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Effects of Temperature and Relative Humidity on the Life Table of *Pieris brassicae* (Linnaeus) (Lepidoptera: Pieridae) on Cauliflower

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ABSRACT

Pieris brassicae, the large cabbage white butterfly, has emerged as a serious pest of cauliflower in India, considering basic studies on its development and survival at different temperatures (17.5 ± 7.5, 20 ± 10, 22.5 ± 12.5, 25 ± 15, 27.5 ± 17.5, 30 ± 20 and 32.5°C ± 22.5°C) at constant Relative Humidity (RH) of (65 ± 5%) level and photoperiod of 14:10 (Light: Dark) to ascertain optimal population growth during 2021 and 2022. A life table was constructed using temperature, humidity and photoperiod. The immature stages duration was 92.61 ± 0.99 days at 17.5°C ± 7.5°C and 65 ± 5% RH, but shortened to 25.25 ± 0.35 days at 32.5℃ ± 22.5℃ at same RH. Adult longevity of male and female was 12.30 ± 0.07 and 14.12 ± 0.04 days at 17.5°C ± 7.5°C and 65% RH, but 4.44 ± 0.06 and 5.80 ± 0.05 days at 32.5°C ± 22.5°C at the same RH. Fecundity was at its maximum (257.06 ± 1.46 eggs/female) at 32.5°C ± 22.5°C and 65% RH, with lower fecundity at 17.5°C ± 7.5°C. The net reproductive rate (Ro) and finite rate of increase (λ) were maximum 25.73 females/female/generation and 1.1184 fold per female per day, respectively at 32.5°C ± 22.5°C and 65% RH suggesting that the population would increase more than 25.73 times per generation and 1.1184 times per female per day. The rates of increase at higher alternating temperatures were generally lower than at 17.5°C ± 7.5°C. The intrinsic rate of increase (rm) was the highest (0.11195) at 32.5°C ± 22.5°C. Our results suggest that 32.5°C ± 22.5°C and 65% RH is the most favorable temperature and RH combination for the optimal population growth of P. brassicae. Our study also predicts the expansion of this pest to other parts of the world in which the average temperature equals to 32.5°C ± 22.5°C with 65% RH.

Keywords: Net reproductive rate (Ro), Development, Cauliflower, Temperature, Survival

INTRODUCTION

Cauliflower (*Brassica oleracea* var. *botrytis* L.) belongs to family Brassicaceae is an important vegetable crop in India. The cauliflower name is derived from Latin words *Caulis* (cabbage) and *Floris* (flower) var. *botrytis* (budding) with chromosome no: 2n=18 [1]. Cauliflower originated in Northeast Mediterranean region mainly in island of Cyprus from where it moved to other areas like Egypt, Italy, Spain, Syria, Turkey and Northwestern Europe [2]. In India, cauliflower occupied area of 459 thousand ha with a production of 8800 thousand tonnes with an average yields of 19.17 tonnes/ha [3]. Cauliflower is a major cole crop of Punjab grown almost throughout the year [4]. In Punjab, it was cultivated on an area of 14.97 thousand ha with a production of 279.67 thousand tones and with an average yield of 18.68 tones/ha [5]. Cauliflower can grow in all types of soils from light soils to clay loam but is sensitive to high acidity and the optimum pH for maximum production is 5.5 to 6.0 and it requires 15℃-20℃ for temperate cultivars and 35℃ for tropical cultivars [6].

Cauliflower is abundant in nutritional value as it is rich in vitamins, minerals (calcium magnesium, iron and phosphorus) and carbohydrates [7-9]. This vegetable is also fat-free as well as low in sodium content which ultimately helps in weight loss. This winter vegetable is also rich in numerous phytochemicals (sulforaphane, glucosinolates, carotenoids, Indole-3-carbinol) which are beneficial to human health and limit the growth of cancerous cells [10].

Life tables play a major role in pest management because it describes the growth, survival and fecundity. It provides the format for recording all the population changes in the life cycle and quantifies the mortality in the population of the insect. The life table is of two types: Cohort or generation life table and period life tables. The cohort or generation life table summarizes the age-specific mortality experience of a given birth cohort for its life and the period life table summarizes the age-specific mortality conditions pertaining to a given or short period of time. Through life table studies, determination of the most vulnerable stage for time-based application of insecticides for insect pest control can be known [11].

Various weather factors play a key role for the incidence and development of insect pests and understanding of these factors is vital to the population dynamics study, predicting pest outbreaks and in the development of pest management strategies. Natural mortality factors are important determinant of species population dynamics and knowledge of these factors help in devising improved management approaches for insect pests [12]. Life tables play a major role in pest management because it provides description on the growth, survival and fecundity.

MATERIALS AND METHODS

Rearing technique of cabbage butterfly, P. brassicae

The larvae of *P. brassicae* were collected from an unsprayed field of cauliflower crop from entomological research farm, PAU, Ludhiana. Larvae were raised in petri dish of 90 mm diameter with fresh leaves. The food was changed every morning until pupation. When the larvae of the fifth instar were ready to pupate, they were transferred to cages and the cages were covered properly to observe the pupal survival. The individual male and female pupae were released in a cage (60 cm x 40 cm) with a plant in a pot for mating and egg lying. For feeding the adults, a cotton swab dipped in a 5 per cent honey solution was also hung in the cage. The freshly laid eggs were collected daily and were used for further studies.

Effect of alternating temperature and humidity on various developmental stages of P. brassicae in cauliflower

This laboratory experiment consists of seven different temperature and RH combinations required the photoperiod (Light: Dark) ratio was kept constant (Table 1).

Table 1. Treatments comprising constant photoperiod and relative humidity at alternating temperatures

Treatments	Temperature (Max: Min)	Photoperiod (Light: Dark)	Relative humidity (%)
T1	17.5:7.5°C	14:10 hrs	65 ± 5
T2	20:10°C	14:10 hrs	65 ± 5
T3	22.5:12.5°C	14:10 hrs	65 ± 5
T4	25:15°C	14:10 hrs	65 ± 5
T5	27.5:17.5°C	14:10 hrs	65 ± 5
T6	30:20°C	14:10 hrs	65 ± 5
T7	32.5:22.5°C	14:10 hrs	65 ± 5

Freshly laid eggs taken from the laboratory culture were kept in a petri dish at 25 eggs per dish with 4 replications (Plate 4) at selected temperature till hatching. Neonates hatching (Plate 5) from eggs was transferred to petri dishes of 90 mm diameter and reared on leaf discs of 4 cm diameter of cauliflower and kept till the pupal stage. Pupae were kept in cages at 5 pupae per cage. Male and female adults emerging from pupae were segregated based on morphological features. Five pair of adults was released in a wooden cage (60 cm x 40 cm) for mating and egg-laying. A cotton swab dipped in honey solution was hung in cages daily. The cages were used for preventing the escape of adults and the eggs laid on the leaves by the females were counted.

Observations recorded

The eggs kept in each treatment were examined after every 12 hours to record the duration of egg stage till hatching. Larvae were examined daily to record the larval period. Similarly, pupae and adults were observed daily to examine the pupal period, adult pre-oviposition, oviposition, post-oviposition period and adult longevity. Mean fecundity per female was also recorded at different alternating temperatures.

Statistical analysis

The significant difference between treatments with regard to egg, larval, pupal and adult stage duration along with fecundity of *P. brassicae* were analyzed using CPCS1 software with completely randomized design.

Effect of alternating temperature and humidity on life history stages of P. brassicae in cauliflower

The age specific life Table of *P. brassicae* on cauliflower were constructed from data recorded from the experiments under laboratory conditions at seven temperature and RH combinations as depicted in Table 1.

Observations recorded: The data were recorded on the various parameters like:

lx=Age specific survivorship for female adults

mx=Age schedule for female birth

x=Pivotal age

The data on the development, survival and reproduction of *P. brassicae* at various levels of temperature and relative humidity were used to compute following parameters given in Table 2 as per Atwal and Bains is as follows:

Table 2. Various life table parameters and their formula

Life table parameter	Formula
Net reproductive rate	$R_0=\sum lxmx$
Mean length of generation	$T=\sum xlxmx/R_0$
Intrinsic rate of increase	$r_m=\log_e R_0/T$
Finite rate of increase	$\lambda=e^{rm}$
Weekly multiplicative rate	λ^7
Doubling time	$DT=\text{Log } 2/\text{Log}\lambda$
Annual rate of increase	$A.R.I.=R_0^{365/T}$

To determine the precise value of rm, graphical method and following formula as per Southwood was followed:

$$\sum e^{7-rmx}.\ lxmx=1097$$

The graph was plotted by taking this value on x-axis and value of r_m on y-axis. The points were plotted against calculated approximate value of r_m and two other r_m values on its lower and upper side and these were joined by a line. In the above equation, two values of r_m were substituted and then the precise value of r_m was worked out by transpolation.

RESULTS AND DISCUSSION

The biology of *P. brassicae* was studied at seven alternating temperatures (Max 14 h: Min 10 h) ranging from 17.5:7.5 to 32.5:22.5ºC at constant RH of 65 ± 5 percent.

