacarus carinatus* Green), yellow mite (*Polyphagotarsonemus latus* Banks) and kanzawa spider mite (*Tetranychus kanzawai* Kishida) were documented by Nadda et al. (2013) in India. Mites are the most serious and persistent pests of tea in all tea growing areas (Hazarika et al. 2009).

In India, out of six mite species namely, red spider mite (*Oligonychuscoffeae*Nietner), scarlet mite (*Brevipalpus californicus* Banks), pink mite (*Acaphyllatheae*Watt), purple mite (*Calacarus carinatus* Green), yellow mite (*Polyphagotarsonemus latus* Banks) and kanzawa spider mite (*Tetranychus kanzawai* Kishida), the red spider mite (RSM), *O. coffeae* is the most important one in India and Himachal Pradesh (Kumari et al. 2012; Kachhawa and Rahman 2013). Its infestation ismainly restricted to the upper surface of the mature leaves as a result of which the leaves appear as reddish bronze in colour and mite infestation in field can be identified from a distance (Roy et al. 2014). Red spider mite causes the damage to tea plants by sucking the sap from the leaves and rarely from the petioles of the plant. It's infestation causes reduction in the photosynthetic capacity of leaves which ultimately leads to wilting of leaves and defoliation as a

result of increase in transpiration and moisture loss (Kachhawa and Kumawat 2018). Bharathi et al. (2022) reported that severe infestation by*O. Coffeae* can lead to crop losses of up to 46 per cent.

Life cycle of RSM consists of five developmental stages namely, egg, larva, protonymph, deutonymph and the adult which has a duration of 10-15 days at a constant temperature of 22°C (Das 1959). The climatic factors have a major impact on the fecundity, incubation period, reproductive capacity, longevity and the development of the RSM. Presence of prolonged dry weather during early stages of flushing season causes an increase in the incidence of RSM whereas in the presence of continuous heavy rains, RSM population flushes out (Roy et al. 2014). Abiotic factors such as temperature and sunshine hours positively influence the RSM population whereas relative humidity and rainfall have a negative effect (Thakur et al. 2024). During the active cropping season (March-October), *O. coffeae* exhibits maximum reproductive potential, with adult females attaining peak fecundity levels of 60-77 eggs per female. Under favorable conditions, the mite completes its developmental cycle rapidly, characterized by a minimum incubation period of 3-5 days and a total life cycle duration of 7-9 days. Because of fast growth and higher reproduction capacity, the mite population increases rapidly in tea fields, leading to severe infestation and damage (Ahmed et al. 2012). Therefore, present investigations were planned to study the annual life cycle of red spider mite in tea.

Materials and methods

The present investigations were undertaken in the Department of Entomology and the farm of the Department of Tea Husbandry and Technology, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, at an altitude of 1290 m amsl (32.0998° N, 76.5446° E) during 2024-25.

Raising of culture

A laboratory culture of red spider mite, *O. coffeae*, was maintained on young tea plants of cv. 'Kangra Asha' raised in plastic pots (diameter 30 cm) throughout the investigations for availability of a large number of mites required for the studies. Pots were filled with a mixture of soil, sand and farmyard manure in a ratio of 1:1:2. Initially, mites were collected from tea plants and their identity was ascertained by microscopic examination following the methodology

suggested by Gupta (1989). After identification, adults were released on potted plants with the help of a camel-hair brush and were allowed to multiply.

Morphometrics and developmental biology

The developmental biology of red spider mite (RSM) was studied on excised leaves of tea at 25°C under laboratory conditions. Adult females (n=10) from the laboratory-raised RSM culture were released on excised leaves. After 24 h, the adult females were removed and the number of eggs laid was counted. The experimentation was replicated five times. Daily observations were recorded on the duration and survival of the egg, larva, protonymph, deutonymph and adult stages. Morphometric measurements of the different developmental stages were also recorded throughout their duration, from initiation to completion, using a stereozoom microscope (Nikon SMZ 800N) with an imaging software (Nikon's NIS-Elements).

