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Exploring developmental plasticity in *Aphis fabae* (Hemiptera: Aphididae) across varied temperature conditions

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Abstract
The vegetable crops cultivated in Bangladesh confront annual threats from insect pests, with aphids, as piercing-sucking insects, emerging as particularly perilous. These pests inflict direct damage by extracting cell sap and indirectly contribute to severe yield loss by transmitting viral diseases. Given that insects, as poikilothermic arthropods, are significantly impacted by temperature fluctuations throughout their life cycle, this study investigates the influence of varying temperatures (15 °C, 20 °C, 25 °C, and 30 °C) on the life table parameters of aphids reared on bean leaves in a controlled laboratory setting during the winter season. The initial aphid culture originated from the experimental fields of the Department of Entomology at Bangabandhu Sheikh Mujibur Rahman Agricultural University in Gazipur. The study, conducted at the university's laboratory, revealed that lower temperatures (15 °C and 20 °C) favored aphid population development, while higher temperatures (25 °C and 30 °C) adversely affected aphid populations. These findings provide crucial insights into the seasonal dynamics of aphid populations, serving as a scientific basis for the development of targeted pest management strategies, particularly during winter conditions.

Keywords: *Aphis fabae*, aphid, life table, temperature effect

Introduction
Global warming is often regarded as one of the most pressing modern environmental challenges. From 1880 to 2012, the average global temperature increased by 0.72 degrees Celsius, and it is expected to climb another 1.1 degrees Celsius to 6.4 degrees Celsius by the end of the twenty-first century (Jamieson *et al*., 2012) [6]. Climate warming poses a significant problem to poikilotherms such as insect herbivores (Bale *et al*., 2002) [3]. Most previously published research found that increases in atmospheric temperature have a direct effect on the life cycles, phenology, behavior, and distribution of insect herbivores, or have an indirect effect through other parameters that respond to temperature-induced changes (Yao *et al*., 2020 and Wang *et al*., 2021) [15, 12].
The Hemiptera, the largest exopterygote group of insects, encompasses over 80,000 known species and presents a diverse array, including scale insects, aphids, whiteflies, true bugs, leafhoppers, planthoppers, treehoppers, cicadas, spittlebugs, and psyllids (Wilson & Turner, 2010) [13]. Among these, aphids are notable pests affecting a broad spectrum of agricultural crops due to their rapid reproduction and growth rates. They not only cause direct damage to their hosts, but they are also important vectors for many plant infections. The aphids indirectly cause mold to form as a result of honeydew excretion. *Aphis fabae* Scopoli (Hemiptera: Aphididae) is a major pest of many cultivated crops, including beans, tomatoes, potatoes, and tobacco, as well as countless wild and ornamental plant species. Given their small body size, aphids are highly sensitive to ambient temperature changes, influencing their development, survival, and reproduction (Wu *et al.,* 2020) [14]. Temperature emerges as the predominant environmental factor influencing insect behavior, dispersal, development, and reproduction (Kocmánková *et al.,* 2009) [7]. The anticipated alterations in insect-plant and insect-environment interactions due to global climate change encompass shifts in geographic ranges, enhanced overwinter survival rates, increased generational turnover, heightened risk of invasive species, and insect-transmitted plant diseases (Srestha, 2019) [9].

Aphids require a temperature range that is specific to their growth rate and development cycle (Wang *et al*., 2020) [11].
This paper focused on examining the impact of climate change since it has a significant impact on the occurrence and developmental stages of insects. Life tables are powerful tools for investigating and understanding the impact of external influences such as temperature on insect population growth, survival, reproduction, and rate of growth (Chi and Su 2006) [6]. To have a better knowledge of the variation in biology of *A. fabae*, accurate life tables for this pest at various temperatures must be developed.

Materials and Methods

Experimental Site

Location: The study was conducted in the laboratory of the Department of Entomology, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur.
Source of Culture: Apterous *A. fabae* nymphs were obtained from a faba bean (*Vicia faba*) field at the Department of Entomology, BSMRAU.

Treatments

Four different temperatures were considered as treatments as we want to investigate different temperature effect on life cycle of aphid. The treatments were - Treatment 1 = 15 °C, Treatment 2 = 20 °C, Treatment 3 = 25 °C and Treatment 4 = 30 °C.