Egg stage

During 2021, the mean duration of egg stage of *P. brassicae* at various alternating temperatures (Max 14 h : Min 10 h) of

17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5ºC, at a constant RH (65 ± 5%), was 14.26 ± 0.05, 12.62 ± 0.08, 9.47 ± 0.05, 8.79 ± 0.08, 6.94 ± 0.04, 4.88 ± 0.07 and 4.45 ± 0.09 days, respectively (Table 3). Similarly, during 2022, it was 16.82 ± 0.04, 13.62 ± 0.07, 10.39 ± 0.03, 8.38 ± 0.08, 6.20 ± 0.09, 5.32 ± 0.04 and 4.93 ± 0.08 days, respectively (Table 4). Pooled data revealed that mean incubation period at 17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5ºC was 15.54 ± 0.06, 13.12 ± 0.04, 9.93 ± 0.09, 9.08 ± 0.03, 7.07 ± 0.05, 5.10 ± 0.08 and 4.69 ± 0.09 days, respectively (Table 5). The order of sequence of treatments for egg duration in descending order was 17.5:7.5>20:10>22.5:12.5> 25:15>27.5:17.5>30:20>32.5:22.5ºC.

Table 3. Effect of various temperature on immature stages of *P. brassicae* on cauliflower at constant relative humidity (65 ± 5%) during 2021

Temperature °C (Max: Min)**	*Mean duration of developmental period (days) (Mean ± SE)								Total developmental period (Days)
	Incubation period (Days)	Larval period (Days)						Pupal period (Days)	
		1st instar	2nd instar	3rd instar	4th instar	5th instar	Total		
17.5:7.5	14.26 ± 0.05	11.78 ± 0.09	8.16 ± 0.09	7.45 ± 0.08	8.52 ± 0.04	12.82 ± 0.12	48.73 ± 0.53	25.31 ± 0.10	88.30 ± 0.96
20:10	12.62 ± 0.08	7.83 ± 0.09	6.16 ± 0.09	5.45 ± 0.08	5.52 ± 0.04	7.82 ± 0.12	32.78 ± 0.50	22.31 ± 0.10	67.71 ± 0.27
22.5:12.5	9.47 ± 0.05	5.66 ± 0.07	4.55 ± 0.12	4.28 ± 0.09	4.84 ± 0.05	5.83 ± 0.08	25.16 ± 0.50	19.98 ± 0.07	54.88 ± 0.57
25:15	8.79 ± 0.08	3.83 ± 0.05	3.61 ± 0.10	3.37 ± 0.03	3.50 ± 0.05	4.53 ± 0.08	18.84 ± 0.51	16.12 ± 0.23	43.75 ± 0.45
27.5:17.5	6.94 ± 0.04	3.58 ± 0.01	2.52 ± 0.05	2.23 ± 0.03	2.34 ± 0.20	3.81 ± 0.08	13.98 ± 0.49	16.10 ± 0.31	37.02 ± 0.77
30:20	4.88 ± 0.07	2.53 ± 0.02	2.30 ± 0.04	2.14 ± 0.02	2.10 ± 0.02	3.57 ± 0.03	12.64 ± 0.45	13.11 ± 0.45	30.63 ± 0.87
32.5:22.5	4.45 ± 0.09	2.17 ± 0.04	1.51 ± 0.03	1.48 ± 0.10	2.07 ± 0.02	3.50 ± 0.09	10.73 ± 0.39	8.56 ± 0.18	23.74 ± 0.19
CD (p=0.05)	0.42	0.57	0.36	0.37	0.52	0.38	0.46	0.41	0.90
Note: *Mean of four replications; 25 individuals in each replication. **These temperatures were maintained for 14:10 h along with L:D photoperiod									

Table 4. Effect of various temperatures on immature stages of *P. brassicae* on cauliflower at constant relative humidity (65 ± 5%) during 2022

Temperature °C (Max: Min)**	*Mean duration of developmental period (days) (Mean ± SE)								Total developmental period (Days)
	Incubation period (Days)	Larval period (Days)						Pupal period (Days)	
		1st instar	2nd instar	3rd instar	4th instar	5th instar	Total		
17.5:7.5	16.82 ± 0.04	12.92 ± 0.02	9.98 ± 0.06	8.28 ± 0.03	8.89 ± 0.06	12.67 ± 0.17	52.74 ± 0.61	27.37 ± 0.12	96.93 ± 0.97
20:10	13.62 ± 0.07	8.96 ± 0.06	7.19 ± 0.07	6.29 ± 0.07	5.82 ± 0.04	8.67 ± 0.11	36.93 ± 0.52	24.20 ± 0.11	74.75 ± 0.73
22.5:12.5	10.39 ± 0.03	6.28 ± 0.04	5.27 ± 0.03	5.48 ± 0.09	4.92 ± 0.07	6.28 ± 0.04	28.23 ± 0.40	20.37 ± 0.09	58.99 ± 0.63
25:15	8.38 ± 0.08	4.27 ± 0.07	3.83 ± 0.05	3.60 ± 0.04	3.33 ± 0.06	5.87 ± 0.08	20.90 ± 0.49	17.48 ± 0.23	46.76 ± 0.54
27.5:17.5	6.20 ± 0.09	4.01 ± 0.06	3.54 ± 0.02	2.89 ± 0.01	3.19 ± 0.05	3.91 ± 0.06	17.54 ± 0.44	15.83 ± 0.22	39.57 ± 0.47
30:20	5.32 ± 0.04	3.83 ± 0.05	2.98 ± 0.04	2.34 ± 0.02	2.71 ± 0.07	3.33 ± 0.03	15.19 ± 0.43	14.68 ± 0.19	35.19 ± 0.59
32.5:22.5	4.93 ± 0.08	2.98 ± 0.02	2.51 ± 0.06	1.38 ± 0.03	2.29 ± 0.05	3.20 ± 0.02	12.36 ± 0.35	9.48 ± 0.17	26.77 ± 0.25
CD (p=0.05)	0.63	0.59	0.42	0.69	0.65	0.74	0.85	0.97	0.98
Note: *Mean of four replications; 25 individuals in each replication, **These temperatures were maintained for 14:10 h along with L:D photoperiod									

Table 5. Effect of various temperatures on the duration of immature stages of *P. brassicae* on cauliflower at constant relative humidity (65 ± 5%) (Pooled 2021and 2022)

Temperature °C (Max: Min)**	*Mean duration of developmental period (days) (Mean ± SE)								Total developmental period (Days)
	Incubation period (Days)	Larval period (Days)						Pupal period (Days)	
		1st instar	2nd instar	3rd instar	4th instar	5th instar	Total		
17.5:7.5	15.54 ± 0.06	12.35 ± 0.05	9.07 ± 0.03	7.86 ± 0.09	8.70 ± 0.06	12.74 ± 0.09	50.73 ± 0.98	26.34 ± 0.34	92.61 ± 0.99
20:10	13.12 ± 0.04	8.39 ± 0.06	6.67 ± 0.09	5.87 ± 0.05	5.67 ± 0.04	8.24 ± 0.03	34.85 ± 0.67	23.25 ± 0.22	71.23 ± 0.76
22.5:12.5	9.93 ± 0.09	5.97 ± 0.06	4.91 ± 0.05	4.86 ± 0.06	4.88 ± 0.06	6.05 ± 0.06	26.69 ± 0.23	20.17 ± 016	56.80 ± 0.68
25:15	9.08 ± 0.03	4.05 ± 0.05	4.72 ± 0.04	3.48 ± 0.03	4.41 ± 0.07	5.20 ± 0.02	19.87 ± 0.34	17.30 ± 0.12	46.25 ± 0.67
27.5:17.5	7.07 ± 0.05	3.79 ± 0.07	3.03 ± 0.07	2.56 ± 0.04	2.76 ± 0.03	3.86 ± 0.01	16.01 ± 0.47	15.96 ± 0.10	39.04 ± 0.56
30:20	5.10 ± 0.08	3.18 ± 0.08	2.64 ± 0.06	2.24 ± 0.05	2.40 ± 0.02	3.45 ± 0.05	13.91 ± 0.14	13.89 ± 0.11	32.91 ± 0.43
32.5:22.5	4.69 ± 0.09	2.57 ± 0.05	2.01 ± 0.03	1.43 ± 0.06	2.18 ± 0.06	3.35 ± 0.01	11.54 ± 0.23	9.02 ± 0.08	25.25 ± 0.35
CD (p=0.05)	0.52	0.58	0.39	0.53	0.59	0.46	0.65	0.79	0.93
Note: *Mean of four replications; 25 individuals in each replication, **These temperatures were maintained for 14:10 h along with L:D photoperiod									

During 2021, incubation period of 14.26 ± 0.05 days at 17.5:7.5ºC was significantly different from 4.45 ± 0.09 days at 32.5:22.5ºC. However, incubation period of 4.88 ± 0.07 days at 30:20ºC was at par with 4.45 ± 0.09 days at 32.5:22.5ºC. Similarly, during 2022, the incubation period at 17.5:7.5ºC (16.82 ± 0.04 days) was significantly different from incubation period at 32.5:22.5ºC (4.93 ± 0.08 days). These results are in similarity with Hasan and Ansari who reported the egg duration of 5.00 ± 0.57 days at temperature of 28ºC, 65 ± 5% RH and 12L:12D photoperiod on artificial diet. It is evident from the studies that the incubation period decreased with increase in temperature.