Annual life cycle

The annual life cycle of RSM on tea was studied under two sets of conditions, namely, laboratory conditions and semi-open conditions (under the shade of trees), on potted plants. Female adults of RSM were released for egg laying on tagged leaves for 24 h. The females were then removed and the number of eggs deposited was counted; the experimentation was replicated five times. Observations were recorded on the duration of the egg stage as well as the number of eggs hatched. The duration from egg hatching to adult formation was also recorded to work out the generation time, and the number of adults formed was counted to work out generation survival. The next generation was initiated after two days (keeping in consideration the pre-oviposition period) when 50 per cent of individuals of the previous generation had transformed to the adult stage. The studies were made throughout the year. Based on the duration and survival, growth indices were worked out as used by Kaushik (2023):

Immature Growth Index (IGI) = Immature survival (%) / Total immature period (days)

Total Growth Index (TGI) = Adult formation (%) / Total developmental period (days)

Population buildup

Observations on population buildup of RSM were recorded under two sets of farming situations, i.e., organic tea plantations (University tea garden) and conventionally maintained tea gardens in

the vicinity of the University, at 15-day intervals from May 2024 to August 2025. For this, 50 tea leaves each from the upper and middle canopy were collected and brought to the laboratory for microscopic examination. The number of eggs and the motile stages of the mites were counted under a stereozoom microscope (Nikon SMZ 800N) on the upper and lower surfaces of the leaves. Observations were also recorded on the prevalent natural enemies of RSM. Based on the total number of leaves observed, per cent leaf infestation was worked out as follows:

Leaf infestation (%) = (Number of leaves with mites / Total number of leaves observed) × 100

Based on the mite population count and leaf infestation, the infestation index as suggested by Bhalla and Verma (1991) and used by Thakur and Sood (2019), was determined:

Infestation index = (Mean mite population × Leaf infestation (%)) / 100

Also relationship between mite population and abiotic weather factors namely, temperature, relative humidity, rainfall and sunshine hours was also worked out. For this, daily meteorological data was procured from the Agro-meteorology Section, Department of Agronomy, CSK HPKV, Palampur. A regression model using step analysis was also deployed for estimating the effect of environmental factors on red spider mite population and generation time.

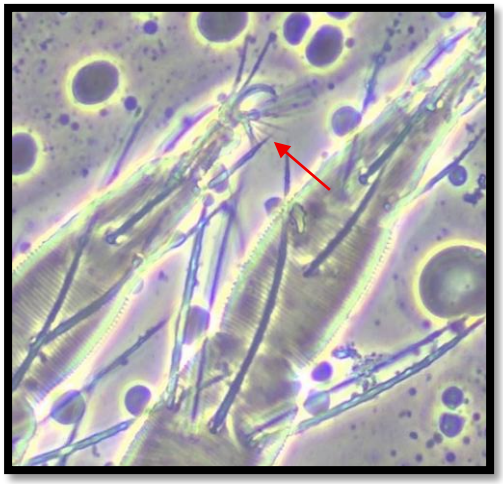
Results

Morphometrics and developmental biology

Developmental biology and morphometrics of red spider mite, *O.coffeae* was studied at constant temperature (25±1°C) and relative humidity(70±5%). The findings are being presented in Table 1 – 3.

Taxonomic characters for identification

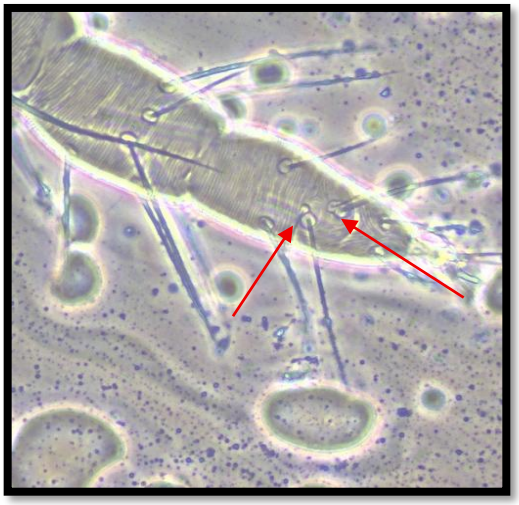
The mite possessed a claw-like empodium bearing proximoventral hairs (Fig.1a). Females had whip-like chelicerae with two sets of duplex setae on the distal end of tarsus I (Fig.1b, c). The aedeagus of the male was bent at an angle of 90°, and the female genital opening bore characteristic cuticular striations (Fig. 1e, f).



a) Empodium with proximoventral hairs (20X)



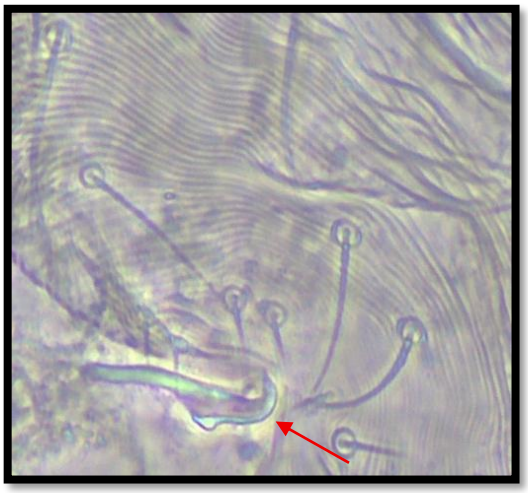
b) Whip like chelicerae in female (20X)



c) Tarsus duplex setae (20X)



d) Thumb claw projection (40X)



e) Male Aedeagus (40X)



f) Cuticular striations around genital opening of female (40X)