Larval stage

Duration of different larval instars of *P. brassicae* at different alternating temperatures of 17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5ºC, at a constant RH of 65 ± 5% was studied. During 2021, the mean duration of first, second, third, fourth and fifth larval instars was observed to be 11.78 ± 0.09, 8.16 ± 0.09, 7.45 ± 0.08, 8.52 ± 0.04 and 12.82 ± 0.12 days at 17.5:7.5ºC, 7.83 ± 0.09, 6.16 ± 0.09, 5.45 ± 0.08, 5.52 ± 0.04 and 7.82 ± 0.12 days at 20:10ºC, 5.66 ± 0.07, 4.55 ± 0.12, 4.28 ± 0.09, 4.84 ± 0.05 and 5.83 ± 0.08 days at 22.5:12.5ºC, 3.83 ± 0.05, 3.61 ± 0.10, 3.37 ± 0.03, 3.50 ± 0.05 and 4.53 ± 0.08 days at 25:15ºC, 3.58 ± 0.01, 2.52 ± 0.05, 2.23 ± 0.03, 2.34 ± 0.20, 3.81 ± 0.08 days at 27.5:17.5ºC, 2.53 ± 0.02, 2.30 ± 0.04, 2.14 ± 0.02, 2.10 ± 0.02 and 3.57 ± 0.03 at 30:20ºC and 2.17 ± 0.04, 1.51 ± 0.03, 1.48 ± 0.10, 2.07 ± 0.02 and 3.50 ± 0.09 days at 32.5:22.5ºC, respectively (Table 6). Total larval period at various alternating temperatures of 17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5ºC was observed to be 48.73 ± 0.53, 32.78 ± 0.50, 25.16 ± 0.50, 18.84 ± 0.51, 13.98 ± 0.49, 12.64 ± 0.45 and 10.73 ± 0.39 days, respectively. All treatments of total larval period were significantly different from each other.

Table 6. Age schedule of survival and births of *P. brassicae* on cauliflower at alternating temperature of 20:10°C at constant relative humidity (65 ± 5%) Pooled 2021 and 2022

Pivotal age in days (x)	Age-schedule of survival (lx)	Age-schedule of female birth (mx)	lxmx	xlxmx
0.0-5.5	1.00	Immature stages		
5.5-13.5	0.96			
13.5-21.5	0.78			
21.5-27.5	0.67			
27.5-33.5	0.59			
33.5-38.5	0.53			
38.5-42.5	0.39			
42.5-46.5	0.30			
46.5-57.5	0.27			
57.5-71.5	0.27			
71.5-75.5	0.24	Pre-oviposition period		
76.5	0.21	18.79	4.0398	301.86135
77.5	0.16	16.18	2.6697	200.632
78.5	0.13	24.25	3.2737	247.47125
79.5	0.11	12.78	1.4697	111.7611
80.5	0.07	7.915	0.59362	44.601025
81.5	0.05	0	0	0
82.5	0.03	0	0	0
83.5	0.02	0	0	0
			$R_0=\Sigma l_x m_x=11.6466$	$\Sigma x l_x m_x= 906.3267$

Note: The temperature was maintained for 14:10 h along with L:D photoperiod
Ro = Net reproductive rate
Based on cohort of 100 eggs
Sex ratio = 50:50 (male: female)

During 2022, the mean duration of first, second, third, fourth, fifth instar at 17.5:7.5ºC was observed to be 12.92 ± 0.02, 9.98 ± 0.06, 8.28 ± 0.03, 8.89 ± 0.06 and 12.67 ± 0.17 days, respectively (Table 7). At 20:10ºC, it was observed to be 8.96 ± 0.06, 7.19 ± 0.07, 6.29 ± 0.07, 5.82 ± 0.04 and 8.67 ± 0.11 days. At 22.5:12.5ºC, the total larval period was 25.16 ± 0.50. Duration of first instar at 25:15ºC (4.27 ± 0.07 days) was at par with 4.01 ± 0.06 days at 27.5:17.5ºC. At 30:20ºC, duration of fifth instar (3.33 ± 0.03 days) was at par with (3.20 ± 0.02 days) at 32.5:22.5ºC. Total larval period at various alternating temperatures of 17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5ºC was observed to be 52.74 ± 0.61, 36.93 ± 0.52, 28.23 ± 0.40, 20.90 ±

0.49, 17.54 ± 0.44, 15.19 ± 0.43 and 12.36 ± 0.35 days, respectively.

Table 7. Age schedule of survival and births of *P. brassicae* on cauliflower at alternating temperature of 22.5:12.5°C at constant relative humidity (65 ± 5%) Pooled 2021 and 2022

Pivotal age in days (x)	Age-schedule of survival (lx)	Age-schedule of female birth (mx)	lxmx	xlxmx
0.0-4.5	1.00	Immature stages		
4.5-9.5	0.88			
9.5-15.5	0.67			
15.5-20.5	0.57			
20.5-25.5	0.45			
25.5-30.5	0.38			
30.5-36.5	0.31			
36.5-45.5	0.28			
45.5-56.5	0.28			
56.5-59.5	0.24	Pre-oviposition period		
60.5	0.20	13.28	2.65600	160.688
61.5	0.16	27.915	4.60597	274.6836
62.5	0.12	25.7	3.21250	192.75
63.5	0.10	26.34	2.63400	167.259
64.5	0.07	7.58	0.53060	34.2237
65.5	0.03	0	0	0
66.5	0.01	0	0	0
			$R_0=\Sigma l_x m_x=13.37908$	$\Sigma x l_x m_x=829.6043$

Note: The temperature was maintained for 14:10 h along with L:D photoperiod
Ro=Net reproductive rate
Based on cohort of 100 eggs
Sex ratio=50:50 (male: female)

Pooled data presented in Table 8 revealed that mean larval period of first, second, third, fourth, fifth instars was maximum at 17.5:7.5ºC with mean value of 12.35 ± 0.05, 9.07 ± 0.03, 7.86 ± 0.09, 8.70 ± 0.05 and 12.74 ± 0.09 days and minimum at 32.5:22.5ºC with mean value of 2.57 ± 0.05, 2.01 ± 0.03, 1.43 ± 0.06, 2.18 ± 0.06 and 3.35 ± 0.01 days, respectively. At 20:10ºC, it was 8.39 ± 0.06, 6.67 ± 0.09, 5.87 ± 0.05, 5.67 ± 0.04 and 8.24 ± 0.03 days. At 22.5:12.5ºC, it was 5.97 ± 0.06, 4.91 ± 0.05, 4.86 ± 0.06, 4.88 ± 0.06 and 6.05 ± 0.06. Duration of first instar at 27.5:17.5ºC (3.79 ± 0.07 days) was at par with 3.18 ± 0.08 days at 30:20ºC. At 30:20ºC, duration of fifth instar (3.45 ± 0.05 days) was at par with (3.35 ± 0.01 days) at 32.5:22.5ºC. Total larval period was observed to be maximum at 17.5:7.5ºC (50.73 ± 0.98 days) and minimum at 32.5:12.5ºC (11.54 ± 0.23 days) while all other treatments were significantly different from each other.

Table 8. Age schedule of survival and births of *P. brassicae* on cauliflower at alternating temperature of 30:20°C at constant relative humidity (65 ± 5%) pooled 2021 and 2022

Pivotal age in days (x)	Age-schedule of survival (lx)	Age-schedule of female birth (mx)	lxmx	xlxmx
0.0-2.5	1.00	Immature stages		
2.5-5.5	0.72			
5.5-8.5	0.67			
8.5-11.5	0.61			
11.5-13.5	0.56			
13.5-16.5	0.42			
16.5-20.5	0.31			

20.5-26.5	0.22			
26.5-32.5	0.22			
32.5-34.5	0.21	Pre-oviposition period		
35.5	0.20	61.435	12.287	436.1885
36.5	0.15	37.5	5.6250	164.25
37.5	0.08	51.255	4.3566	153.765
38.5	0.05	38.13	1.9065	73.40025
39.5	0.02	24.24	0.4848	19.1496
40.5	0.01	0	0	0
			$R_{0}=\Sigma l_x m_x$=23.2799	$\Sigma x l_x m_x$= 846.75335

Note: The temperature was maintained for 14:10 h along with L:D photoperiod
Ro=Net reproductive rate
Based on cohort of 100 eggs
Sex ratio=50:50 (male: female)

The results are in similarity with Hasan and Ansari who reported the egg duration of 26.98 ± 1.19 days at temperature of 28ºC, 65 ± 5% RH and 12L:12D photoperiod on artificial diet. Firake, et al., reported that larval duration of *P. brassicae* was 21.80 ± 0.49, 23.80 ± 0.37, 24.40 ± 0.24 and 24.40 ± 0.25 days on cabbage, knol-khol, cauliflower and broc coli at temperature of 20 ± 2ºC, 75 ± 5% RH, 16:8 (light: dark period). The variation in larval duration between present studies and other studies may be due to greater suitability of artificial diet for *P. brassicae* larvae as compared to natural host. It is noticeable from the studies that variation in larval duration at different alternating temperatures was possibly due to variation in temperature conditions as larval duration decreases with increase in temperature.

Pupal stage

During 2021, pupal duration of *P. brassicae* at different alternating temperatures of 17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5ºC was observed to be 25.31 ± 0.10, 22.31 ± 0.10, 19.98 ± 0.07, 16.12 ± 0.23, 16.10 ± 0.31, 13.11 ± 0.45 and 8.56 ± 0.18 days, respectively (Table 3). Similarly, during 2022, pupal duration was observed to be 27.37 ± 0.12, 24.20 ± 0.11, 20.37 ± 0.09, 17.48 ± 0.23, 15.83 ± 0.22, 14.68 ± 0.19 and 9.48 ± 0.17 days, respectively (Table 4).

Pooled data presented in Table 5 revealed that pupal duration was maximum at 17.5:7.5ºC (26.34 ± 0.34 days) and minimum at 32.5:12.5ºC (9.02 ± 0.08 days). The order of sequence of treatments for pupal duration in descending order was 17.5:7.5>20:10>22.5:12.5>25:15>27.5:17.5>30:20>32.5:22.5ºC.

The impact of different alternating temperatures on pupal period was statistically significant. Results are in agreement with Hasan and Ansari who observed the pupal duration of 11.66 ± 2.07 days at 28ºC, 65 ± 5% RH and 12L:12D photoperiod on artificial diet. These durations recorded on artificial diet are very close to the values recorded in the present studies. Similarly, Mehrkhou and Sarhozaki also revealed that pupal period was in range of 13.3-17.5 days on different cole crops at 26°C ± 1°C with 60 ± 5% RH and photoperiod of 16:8 (L:D) h. It is evident from present findings that the difference in values of pupal duration may be due to difference in temperature condition as pupal duration decreases with increase in temperature.

Total developmental period

Total developmental period at different alternating temperatures of 17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5ºC during 2021 was observed to be 88.30 ± 0.96, 67.71 ± 0.27, 54.88 ± 0.57, 43.75 ± 0.45, 37.02 ± 0.77, 30.6 ± 0.87 and 23.74 ± 0.19 days, respectively (Table 3) and during 2022, it was observed to be 96.93 ± 0.97, 74.75 ± 0.73, 58.99 ± 0.63, 48.76 ± 0.54, 39.57 ± 0.47, 35.19 ± 0.59 and 26.77 ± 0.25 days, respectively (Table 4). Pooled data revealed that total developmental period was significant maximum at 17.5:7.5ºC (92.61 ± 0.99 days) and minimum at 32.5:12.5ºC (25.25 ± 0.35 days) as depicted in Table 5. Total developmental period was statistically significantly at different alternating temperatures.

Results are in agreement with Mehrkhou and Sarhozaki who reported that the total developmental period of *P. brassicae* varied between 40.5 and 51.8 days on various cole crops at 26°C ± 1°C with 60 ± 5% RH and photoperiod of 16:8 (L:D) h. Disparity in the results of total developmental period between present findings and the other studies could be attributed to differences in the hosts, as improved nutrition obtained from artificial diet may have contributed to shorter developmental period as compared to natural diet. Similarly, Firake et al estimated that the total developmental period for cabbage, knolkhol, cauliflower and br°C coli was 34.40, 35.80, 36.80 and 37.20 days, respectively at temperature of 20°C ± 2ºC, 75 ± 5% RH, 16:8 (light: Dark period). It is evident from the studies that with the increase in temperature there was decrease in total development period of *P. brassicae*.

Adult stage

During 2021, male longevity was observed at different alternating temperature of 17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5ºC and it was found to be 12.33 ± 0.31, 10.92 ± 0.34, 8.33 ± 0.31, 7.92 ± 0.34, 6.50 ± 0.28, 4.83 ± 0.24 and 4.13 ± 0.21 days, respectively (Table 9). During 2022, it was observed to be 12.27 ± 0.28, 10.85 ± 0.32, 8.27 ± 0.28, 7.85 ± 0.32, 6.91 ± 0.23, 5.06 ± 0.28 and 4.75 ± 0.24 days, respectively (Table 10). Pooled data presented in Table 8 revealed that male longevity was maximum at 17.5:7.5ºC (12.30 ± 0.07 days) and minimum at 32.5:22.5ºC (4.44 ± 0.04 days). The difference in male longevity was found to be at par at alternating temperatures of 30:20ºC and 32.5:12.5ºC during both the years.

Table 9. Effect of various temperatures on adult longevity and fecundity of *P. brassicae* on cauliflower at constant relative humidity (65 ± 5%) during 2021

Temperature °C (Max: Min)*	**Longevity (days) (Mean ± SE)**					**Fecundity (eggs/female)**
	Male	**Female**				
		Pre-oviposition period	**Oviposition period**	**Post-oviposition period**	**Total**	
17.5:7.5	12.33 ± 0.31	3.83 ± 0.09	7.87 ± 0.29	2.28 ± 0.07	13.98 ± 0.19	59.68 ± 0.34
20:10	10.92 ± 0.34	3.12 ± 0.12	7.15 ± 0.31	2.22 ± 0.04	12.49 ± 0.12	81.39 ± 0.63
22.5:12.5	8.33 ± 0.31	2.83 ± 0.09	6.87 ± 0.29	1.85 ± 0.03	11.55 ± 0.19	104.89 ± 0.85
25:15	7.92 ± 0.34	2.12 ± 0.12	6.15 ± 0.31	1.57 ± 0.06	9.84 ± 0.12	156.75 ± 0.86
27.5:17.5	6.50 ± 0.28	1.57 ± 0.08	4.75 ± 0.15	1.34 ± 0.05	7.66 ± 0.15	187.25 ± 0.75
30:20	4.83 ± 0.24	1.41 ± 0.14	4.62 ± 0.14	1.26 ± 0.02	7.29 ± 0.17	235.64 ± 0.70
32.5:22.5	4.13 ± 0.21	1.33 ± 0.11	3.39 ± 0.12	1.02 ± 0.04	5.74 ± 0.14	260.25 ± 1.85
CD ($p_=0.05$)	1.38	0.55	0.62	0.43	1.36	6.64

Note: The temperature was maintained for 14:10 h along with L:D photoperiod
Ro=Net reproductive rate
Based on cohort of 100 eggs
Sex ratio=50:50 (male: female)

Table 10. Effect of various temperatures on adult longevity and fecundity of *P. brassicae* on cauliflower at constant relative humidity (65 ± 5%) during 2022

Temperature °C (Max: Min)*	**Longevity (days) (Mean ± SE)**					**Fecundity (eggs/female)**
	Male	**Female**				
		Pre-oviposition period	**Oviposition period**	**Post-oviposition period**	**Total**	
17.5:7.5	12.27 ± 0.28	3.98 ± 0.08	7.56 ± 0.07	2.75 ± 0.03	14.29 ± 0.83	63.59 ± 0.59
20:10	10.85 ± 0.32	2.92 ± 0.12	7.49 ± 0.13	2.25 ± 0.05	13.66 ± 0.04	89.44 ± 0.12
22.5:12.5	8.27 ± 0.28	2.89 ± 0.08	6.91 ± 0.07	2.15 ± 0.08	11.95 ± 0.83	110.37 ± 0.73
25:15	7.85 ± 0.32	1.91 ± 0.12	5.49 ± 0.13	2.12 ± 0.03	9.52 ± 0.04	145.62 ± 0.47
27.5:17.5	6.91 ± 0.23	1.58 ± 0.08	4.77 ± 0.08	1.84 ± 0.04	8.19 ± 0.10	196.56 ± 0.77
30:20	5.06 ± 0.23	1.39 ± 0.14	4.64 ± 0.11	1.63 ± 0.05	7.66 ± 0.12	228.09 ± 0.85
32.5:22.5	4.75 ± 0.23	1.21 ± 0.11	3.37 ± 0.05	1.29 ± 0.06	5.87 ± 0.07	253.87 ± 1.58
CD ($p_=0.05$)	1.43	0.49	0.69	0.41	1.61	6.55

The results of male longevity are in line with Kumar et al., who reported that male adults lived for 7-9 days with an average of 8.15 ± 0.58 days whereas females lived for 8-11 days with an average of 9.00 ± 0.72 days. Hasan and Ansari reported that the adult longevity of male and female on various cole crops varied between 6.4-9.0 and 7.0-11.8 days, respectively at 28ºC, 65 ± 5% RH and 12L:12D photoperiod [13].

During 2021, the female pre-oviposition was observed at different alternating temperatures of 17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5ºC and it was found to be 3.83 ± 0.09, 3.12 ± 0.12, 2.83 ± 0.09, 2.12 ± 0.12, 1.57 ± 0.08, 1.14 ± 0.14 and 1.33 ± 0.11 days, respectively. The female oviposition period at six different alternating temperature was observed to be 7.87 ± 0.29, 7.15 ± 0.31, 6.87 ± 0.15, 6.15 ± 0.31, 4.75 ± 0.15, 4.62 ± 0.14 and 3.39 ± 0.12 days, respectively (Table 9) and post-oviposition period was 2.28 ± 0.07, 2.22 ± 0.04, 1.85 ± 0.03, 1.57 ± 0.06, 1.34 ± 0.05, 1.26 ± 0.02 and 1.02 ± 0.04 days.

Similarly, during 2022, pre-oviposition period was observed to be 3.98 ± 0.08, 2.92 ± 0.12, 2.89 ± 0.08, 1.91 ± 0.12, 1.58 ± 0.08, 1.39 ± 0.14 and 1.21 ± 0.11 days, respectively. The female oviposition period was found to be 7.56 ± 0.07, 7.49 ± 0.13, 6.91 ± 0.07, 5.49 ± 0.13, 4.77 ± 0.08, 4.64 ± 0.11 and 3.37 ± 0.05 days, also the post-oviposition period was 2.75 ± 0.03, 2.25 ± 0.05, 2.15 ± 0.08, 2.12 ± 0.03, 1.84 ± 0.04, 1.63 ± 0.05 and 1.29 ± 0.06 days at different alternating temperatures of 17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5ºC, respectively (Table 10).

Hasan and Ansari also studied the pre-oviposition and oviposition period of P. brassicae and it was found to be 1.85 ± 0.10 and 5.0 ± 0.30 days, respectively at temperature of about 28ºC, 65 ± 5% RH and 12L:12D photoperiod. These observations recorded on cauliflower crop in the laboratory are close to the values recorded in the present studies on the same crop in the field. It is evident from the present findings that pre-oviposition, oviposition period and post-oviposition period decreases with increase in temperature

The female longevity at different alternating temperatures of 17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5ºC was found to be 13.98 ± 0.19, 12.49 ± 0.12, 11.55 ± 0.19, 9.84 ± 0.12, 7.66 ± 0.15, 7.29 ± 0.17 and 5.74 ± 0.14 days, respectively during 2021 (Table 9). Similarly, during 2022, it was observed to be 14.29 ± 0.83, 13.66 ± 0.04, 11.95 ± 0.83, 9.52 ± 0.04, 8.19 ± 0.10, 7.66 ± 0.12 and 5.87 ± 0.07 days, respectively (Table 10). Pooled data revealed that maximum female longevity was observed at 17.5:7.5ºC (14.12 ± 0.04 days) and minimum at 32.5:22.5ºC (5.80 ± 0.05 days) as depicted in Table 11. The female longevity at 27.5:12.5ºC (7.92 ± 0.04 days) was at par with female longevity at 30:20ºC (7.47 ± 0.07 days). When compared to male longevity, female longevity was observed to be more in the present studies. This was in agreement with Hasan and Ansari who also reported female longevity (11.2 ± 0.37) days was higher as compared to male longevity (7.8 ± 0.37) days [14].