Fig. 1 Identification characters of *Oligonychus coffeae*: (a) empodium with proximoventral hairs (b) whip-like chelicerae in female (c) tarsus I duplex setae (d) thumb-claw projection (e) male aedeagus (f) cuticular striations around the female genital opening

Morphometrics and developmental biology

Eggs: Females deposited eggs singly primarily on the upper surface of leaves. The freshly laid eggs were blood red to chrome red, but before hatching they changed to light orange. A filamentous process arises from the upper pole which bends in the form of a hook after one day of egg laying. The length and breadth of eggs ranged between 0.11 to 0.14 mm (average 0.13 mm) and 0.11 to 0.13 mm (average 0.12 mm), respectively (Table 1). The mean duration of the egg stage was 4.6 ± 0.27 days; the survival percentage was the highest (89.0 ± 0.41) in comparison to other stages (Table 1).

Larva: The freshly emerged six-legged larvae were round in shape and yellowish orange in colour, their colour changing to pale orange subsequently. The length of larvae ranged from 0.10 to 0.14 mm with a mean of 0.12 mm, and mean breadth of 0.11 mm (range 0.10 to 0.11 mm) (Table 1). The mean duration of the larval stage was 1.9 ± 0.24 days with a survival percentage of 85.9 (Table 2).

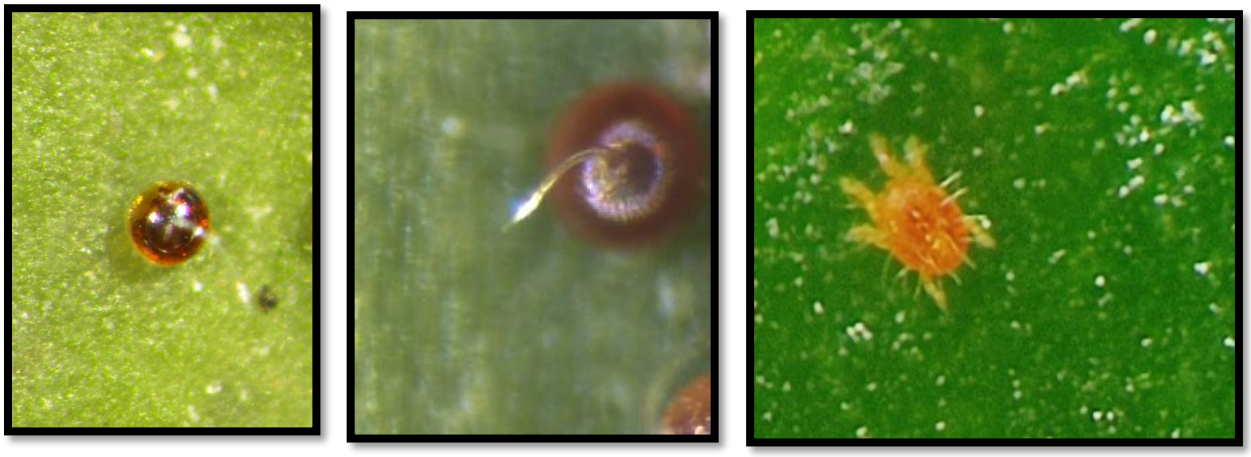
Protonymph: There were two nymphal stages in *O. coffeae*. The freshly hatched protonymphs were pale crimson in colour and carried four pairs of legs; the shape of the body was somewhat oval. The mean length of the protonymph was 0.16 mm, while breadth ranged from 0.12 to 0.14 mm (average 0.13 mm) (Table 1). This stage lasted for 2.6 ± 0.16 days, with a survival of 84.0 per cent (Table 2).

Deutonymph: There was very little difference between the protonymph and deutonymph except in size; the sexes could be differentiated at this stage, with females slightly bigger than males. The mean length of the female deutonymph was 0.24 mm (range 0.21 to 0.26 mm), while breadth ranged from 0.14 to 0.18 mm with a mean of 0.16 mm (Table 1). The duration of the female deutonymphal stage lasted for 2-3 days with a mean of 2.4 days, and a survival percentage of 77.7 was recorded during this stage (Table 2).

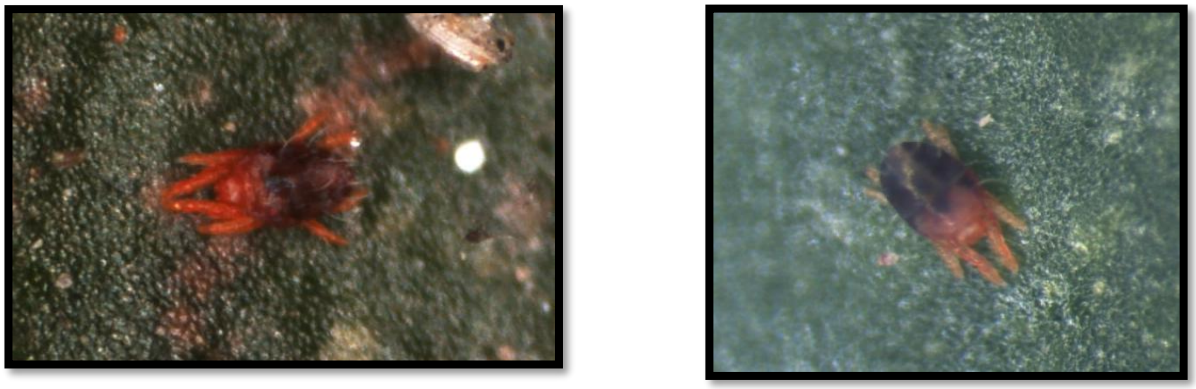
Adult: *Male*: The males were slimmer, the abdomen being much narrower and almost tapering to a point. Their length ranged from 0.23 to 0.25 mm with a mean of 0.24 mm while their

breadth ranged from 0.14 to 0.19 mm (average = 0.18 mm) (Table 1).The male longevity ranged from 10-12 days (mean: 11.1 ± 0.28 days). A survival of 42. 9 per cent was recorded (Table 2).

***Female*:** The females differed from the males in size and body shape and were bigger in size. The females were elliptical with abdomen broadly rounded at its posterior end. The body length of the females ranged between 0.32 to 0.38 mm with an average of 0.35 mm with a breadth of 0.22 mm (range: 0.21 to 0.25 mm) (Table 1). Female on an average lived for 20.9 days (Table 2). Before initiating egg laying, the females observed a pre-ovipositionperiod of 1-2 days (mean: 1.6 days). During the oviposition period of 17.6 days, the females deposited on an average 67.1 eggs/female. A post-oviposition period of 1.7 days was also observed. The female longevity ranged from 17-22 days (mean: 20.9 days) (Table 2). The survival percentage was observed to be 55.0 (Table 2).



a) Egg (40X) **b) Larva (40X)**



c) Protonymph (40X) **d) Deutonymph (20X)**



e) Adult (Female and male) (40X)

Fig.2 Developmental stages of *Oligonychus coffeae*

Table 1 Morphometrics of different developmental stages of *Oligonychus coffeae* on tea

Developmental stage		Length (mm)		Breadth (mm)	
		Mean ± SE	Range	Mean ± SE	Range
Egg		0.13± 0.003	0.11-0.14	0.12 ± 0.003	0.11-0.13
Immature stages					
Larva		0.12 ± 0.004	0.10-0.14	0.11 ± 0.002	0.10-0.11
Protonymph		0.16 ± 0.006	0.12-0.19	0.13 ± 0.003	0.12-0.14
Deutonymph	Male	0.19 ± 0.003	0.18-0.20	0.16 ± 0.004	0.13-0.17
	Female	0.24 ± 0.005	0.21-0.26	0.16 ± 0.004	0.14-0.18
Adult	Male	0.24 ± 0.003	0.23-0.25	0.18± 0.006	0.14-0.19
	Female	0.35 ± 0.005	0.32-0.38	0.22 ± 0.004	0.21-0.25

Table 2 Developmental biology of *Oligonychus coffeae* at 25°C

Developmental stage	Mean± S.E.	Range
Egg		
Incubation period (days)	4.6 ± 0.27	4 - 6
Hatchability (%)	89.0 ± 0.41	87.7- 90.9
Immature stages		
Larva (days)	1.9 ± 0.24	1 - 3
Survival (%)	85.9 ± 0.49	84.5-87.3
Protonymph (days)	2.6 ± 0.16	2 - 3
Survival (%)	84.0 ± 0.67	81.0-86.9
Deutonymph (days)		
Male	1.5 ± 0.16	1- 2
Female	2.4 ± 0.16	2 - 3
Survival (%)	77.7 ± 0.83	73.5-80.4
Total developmental period (Egg to Adult formation) Duration (days)		
Male	10.6 ± 0.26	8 - 14
Female	11.5± 0.37	9- 15
Survival (%)		
Male	42.9 ± 0.73	40.0-46.2