Table 11. Effect of various temperatures on adult longevity and fecundity of *P. brassicae* on cauliflower at constant relative humidity (65 ± 5%) (Pooled 2021 and 2022)

Temperature °C (Max: Min)*	Longevity (days) (Mean ± SE)					Fecundity (eggs/female)
	Male	Female				
		Pre-oviposition period	Oviposition period	Post-oviposition period	Total	
17.5:7.5	12.30 ± 0.07	3.90 ± 0.06	7.71 ± 0.09	2.51 ± 0.07	14.12 ± 0.04	61.63 ± 0.07
20:10	10.88 ± 0.08	3.51 ± 0.04	7.32 ± 0.03	2.23 ± 0.06	13.06 ± 0.07	85.41 ± 0.04
22.5:12.5	8.30 ± 0.04	2.65 ± 0.08	5.89 ± 0.05	2.01 ± 0.04	10.55 ± 0.03	107.63 ± 0.21
25:15	7.88 ± 0.05	2.01 ± 0.07	5.32 ± 0.03	1.84 ± 0.02	9.17 ± 0.06	151.18 ± 0.38
27.5:17.5	6.70 ± 0.04	1.57 ± 0.04	4.76 ± 0.06	1.59 ± 0.03	7.92 ± 0.04	191.90 ± 0.95
30:20	4.94 ± 0.06	1.40 ± 0.09	4.63 ± 0.07	1.44 ± 0.07	7.47 ± 0.07	231.86 ± 0.98
32.5:22.5	4.44 ± 0.06	1.27 ± 0.06	3.38 ± 0.06	1.15 ± 0.02	5.80 ± 0.05	257.06 ± 1.46
CD ($p_=0.05$)	1.40	0.52	0.64	0.34	1.42	6.33
Note: These temperatures were maintained for 14:10 h along with L:D photoperiod						

Fecundity

During 2021, the lowest fecundity of 59.68 ± 0.34 eggs per female was observed at 17.5:7.5ºC and highest fecundity of 260.25 ± 1.85 eggs per female at 32.5:22.5ºC (Table 12). Similarly, during 2022 (Table 6), it was minimum at 17.5:7.5ºC (63.59 ± 0.59 eggs per female) and maximum at 32.5:22.5ºC (253.87 ± 1.58 eggs per female). Also, pooled data revealed that fecundity was minimum at 17.5:7.5ºC (61.63 ± 0.07 eggs per female) and maximum at 32.5:22.5ºC (257.06 ± 1.46 eggs per female) as shown in Table 8. So, from these findings we can conclude that with the increase in alternating temperature there was a decrease in fecundity. The maximum observed values of fecundity in present findings are in similarity with Aslam and Suleman (1999) who reported females typically laid 141.25 eggs per female. The fecundity of *P. brassicae* per female varied between 198 and 281 on different cole crops (Hasan and Ansari 2010b). Improved nutrition obtained from artificial diet may have contributed to these higher fecundity values than those observed on natural host *i.e.* cauliflower.

Table 12. Age schedule of survival and births of *P. brassicae* on cauliflower at alternating temperature of 17.5:7.5°C at constant relative humidity (65 ± 5%) Pooled 2021 and 2022

Pivotal age in days (x)	Age-schedule of survival (lx)	Age-schedule of female birth (mx)	lxmx	xlxmx
0.5-5.5	1.00	Immature stages		
5.5-15.5	0.97			
15.5-21.5	0.92			

21.5-27.5	0.69			
27.5-31.5	0.61			
31.5-36.5	0.54			
36.5-43.5	0.48			
43.5-51.5	0.45			
51.5-65.5	0.38			
65.5-75.5	0.29			
75.5-96.5	0.29			
96.5-100.5	0.24	Pre-oviposition period		
101.5	0.16	17.035	2.7256	276.6484
102.5	0.16	13.62	2.1792	223.368
103.5	0.14	10.35	1.4490	149.9715
104.5	0.09	9.285	1.1142	87.325425
105.5	0.05	6.975	0.7323	36.793125
106.5	0.03	6.48	0.6156	20.7036
107.5	0.01	0	0	0
			$R_0=\Sigma l_x m_x=7.7303$	$\Sigma x l_x m_x= 794.8100$

Note: The temperature was maintained for 14:10 h along with L:D photoperiod
Ro=Net reproductive rate
Based on cohort of 100 eggs
Sex ratio=50:50 (male: female)

Effect of alternating temperatures on life table parameters of P. brassicae on cauliflower

Life fecundity table of *P. brassicae* on cauliflower was constructed at different alternating temperatures to determine the survival of female (lx) and age specific fecundity (mx) as depicted in Tables 13-15. Fecundity per female was observed at different alternating temperatures (14:10h) of 17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5ºC at constant RH (65 ± 5%). The fecundity values were halved at each alternating temperature daily during oviposition period because of 1:1 (male: female) sex ratio to secure the value of mx.

Table 13. Effect of alternating temperature on the life table parameters of *P. brassicae* reared on cauliflower during 2021

Temperature °C (Max: Min)*	Net Reproductive Rate(R_0)	Mean generation time (($T= \sum xlxmx/R_0$) (Days)	Intrinsic rate of increase ($r_m=\log_e R_0/T$)	Precise value of (r_m)	Finite rate of increase ($\lambda=e^{rm}$)	Weekly multiplicative rate (λ^7)	Doubling time DT= (Log 2/Logλ)	Annual rate of increase ($R_0^{365/T}$)
17.5:7.5	9.54	96.75	0.02331	0.02045	1.0235	1.1772	29.7327	4.95×10^3
20:10	12.29	73.82	0.03398	0.03399	1.0345	1.2685	20.3955	2.43×10^5
22.5:12.5	13.38	59.88	0.04331	0.04333	1.0442	1.3542	16.0021	7.35×10^6
25:15	16.53	48.97	0.05728	0.05732	1.0589	1.4932	12.1002	1.20×10^9
27.5:17.5	22.48	42.07	0.07398	0.07406	1.0767	1.6785	9.36852	5.34×10^{11}
30:20	24.89	35.24	0.09121	0.09131	1.0955	1.8936	7.59893	2.88×10^{14}
32.5:22.5	26.54	28.5	0.11504	0.20920	1.1219	2.2373	6.02524	1.72×10^{18}

Note: *These temperatures were maintained for 14:10 h along with L:D photoperiod

Table 14. Effect of alternating temperature on the life table parameters of *P. brassicae* reared on cauliflower during 2022

Temperature °C (Max: Min)*	Net Reproductive Rate(R_0)	Mean generation time (($T = \sum xlxmx/R_0$) (Days)	Intrinsic rate of increase ($r_m = \log_e R_0/T$)	Precise value of (r_m)	Finite rate of increase ($\lambda = e^{rm}$)	Weekly multiplicative rate(λ^7)	Doubling time DT= (Log 2/Logλ)	Annual rate of increase ($R_0^{365/T}$)
17.5:7.5	7.35	104.02	0.01917	0.01918	1.0193	1.1436	36.1463	1.09×10^3
20:10	11.78	80.83	0.03051	0.03052	1.0309	1.2381	22.7161	6.86×10^4
22.5:12.5	14.85	65.13	0.04142	0.04144	1.0422	1.3363	16.7326	3.68×10^6
25:15	15.43	52.04	0.05258	0.05261	1.0539	1.4449	13.1824	2.16×10^8

27.5:17.5	22.25	39.57	0.07985	0.07996	1.0831	1.7489	9.7570	4.55×10^{12}
30:20	23.57	37.68	0.08233	0.08243	1.0858	1.7795	8.6797	1.12×10^{13}
32.5:22.5	24.06	30.18	0.10538	0.10550	1.1111	2.0911	6.5772	5.07×10^{16}
Note: *These temperatures were maintained for 14:10 h along with L:D photoperiod								

Table 15. Effect of alternating temperature on the life table parameters of *P. brassicae* reared on cauliflower (Pooled 2021 and 2022)

Temperature °C (Max: Min)*	**Net Reproductive Rate (R_0)**	**Mean generation time (($T=\sum xlxmx/R_0$) (Days)**	**Intrinsic rate of increase ($r_m=\log_e R_0/T$)**	**Precise value of (r_m)**	**Finite rate of increase ($\lambda=e^{rm}$)**	**Weekly multiplicative rate(λ^7)**	**Doubling time DT=(Log 2/Logλ)**	**Annual rate of increase ($R_0^{365/T}$)**
17.5:7.5	8.20	102.88	0.02045	0.02108	1.0206	1.1539	34.8690	1.74×10^4
20:10	12.04	77.83	0.03197	0.03198	1.0324	1.2508	21.9795	1.16×10^5
22.5:12.5	13.63	62.04	0.04210	0.04212	1.0430	1.3427	16.5841	4.72×10^6
25:15	14.54	54.90	0.04876	0.04878	1.0499	1.4068	14.4001	5.36×10^7
27.5:17.5	23.35	40.88	0.07706	0.07715	1.0801	1.7151	9.0446	1.64×10^{12}
30:20	24.65	36.39	0.08806	0.08815	1.0920	1.8523	8.0147	9.12×10^{13}
32.5:22.5	25.73	29.01	0.11195	0.11150	1.1184	2.1894	6.2467	5.57×10^{17}
Note: *These temperatures were maintained for 14:10 h along with L:D photoperiod								