Female	55.0± 0.69	52.4-57.7
Adult		
Male longevity (days)	11.1± 0.28	10- 12
Female longevity (days)	20.9± 0.34	17 – 22
Pre-oviposition period (days)	1.6± 0.16	1 – 2
Oviposition period (days)	17.6± 0.27	15-18
Post-oviposition period (days)	1.7± 0.17	1 – 2
Fecundity (Number of eggs/ female)	67.1± 2.21	57 – 77

Annual life cycle: Comparison of laboratory and semi-field conditions

Mites reared on potted tea plants completed 24 generations from September 13, 2024 to September 6, 2025 in a year under laboratory conditions (Table 3). The duration of the life cycle varied from 9.0 to 23.0 days, the minimum corresponding to generations occurring during June-July 2025 (G18 and G19) with a prevailing mean maximum temperature of 30.3 and 27.8°C. Generation time was prolonged to 18.0-23.0 days in the generations occurring during the winter season, and duration was maximum during generations G8 and G9, corresponding to January-February 2025, with a maximum temperature of 20.4 and 21.0°C. The minimum duration of the life cycle during June-July 2025 (G18 and G19) was significantly different from the maximum duration during January-February 2025 (G8 and G9). Per cent hatchability and generation survival were maximum during the generation occurring in June-July 2025 (G19) and minimum during January-February 2025 (G9).

Under semi-field conditions, *O. coffeae* completed 22 generations in a year (Table 3), with generation time of 11.0 to 27.0 days, the minimum corresponding to generations occurring during June-July (G16 and G17) experiencing a mean maximum temperature of 28.6 and 25.3°C, and the maximum to the generation occurring between December 5-31, 2024, having a mean maximum temperature of 17.0°C. The duration of the life cycle was prolonged under semi-field conditions between mid-November and mid-March (G5-G9) as compared with laboratory conditions, with the maximum temperature ranging from 16.8-20.5°C; the minimum duration during June-July 2025 (G16 and G17) was significantly different from that of November 2024-

March 2025 (G5-G9). Per cent hatchability and generation survival were maximum during the generation of June-July 2025 (G17) and minimum during the generation of December 2024 (G6).

Table 3 Comparison of the annual life cycle of *Oligonychus coffeae* on tea under laboratory and semi-field conditions during 2024-25

Generation	Period - laboratory conditions	Egg to adult duration (days)	Generation survival (%)	Period - semi-field conditions	Egg to adult duration (days)	Generation survival (%)
G1	Sept 13-Sept 23, 2024	11.0	71.1	Sept 13-Sept 25, 2024	13.1	67.0
G2	Sept 26-Oct 7	12.0	68.2	Sept 28-Oct 10	13.0	61.7
G3	Oct 10-Oct 22	12.5	62.8	Oct 13-Oct 26	14.0	54.4
G4	Oct 25-Nov 5	12.0	56.6	Oct 29-Nov 11	14.0	47.6
G5	Nov 8-Nov 25	18.0	48.3	Nov 14-Dec 2	19.2	36.1
G6	Nov 28-Dec 15	18.0	40.6	Dec 5-Dec 31	27.0	25.5
G7	Dec 18-Dec 31	14.0	40.5	Jan 3-Jan 25, 2025	24.0	29.4
G8	Jan 3-Jan 25, 2025	23.0	32.7	Jan 28-Feb 18	23.6	27.8
G9	Jan 28-Feb 19	23.0	30.9	Feb 21-Mar 12	20.2	27.3
G10	Feb 22-Mar 13	20.0	29.9	Mar 15-Mar 30	16.0	29.7
G11	Mar 16-Mar 30	14.8	39.7	Apr 2-Apr 14	12.5	48.8
G12	Apr 2-Apr 12	10.8	57.1	Apr 17-Apr 29	13.0	50.6
G13	Apr 15-Apr 25	11.0	57.9	May 2-May 13	12.0	53.1
G14	Apr 28-May 7	10.0	72.0	May 16-May 27	12.0	54.6
G15	May 10-May 19	10.2	70.3	May 30-Jun 10	12.0	56.8
G16	May 22-May 31	10.0	74.7	Jun 13-Jun 23	11.0	63.8
G17	Jun 3-Jun 11	9.4	79.2	Jun 26-Jul 6	11.0	67.2
G18	Jun 14-Jun 22	9.0	76.4	Jul 9-Jul 20	12.1	65.3
G19	Jun 25-Jul 3	9.0	78.3	Jul 23-Aug 3	12.0	65.7
G20	Jul 6-Jul 16	11.3	72.8	Aug 6-Aug 17	12.3	64.4
G21	Jul 19-Jul 29	11.0	69.2	Aug 20-Aug 31	12.0	66.9
G22	Aug 1-Aug 11	11.0	73.1	Sept 3-Sept 13	13.0	65.6
G23	Aug 14-Aug 24	10.5	69.1	-	-	-
G24	Aug 27-Sept 6	11.0	71.2	-	-	-
CD (P=0.05)	**-**	**1.15**	**0.87**	**-**	**0.98**	**1.00**

Growth indices

On the basis of duration and survival, the immature growth index (IGI) and total growth index (TGI) were highest during generation 18 (G18) and generation 12 (G12) under laboratory conditions and generation 16 (G16) and generation 21 (G21) under semi-field conditions and were lowest during the winter generations (G8-G9, laboratory; G6-G7, semi-field.

Relationship of generation time with abiotic factors

It was evident that the duration of generation was influenced by temperature, as indicated by the 'r' value (Table 4). Generation time was negatively correlated with maximum and minimum temperature and with minimum relative humidity under both laboratory and semi-field conditions. The regression model worked out indicated that maximum relative humidity under laboratory conditions (Y = -1.14 + 0.78 RHmax; R2 = 0.78) and minimum temperature under semi-open conditions (Y = 7.67 + 0.91 T min; R2 = 0.91) significantly influenced the generation time of *O. coffeae* (Table 5).

Table 4 Relationship between abiotic factors of the environment and generation time of *Oligonychuscoffeae* in tea under laboratory and semi-field conditions

Abiotic factor		Correlation Coefficient (r)	
		Laboratory conditions	Semi-field conditions
Temperature (°C)	Maximum	-0.915**	-0.896**
	Minimum	-0.853**	-0.928**
Relative humidity (%)	Maximum	-0.295^{NS}	-0.297^{NS}
	Minimum	-0.422*	-0.474*

*Significant at P=0.05, **Significant at P=0.01,NS= Non-significant

Table 5 Step-wise regression model for estimating the generation time of red spider mite, *Oligonychus coffeae* population in tea

Mite rearing situation	Regression model (Y)	Adj R^2
Laboratory conditions	-1.14 + 0.78 RH_{max}	0.78
Semi-field conditions	7.67 + 0.91 T_{min}	0.91

Discussion

Females of *O. coffeae* were observed to lay eggs singly, mostly on the upper surface of tea leaves. The newly deposited eggs were blood red to chrome red in colour and turned to light orange before hatching. After one day, a filamentous projection emerged from the upper pole of the egg and bent to form a hook-like structure. The eggs measured between 0.11-0.14 mm in length (mean 0.13 mm) and 0.11-0.13 mm in breadth (mean 0.12 mm); the incubation period was 4.6 days at 25°C. The measurements recorded are in close proximity to those observed by Das (1959), who reported eggs to be 0.11 mm in diameter with a mean duration of 5 days at 25.6°C.

The newly hatched, six-legged larvae were round in shape, exhibiting a yellowish-orange coloration and turning to pale orange with age. The length of the larval body varied between 0.10 and 0.14 mm, while breadth varied from 0.10 to 0.11 mm; average larval duration was 1.9 days. The findings of Das (1959) on the morphometrics of the larval stage are close to the present observations, who reported an average length of 0.16 mm. Larval duration recorded in the present investigation was slightly shorter than that reported by Chakrabotry et al. (2015) (2.45 days at 25.5°C); the variation observed can be attributed to differences in host-plant quality under the two situations. *O. coffeae* passed through two nymphal stages. The newly hatched protonymphs were pale crimson in colour and possessed four pairs of legs, their bodies unevenly oval in shape. On average, protonymphs measured 0.16 mm in length and 0.13 mm in breadth; this stage typically lasted 2-3 days, with an average duration of 2.6 days. The findings of Das (1959) on the morphometrics of the mite are in conformity with the present findings, who observed the protonymph to have an average length of 0.20 mm and width of 0.13 mm, and the duration recorded is in close conformity with Chakrabotry et al. (2015), who observed that the protonymph took 2.37 days at 25.5°C.

There was very little difference between a protonymph and a deutonymph except in size; the sexes could be differentiated at this stage, with females slightly bigger than males, measuring 0.24 mm in length and 0.16 mm in breadth. The deutonymphal stage lasted 2-3 days. These findings on morphometrics are in conformity with Das (1959), who observed the deutonymph to have an average length of 0.26 mm and average width of 0.16 mm, while the duration of the deutonymph recorded is in close proximity to Chakrabotry et al. (2015), who observed it to be 2.52 days at 25.5°C.