Net reproductive rate (R0)

During 2021, net reproductive rate depicted that population was multiplied by a factor of 9.54, 12.29, 13.38, 16.53, 22.48, 24.89 and 26.54 at alternating temperatures of 17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5ºC, respectively at the end of each generation (Table 13) [15]. Similarly, during 2022, the net reproductive rate at each alternating temperature of 17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5ºC was observed to be 7.35, 11.78, 14.85, 15.43, 22.25, 23.57 and 24.06, respectively (Table 14). Pooled data revealed that the highest R0 (25.73) was reported at alternating temperature of 32.5:22.5℃ which was close to 24.65 at 30:20℃ (Table 15 and Figure 1). So, 32.5:22.5℃ and 30:20℃ appeared to be optimum temperatures for multiplication of *P. brassicae*. The results are in conformity with Hasan and Ansari who reported that net reproductive rate of *P. brassicae* on cauliflower crop was found to be 27.10, 24.89, 10.15, 7.76 and 14.96 at 28℃, 65 ± 5% RH in cauliflower, cabbage, mustard, radish and broc coli, respectively. This value of net reproductive rate was in close proximity with value at 17.5:7.5℃ in the present studies. The net reproductive rate of *P. brassicae* at different alternating temperature followed the decreasing sequence as: 17.5:7.5<20:10<22.5:12.5<25:15<27.5:17.5<30:20<32.5:22.5ºC.

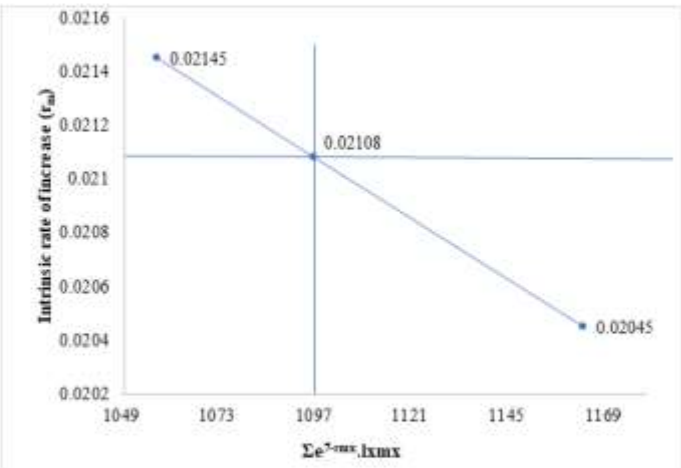

Figure 1. Determination of precise value of r_m of *P. brassicae* in cauliflower at 17.5:7.5°C and 65% RH (Pooled) in the laboratory.

Hasan and Ansari reported the net reproductive rate of *P. brassicae* as 49.00 ± 1.15, 20.00 ± 1.15, 15.52 ± 1.52 and 29.10 ±

0.58 on cabbage, mustard, radish and br°C coli, respectively at 28°C, 65 ± 5% RH. Vaishnav et al., reported the highest value of net reproductive rate (44.75 females/female/generation) on cabbage at 25°C, 60 ± 5% RH [16].

Mean generation time (T)

It is the mean interval between the birth of an individual and its offspring. During 2021, the mean generation time at different alternating temperatures of 17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5ºC was found to be 96.75, 73.82, 59.88, 48.97, 42.07, 35.24 and 28.50 days, respectively (Table 16). Similarly, during 2022, the mean generation time at seven different alternating temperatures was found to be 104.02, 80.83, 65.13, 52.04, 39.57, 37.68 and 30.18 days, respectively Table 14). The mean generation time (T) decreased with rise in alternating temperature. Pooled data revealed (Figure 2) that highest mean generation time (T) of 102.88 days was observed at 17.5:7.5°C followed by 20:10°C (77.83 days) and minimum was observed at 32.5:22.5°C (29.01 days) as depicted in Table 15.

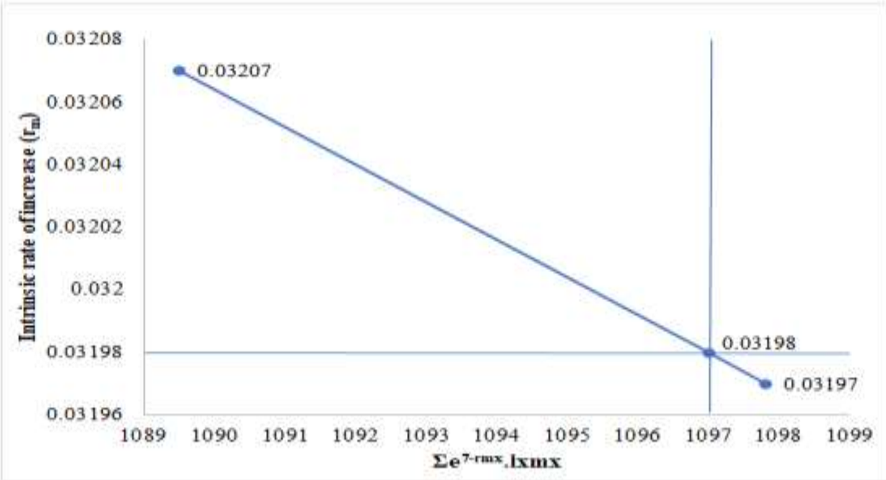

Figure 2. Determination of precise value of r_m of *P. brassicae* in cauliflower at 20:10°C and 65% RH (Pooled) in the laboratory.

It was observed that increase in maximum temperature generally effect the mean generation time as compared to increase in minimum temperature as difference in mean generation time was less between 27.5:17.5°C (40.88 days) and 30:20°C (36.39 days) and more in case of 17.5:7.5°C (102.88 days) and 32.5:22.5°C (29.01 days). Results are in agreement with Hasan and Ansari (2010b) who reported that mean generation time of *P. brassicae* on cauliflower crop was 34.55 ± 0.58 at 28°C, 65 ± 5% RH, also the mean generation time calculated on various cole crops were cabbage (34.60 ± 2.08), mustard (34.31 ± 1.15), radish (34.29 ± 1.52) and broc coli (34.35 ± 0.57) on artificial diet. It suggested that 27.5:17.5 and 30:20°C were the most favorable alternating temperatures for the multiplication of *P. brassicae* on cauliflower crop [17].

Intrinsic rate of increase (r_m)

It is the rise in the population of a species under the given situation that there are no density-dependent forces regulating the population. During 2021, the value of intrinsic rate of increase (r_m) of *P. brassicae* at different alternating temperatures followed the order: 17.5:7.5<20:10<22.5:12.5<25:15<27.5:17.5<30:20<32.5:22.5ºC (Table 16). The intrinsic rate of increase at different alternating temperatures of 17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5ºC was observed to be 0.02331, 0.03398, 0.04331, 0.05728, 0.07398, 0.09121 and 0.1150, respectively.

Similarly, during 2022, it was observed to be 0.01917, 0.03051, 0.04142, 0.05258, 0.07985 0.08233 and 0.10538, respectively (Table 14). The highest r_m was observed at 32.5:22.5°C and 30:20°C and it was reported to be 0.10538 and 0.08233, respectively and lowest was observed at 17.5:7.5°C and 20:10°C which was 0.01917 and 0.03051, respectively. Pooled data in Table 15 revealed that lowest value of r_m was observed at 17.5:7.5°C (0.02045) and 20:10°C (0.3197) and highest was observed at 32.5:22.5°C (0.11195) (Figure 3). Hasan and Ansari (2010b) reported the intrinsic rate of increase of *P. brassicae* on artificial diet and it was observed to be 0.113 ± 0.22 at 28°C, 65 ± 5% RH. Vaishnav et al., reported the intrinsic rate of increase as (0.0504 females/female/day) on cabbage at 25°C, 60 ± 5% RH [18]. These values of intrinsic rate of increase were lower than the values obtained from present studies, which implied that it might be due to rearing *of P. brassicae* larvae on artificial diet.

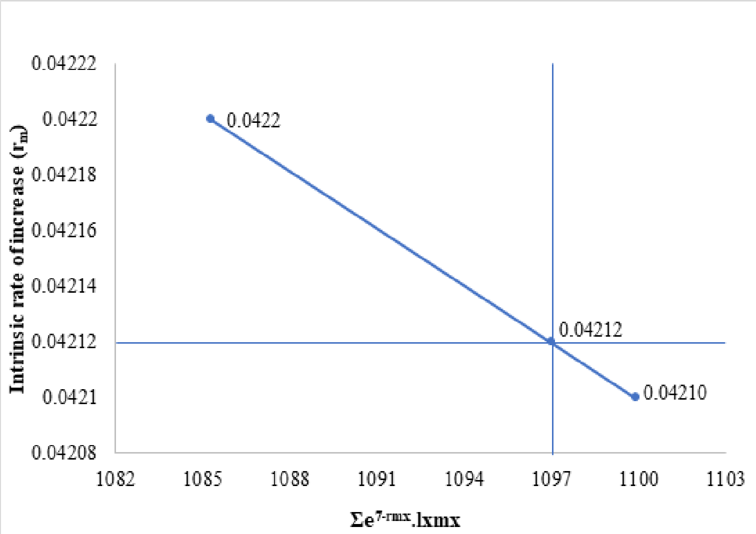

Figure 3. Determination of precise value of r*m* of *P. brassicae* in cauliflower at 22.5:12.5°C and 65% RH (Pooled) in the laboratory.