Females differed from males in size and body shape and were bigger; they were elliptical, with the abdomen broadly rounded at the posterior end. Body length of females ranged between 0.32 and 0.38 mm with an average of 0.35 mm and a breadth of 0.22 mm. Females on average lived for 20.9 days; before initiating egg laying, females had a pre-oviposition period of 1-2 days (mean 1.6 days), during the oviposition period of 15-18 days they deposited 57-77 eggs (mean 67.1 eggs/female), and a post-oviposition period of 1-2 days (mean 1.5 days) was also observed. The observations recorded by Das (1959) on body size and duration of the female are in line with the present studies, and the durations of the pre-oviposition, oviposition and post-oviposition periods recorded are comparable to those reported by Chakrabotry et al. (2015), who observed pre-oviposition, oviposition and post-oviposition periods of 1.63, 15.78 and 1.73 days, respectively, at 25.5°C.

Males were slimmer, the abdomen being much narrower and almost tapering to a point; their length ranged from 0.23 to 0.25 mm with a mean of 0.24 mm, while breadth ranged from 0.14 to 0.19 mm (average 0.18 mm). Male longevity ranged from 10-12 days (mean 11.1 ± 0.28 days). The present findings on body size and duration of the male are in accordance with those of Das (1959), who observed it to be 0.27-0.31 mm in length and 0.14-0.16 mm in width, with an average duration of 12 days.

In the present study, *O. coffeae* completed 24 generations under laboratory conditions and 22 generations under semi-field conditions. The variation in the number of generations under laboratory and semi-open conditions can be attributed to differences in temperature. It was evident that the duration of generation was influenced by temperature, as indicated by the 'r' value; more stable temperature and shorter egg duration in the laboratory favoured faster development of the mite, whereas fluctuations under semi-field conditions slowed the growth of the mite and resulted in a lesser number of generations. The regression model worked out indicated that maximum relative humidity under laboratory conditions and minimum temperature under semi-open conditions significantly influenced the generation time of *O. coffeae*. Earlier studies by Hu and Wang (1965) and Roy et al. (2014) also reported about 22 overlapping generations under favourable conditions. The findings on the influence of weather factors on generation time of the mite under laboratory conditions derive support from Das and Das (1967) and Das et al. (2012), who observed that higher relative humidity accelerated development of the

mite as compared with lower relative humidity, which increased the developmental period of the immature stages. Under semi-field conditions, the influence of minimum temperature on the life cycle of the mite, as observed by Haque et al. (2008), resulted in prolongation of developmental duration, which fully supports the findings of the present study.

Conclusion

The present study provides an integrated, comparative account of the biology of *Oligonychus coffeae* under laboratory and field conditions in the western Himalayan tea belt of Himachal Pradesh. Development from egg to adult was completed in 10.6-11.5 days at 25°C, with females outliving males by nearly two-fold and laying an average of 67 eggs. The mite completed more generations under stable laboratory conditions (24) than under semi-field conditions (22), with generation time governed principally by relative humidity in the laboratory and by minimum temperature in the semi-field situation. In the field, *O. coffeae* bred continuously through the year, with population buildup driven predominantly by temperature and peaking in May and October in both conventional and organic tea plantations, while its natural enemy complex - including the first record of *Amblyseius adhatodae* from tea in Himachal Pradesh - was confined to the organically managed system. These findings define the thermal and seasonal windows within which *O. coffeae* populations are likely to increase most rapidly, providing a biological basis for the timely deployment of monitoring and management measures, including conservation of naturally occurring predators in organically managed tea.

Acknowledgements

The authors thank the Department of Entomology and the Department of Tea Husbandry and Technology, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, for providing the facilities and field sites used in this study.

Declarations

Funding No external funding was received for this study.

Conflicts of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or vertebrate animals performed by any of the authors.

Data availability The datasets generated and analysed during the present study are available from the corresponding author on reasonable request.

References

Ahmed M, Mamun MSA, Hoque MM, Chowdhury RS (2012) Influence of weather parameters on red spider mite - a major pest of tea in Bangladesh. J Sci Technol 19:47-53

Ahmed S, Griffin TS, Kraner D, Schaffner MK, Sharma D, Hazel M, Leitch AR, Orians CM, Han W, Stepp JR, Robbat A (2014) Environmental factors variably impact tea secondary metabolites in the context of climate change. Front Plant Sci 5:100

Bhalla OP, Verma AK (1991) Integrated pest management studies on cauliflower and cabbage in temperate regions of Himachal Pradesh. Final report, ICAR Research Scheme, Department of Entomology, Dr YSP University of Horticulture and Forestry, Nauni, Solan

Bharathi NS, Rabeesh TP, Mahendran P, Sujatha K (2022) Toxicity of commonly using pesticides against the eggs and adults of *Helopeltis theivora* (Hemiptera: Miridae) and *Oligonychus coffeae* (Acarina: Tetranychidae) in tea. J Entomol Res 46:1063-1068

Bora P, Bora LC, Bhuyan RP, Hashem A, Abd-Allah EF (2022) Bioagent consortia assisted suppression in grey blight disease with enhanced leaf nutrients and biochemical properties of tea (*Camellia sinensis*). Biol Control 170:104907

Chakrabotry G, Roy D, Sarkar PK (2015) Effect of temperature on tea red spider mite *Oligonychus coffeae* Nietner and its management using cyflumetofen 20SC. Bioscan 10:1093-1098

Chen Z, Luo Z (2025) Management of insect pests on tea plantations: safety, sustainability and efficiency. Annu Rev Entomol 70:359-377

Das GM (1959) Bionomics of the tea red spider mite, *Oligonychus coffeae* (Nietner). Bull Entomol Res 50:265-274

Das GM (1965) Pests of tea in North East India and their control. Tocklai Experimental Station, Jorhat, p 115

Das GM, Das SC (1967) Effect of temperature and humidity on the development of tea red spider mite, *Oligonychus coffeae* (Nietner). Bull Entomol Res 57:433-436

Das P, Saikia S, Kalita S, Kanta HL, Kumar DS (2012) Effect of temperature on biology of red spider mite *Oligonychus coffeae* on three different TV clones. Indian J Agric Sci 82:255

FAO (2024) Current and global market situation and medium-term outlook. https://openknowledge.fao.org/handle/20.500.14283/cd0688en

Fernandes IAA, Maciel GM, Bortolini DG, Pedro AC, Rubio FTV, Carvalho KQ, Haminiuk CWI (2023) The bitter side of teas: pesticide residues and their impact on human health. Food Chem Toxicol 179:113955

Gupta SK (1989) Mites occurring on tea plants in India with a key for their identification. In: Channabasavanna GP, Viraktamath CA (eds) Progress in acarology. Oxford and IBH, New Delhi, pp 177-182

Gurusubramanian G, Rahman A, Sarmah M, Ray S, Bora S (2008) Pesticide usage pattern in tea ecosystem, their retrospects and alternative measures. J Environ Biol 29:813-826

Haque M, Wahab A, Naher N, Begum A (2008) Developmental stages of red spider mite, *Oligonychus coffeae* Nietner (Acari: Tetranychidae) infesting rose. Univ J Zool 26:71-72

Hazarika LK, Bhuyan M, Hazarika BN (2009) Insect pests of tea and their management. Annu Rev Entomol 54:267-284

Hu CC, Wang LC (1965) A study on the annual life cycles of the tea red spider mite, *Oligonychus coffeae* Nietner. Bull Pinchen Tea Exp Stn 23:14

Kachhawa D, Rahman S (2013) Factors influencing incidence of red spider mite of tea, *Oligonychus coffeae* (Nietner) in Assam. J Plant Prot Sci 5:33-39

Kaushik E (2023) Studies on novel approaches for the management of greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) on tomato under protected environment. PhD Thesis, Department of Entomology, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, p 41

Kumari A, Kumar A, Tewary DK, Nadda G (2012) Field evaluation of bifenazate (Acramite 50WP) for control of tea mites. Munis Entomol Zool 7:780-786

Nadda G, Reddy SE, Shanker A (2013) Insect and mite pests of tea and their management. Sci Tea Technol 5:317-333

PIB Ministry of Commerce and Industry (2025) Cumulative exports (merchandise and services) during April-March 2024-25. https://pib.gov.in

Roy S (2019) Detection and biochemical characterization of acaricide resistance in field populations of tea red spider mite, *Oligonychus coffeae* (Acari: Tetranychidae) in Assam tea plantation of India. Int J Acarol 45:470-476

Roy S, Muraleedharan N, Mukhopadhyay A (2014) The red spider mite, *Oligonychus coffeae* (Acari: Tetranychidae): its status, biology, ecology and management in tea plantations. Exp Appl Acarol 63:431-463

Thakur S, Sood AK (2019) Lethal and inhibitory activities of natural products and biopesticide formulations against *Tetranychus urticae* Koch (Acarina: Tetranychidae). Int J Acarol 45:381-390

Thakur SL, Sood AK, Sharma PK (2024) Population buildup of red spider mite, *Oligonychus coffeae* N. in tea. Himachal J Agric Res 50:133-136