Precise value of r_m (åe 7-rmx. lxmx=1097)

During 2021, the precise value of r_m at different alternating temperatures of 17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5ºC was found to be 0.02045, 0.03399, 0.04333,0.05732, 0.07406, 0.09121 and 0.20920 (Table 13). Similarly, during 2022, the precise value was 0.01918, 0.03052, 0.04144, 0.05261, 0.07996, 0.08243 and 0.10550 (Table 14). Pooled data revealed that precise value of r_m was 0.02108, 0.03198, 0.04212, 0.04878, 0.07715, 0.08815 and 0.11150 (Table 15). The highest value was observed at 32.5:22.5ºC and lowest was observed at 17.5:7.5ºC. The value obtained from present findings can be due to differences in temperature conditions and also might be due to nutrition obtained from artificial diet (Figure 4).

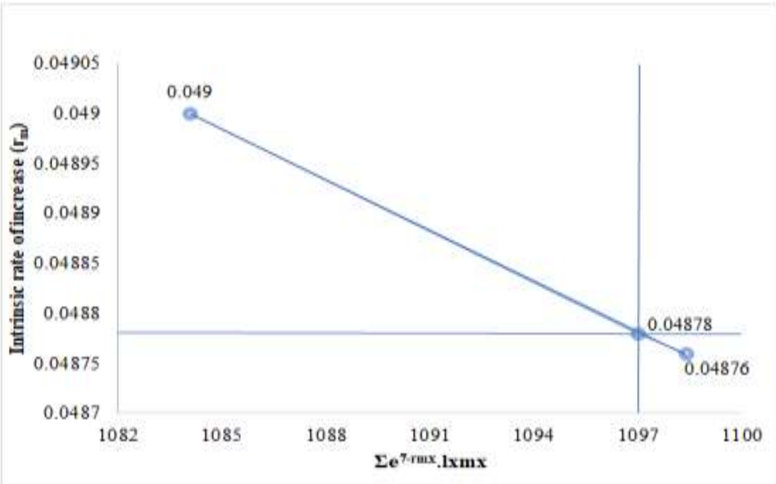

Figure 4. Determination of precise value of rm of *P. brassicae* in cauliflower at 25:15°C and 65% RH (Pooled) in the laboratory.

Finite rate of increase (λ)

During 2021, the finite rate of increase at different alternating temperatures of 17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5°C was found to be 1.0235, 1.0345, 1.0442, 1.0589, 1.0767, 1.0955 and 1.1219. The finite rate of increase on weekly basis (λ7) was found to be 1.1772, 1.2685, 1.3542, 1.4932, 1.6785, 1.8936 and 2.2373, respectively (Table 13). Similarly, during 2022, the finite rate of increase on daily basis was found to be 1.0193, 1.0309, 1.0422, 1.0539, 1.0831, 1.0858 and 1.1111 and on weekly basis it was found to be 1.1436, 1.2381, 1.3363, 1.4449, 1.7489, 1.7795 and 2.0911 (Table 17). Pooled data revealed that highest value of λ was observed at 32.5:22.5°C (1.1184) and 30:10°C (1.0920) and lowest was observed at alternating temperatures of 17.5:7.5°C (1.0206) and 20:10°C (1.0324) as depicted in Table 15 (Figure 5).

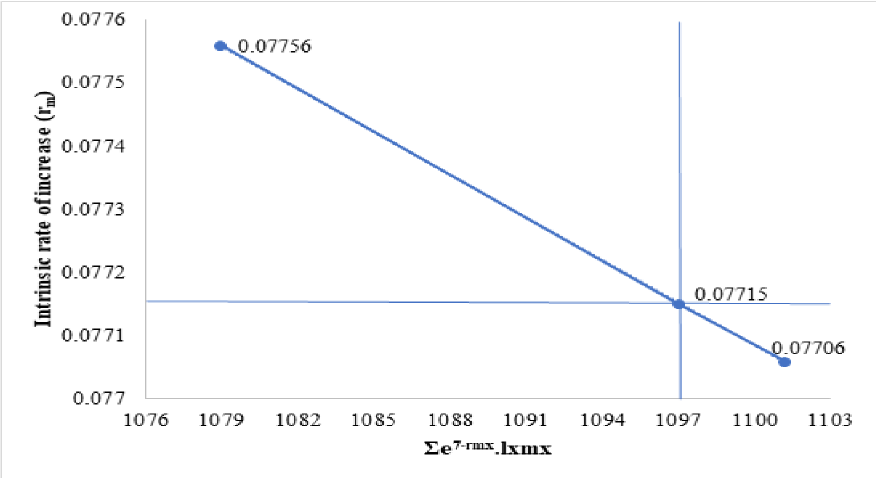

Figure 5. Determination of precise value of r_m of *P. brassicae* in cauliflower at 27.5:17.5°C and 65% RH (Pooled) in the laboratory.

Similarly, during 2022, the value was highest at alternating temperature of 32.5:22.5℃ (1.1219) and lowest at 17.5:7.5℃ (1.0235) as depicted in Table 14. It describes that population was increased by a factor of 1.1219 females per head per day at 32.5:22.5℃. Hasan and Ansari also reported the value of λ as 1.10, 1.08, 1.07, 1.06 and 1.08 females/female/day on cauliflower, cabbage, mustard, radish and br℃ coli, respectively of about at 28℃, 65 ± 5% RH. Vaishnav et al., reported the finite rate of increase of *P. brassicae* was (1.0517 females/female/day) and weekly multiplication of population of about 1.4229 times on cabbage at 25℃, 60 ± 5% RH. The values of λ observed by Hasan and Ansari on different cole crops were 1.12 ± 0.012, 0.75 ± 0.34, 1.08 ± 0.35 and 1.09 ± 0.34 females/female/day on cabbage, mustard, radish and broc coli, respectively at 28℃, 65 ± 5% RH. The value obtained from present findings was lower as compared to other findings which might be due to nutrition obtained from artificial diet as compared to natural diet [19].

Doubling time (Log 2/Logλ)

It is defined as the time required for the population to double. During 2021, the value of doubling time at different alternating temperatures of 17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5ºC were observed to be 29.7327, 20.3955, 16.0021, 12.1002, 9.3685, 7.5989 and 6.02524, respectively. During 2022, it was observed to be 36.1463, 22.7161, 16.7326, 13.1824, 9.7570, 8.6797 and 6.5772, respectively. Pooled data revealed that doubling time was 34.8690, 21.9795, 16.5841, 14.4001, 9.0446, 8.0147 and 6.2767, respectively as depicted in Table 15 and Figure 6). It is evident from the present studies that doubling time increases with rise in temperature.

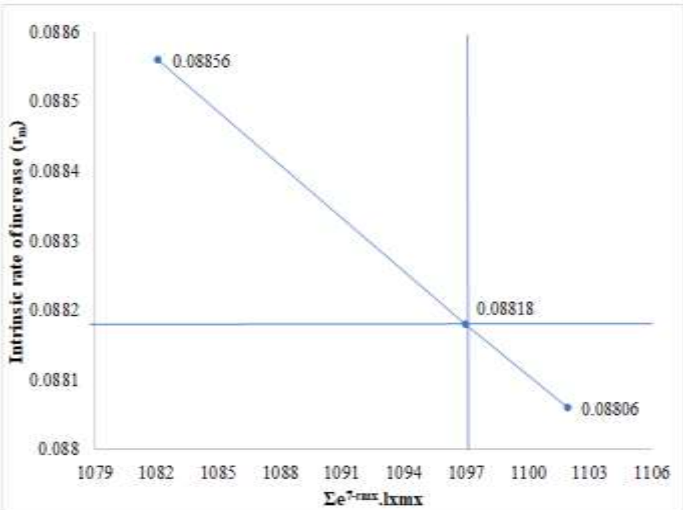

Figure 6: Determination of precise value of r_m of *P. brassicae* in cauliflower at 30:20°C and 65% RH (Pooled) in the laboratory

Results are in conformity with Ali who reported the doubling time of *P. brassicae* as 10.24, 9.16, 8.41, and 7.29 and 6.41 days on Indian mustard, yellow mustard, gobhi sarson, cauliflower and cabbage, respectively. Hasan and Ansari) who reported the doubling time of *P. brassicae* 6.11 ± 1.15 days on cauliflower crop and also 6.00 ± 1.00, 7.89 ± 1.52, 8.66 ± 2.08 and 7.05 ± 1.15 days on cabbage, mustard, radish and broc coli, respectively at 28℃, 65 ± 5% RH. The shortest doubling time was recorded on cabbage followed by cauliflower crop. The data revealed that shortest doubling time was estimated at 20:10ºC of about 7.4577 days. The difference in values obtained from present findings might be due to nutrition obtained from artificial diet as compared to natural diet.

Annual rate of increase (R0365/T)

It is defined as the change in population number from one point of time to another, assuming that the rate of increase was constant throughout the year. This can be calculated from the intrinsic rate of increase (r) or finite rate of increase (λ) or doubling time (DT), or the net reproductive rate (R0). During 2021, the annual rate of increase at different alternating temperatures of 17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5ºC was observed to be 4.95×10^3, 2.43×10^5, 7.35×10^6, 1.20×10^9, 5.34×10^{11}, 2.88×10^{14} and 1.72×10^{18} respectively. The highest annual rate of increase was seen at 32.5:22.5ºC (1.72×10^{18}). During 2022, it was observed to be 1.09×10^3, 6.86×10^5, 3.68×10^6, 2.16×10^8, 4.55×10^{12}, 1.12×10^{13} and 5.07×10^{16}, respectively. Pooled data revealed that annual rate of increase was 1.74×10^3, 1.16×10^5, 4.72×10^6, 5.36×10^8, 1.64×10^{12}, 9.12×10^{13} and 5.57×10^{17}, respectively (Figure 7). It is evident from the present studies that doubling time increases with rise in temperature.

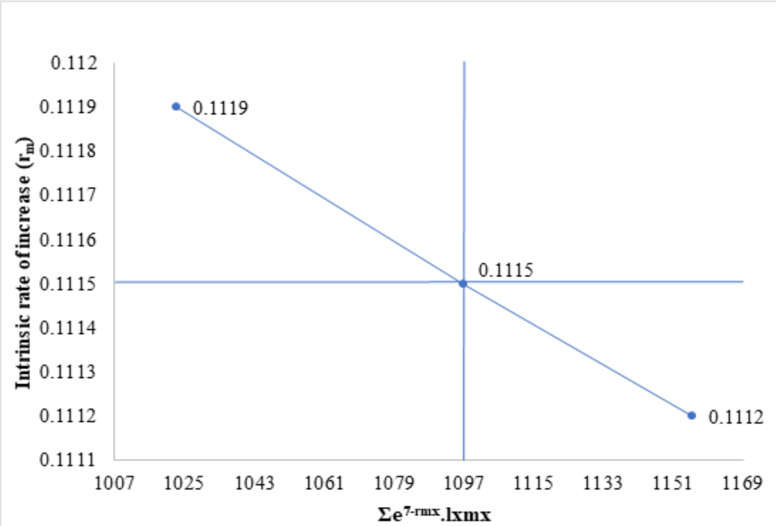

Figure 7: Determination of precise value of r_m of *P. brassicae* in cauliflower at 32.5:22.5°C and 65% RH (Pooled) in the laboratory

Results are in conformity with Hasan and Ansari who reported the annual rate of increase of *P. brassicae* $2.11 \pm 0.57 \times 10^{18}$ times on cauliflower crop and on cabbage, mustard, radish and broc coli it was $9.81 \pm 1.52 \times 10^{17}$, $8.28 \pm 2.08 \times 10^{12}$, $4.80 \pm 1.00 \times 10^{12}$ and $3.68 \pm 0.57 \times 10^{15}$ times, respectively at 28℃, 65 ± 5% RH. Vaishnav et al., reported the annual rate of increase as 97191147.07 times on cabbage crop at 25℃, 60 ± 5% RH [20]. Ali reported the annual rate of increase as 1.42×10^{17}, 1.19×10^{15}, 1.15×10^{13}, 9.99×10^{11} and 5.39×10^{10} on cabbage, cauliflower, gobhi sarson, yellow mustard and Indian mustard, respectively. The difference in values obtained from present findings might be due to nutrition obtained from artificial diet as.

CONCLUSION

The study was also conducted to determine the effect of alternating temperatures *i.e.* 17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5ºC on various developmental stages of *P. brassicae*. Temperature significantly affected the incubation period, larval period, pupal period, adult longevity and fecundity of *P. brassicae*. During 2021, it was observed that egg duration of *P. brassicae* ranged from 14.26 ± 0.05 days at 17.5:7.5ºC to 4.45 ± 0.09 days at 32.5:22.5ºC. Total larval duration was longest at 17.5:7.5ºC (48.73 ± 0.53 days) and shortest at 32.5:22.5ºC (10.73 ± 0.39 days). Pupal period of *P. brassicae* varied from 25.31 ± 0.10 days at 17.5:7.5ºC and 8.56 ± 0.18 days at 32.5:22.5ºC. The male longevity ranged from 12.33 ± 0.31 days at 17.5:7.5ºC to 4.13 ± 0.21 days at 32.5:22.5ºC. The female pre-oviposition was observed to be maximum at alternating temperature of 17.5:7.5ºC (3.83 ± 0.09 days) and minimum at 32.5:22.5ºC (1.33 ± 0.11 days), oviposition period varied from 17.5:7.5ºC (7.87 ± 0.29 days) to 32.5:22.5ºC (3.39 ± 0.12 days) and post-oviposition period was maximum at 17.5:7.5°C (2.28 ± 0.07 days) and minimum at 32.5:22.5ºC (1.02 ± 0.04 days).

The overall female longevity was highest at 17.5:7.5°C (13.98 ± 0.19 days) and lowest at 32.5:22.5ºC (5.74 ± 0.14 days). With increase in alternating temperature, there was a significant decline in female longevity. The highest fecundity of 260.25 ± 1.85 eggs per female was observed at 32.5:22.5ºC and minimum fecundity of 59.68 ± 0.34 eggs per female at 17.5:7.5ºC. During 2022, incubation period varied from 16.82 ± 0.04 days at 17.5:7.5ºC and 4.93 ± 0.18 days at 32.5:22.5ºC. Total larval duration was longest at 17.5:7.5ºC (52.74 ± 0.61 days) and shortest at 32.5:22.5ºC (12.36 ± 0.35 days). Pupal period of *P. brassicae* was longest at 17.5:7.5°C (27.37 ± 0.12 days) and shortest at 32.5:22.5ºC (9.48 ± 0.17 days). Differences in the results of total duration of various developmental stages might be due to variation in alternating temperatures. The male longevity ranged from 12.27 ± 0.28 days at 17.5:7.5ºC to 4.75 ± 0.23 days at 32.5:22.5ºC. Female pre-oviposition was observed to be maximum at alternating temperature of 17.5:7.5ºC (3.98 ± 0.08 days) and minimum at 32.5:22.5ºC (1.21 ± 0.11 days), oviposition period varied from 17.5:7.5°C (7.56 ± 0.07days) to 32.5:22.5ºC (3.37 ± 0.05 days) and post-oviposition period was maximum at 17.5:7.5°C (2.75 ± 0.03days) to 32.5:22.5ºC (1.29 ± 0.06 days). The overall female longevity was highest at 17.5:7.5°C (14.29 ± 0.83 days) and lowest at 32.5:22.5ºC (5.87 ± 0.07 days). The highest fecundity of 253.87 ± 1.58 eggs per female was observed at 32.5:22.5ºC and minimum fecundity of 63.59 ± 0.59 eggs per female at 17.5:7.5°C. It is evident from the present studies that with increase in alternating temperature there was an increase in fecundity.

During 2021, among the life table parameters of *P. brassicae*, the net reproductive rate (R0) ranged from 9.54 at alternating temperature of 17.5:7.5°C and 26.54 at 32.5:22.5ºC depicting 9.54 times the population would multiply after completion of a generation at 17.5:7.5ºC. The maximum mean generation time was observed at 17.5:7.5°C (96.75 days) and minimum at 32.5:22.5ºC (28.50 days). Intrinsic rate of increase (r_m) of *P. brassicae* was observed to be highest at 32.5:22.5ºC (0.11504) and lowest at 17.5:7.5ºC (0.02331). Finite rate of increase of *P. brassicae* was recorded highest at 32.5:22.5ºC (1.1219) and lowest at 17.5:7.5ºC (1.0235). Similarly, during 2022, the net reproductive rate (R0) ranged from 7.35 at alternating temperature of 17.5:7.5°C and 24.06 at 32.5:22.5ºC depicting 7.35 times the population would multiply after completion of a generation at 17.5:7.5°C. The maximum mean generation time was observed at 17.5:7.5°C (104.02 days) and minimum at 32.5:22.5ºC (30.18 days).

Intrinsic rate of increase (r_m) of *P. brassicae* was observed to be highest at 32.5:22.5ºC (0.10538) and lowest at 17.5:7.5°C (0.01917). Finite rate of increase of *P. brassicae* was recorded highest at 32.5:22.5ºC (1.1111) and lowest at 17.5:7.5°C (1.0193). Precise value of r_m was calculated using formula of (Southwood 1978) and precise value of pooled data was 0.02108, 0.03198, 0.04212, 0.04878, 0.07715, 0.08815 and 0.11150 at alternating temperatures of 17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5ºC, respectively. Maximum weekly multiplicative rate was recorded 2.1894 at 32.5:22.5ºC and minimum was recorded 1.1539 at 17.5:7.5°C. Longest doubling time was recorded at 17.5:7.5°C (34.8690) and shortest at 32.5:22.5ºC (6.2767). Pooled data of annual rate of increase was 1.74×103, 1.16×105, 4.72×106, 5.36×108, 1.64×1012, 9.12×1013 and 5.57×1017, respectively at alternating temperatures of 17.5:7.5, 20:10, 22.5:12.5, 25:15, 27.5:17.5, 30:20 and 32.5:22.5ºC, respectively.

Among all alternating temperatures maximum population was observed at 30:20℃ and was found to be appropriate temperature for growth and development of *P. brassicae* on cauliflower. Overall, on the basis of two seasons study, the maximum growth index was observed on late season crop as compared to main season crop which indicated that *P. brassicae* grew well on late season crop. In field life tables, it can be concluded that the maximum key mortality factors were operating on the early instar larval stages (I-III) of *P. brassicae*. On the basis of tested alternating temperature combinations, 27.5:17.5°C and 30:20℃ at 65 per cent R.H. were found to be the most favourable conditions for the growth and development of *P. brassicae* on cauliflower crop as damage caused by *P. brassicae* could be reduced by integrated pest management practices to reduce the economic yield loss of the crop.

AUTHORS CONTRIBUTIONS

DS designed the study. DS conducted experiments and collected data, analyzed the data. Contributed materials and tools. DS wrote the manuscript and edited the manuscript. Author have read and approved the manuscript.

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DATA AVAILABILITY

All data will be made available upon request.

COMPETING INTERESTS

The authors declare no competing interests.

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