Collection of apterous aphid for laboratory research

Aphid infested plant parts were randomly selected from the bean field at the Entomology department, BSMRAU. After selecting the parts (the first 3 leaves from the apical portion of the selected plants) aphid nymphs were removed from them with the help of thin brush and collected for further study conducting in the laboratory.

Rearing of Aphid under Laboratory Conditions

Temperature for Culture Maintenance: Insects were reared on *V. faba* leaves and housed in a growth chamber at 25±1 °C, 70±5% RH, with a photoperiod of 16:8 (L:D) h to facilitate the development of nymphs into adults for further research.

Adult Treatment and Data Collection

Experimental Setup

60 adults of *A. fabae* were collected and transferred to faba bean leaves for the life table investigation and were kept in the plastic petri dishes (9 cm in diameter). To keep a bigger room for the leaf, a cardboard paper was rolled to encircle the petri dish, holes were punctured in the cardboard paper with many pinholes for ventilation, and then covered with the petri dish lid.

Replicates

Three replicates were used. 60 adults were divided into 3 replicates, each with 20 adults, for four constant temperature treatments (15 °C, 20 °C, 25 °C, and 30 °C).

Feeding

As aphids are sucking pests and they suck cell sap from the tender leaves and plant parts, faba bean leaves were placed in the petri dishes as a source of cell sap for the insects. To keep the leaf from drying out, a moist cotton pad (0.5 cm thick) was placed around the petiole. As needed (every 2-3 days), leaves were replaced with fresh ones.

Data Recorded

Adult period, fecundity, pre-reproductive period and reproductive period were recorded daily.

Nymph Treatment

Nymph Division: Each life table began with 20 newborn nymphs produced under the respective temperatures with 3 replicates (20 nymphs each) for each treatment (15 °C, 20 °C, 25 °C, and 30 °C).

Conditions

Newborn *A. fabae* nymphs were transferred to the undersurface of an apical leaf in plastic petri dishes (9 cm in diameter).

Observation

Until the adult stage, nymphal developmental period was recorded every 24 hours. After adults emerged, the number of nymphs produced by females was recorded daily until all adults died.

Data Analysis

Principal component analysis was done to determine the contribution of different parameters to evaluate the temperature effect on the life stages of aphid. All the statistical analysis to determine the temperature effect on life stages of aphid were performed through statistical package "R".

Results

Table 1 summarizes the mean duration of each stage of *A. fabae* at four constant temperatures. The duration of the immature/nymphal stage ranged from 5.12 days (25 °C) to 11.45 days (15 °C).
Adult *A. fabae* lived 34.23 days on average at 15 °C, but only 11.42 days at 30 °C. As a result, temperatures had a significant impact on *A. fabae* total longevity; the highest longevity was 45.68 day at 15 °C, while the shortest was 18.44 day, occurred at 30 °C.
At 15 °C, *A. fabae* began to produce offspring at age 12.14 day (pre-reproductive period) when the age was counted from birth, which was much later than those reared at 25 °C (6.01 day). However, at 30 °C, the pre-reproductive period was 8.21 day, which was significantly longer than that at 25 °C. The shortest reproductive period was 3.51 day at 30 °C. The highest mean fecundity was observed at 15 °C, while the lowest value was 4.11 offspring at 30 °C.

Table 1: Durations of different life stages of bean aphid *(Aphis fabae).* Each data is the mean of 3 replications

Variables (Different life stages of aphid)	Treatment mean (Temperature)			
	T_1=15 °C	T_2=20 °C	T_3=25 °C	T_4=30 °C
Nymph period	11.45 a	7.56 b	5.12 d	7.02 c
Prereproductive period	12.19 a	8.09 c	6.01 d	8.21 b
Reproductive period	23.51 a	16.53 b	14.24 c	3.51 d
Adult period	34.23 a	22.43 b	19.53 c	11.42 d

Total longevity	45.68 a	29.99 b	24.65 c	18.44 d
Fecundity	89.35 a	77.67 c	81.49 b	4.11 d

[Each data is the mean of 3 replications. Means with the same letter are not significantly different]

The correlation among the variables was analyzed using the correlation matrixes (Fig 1), the blue to white colors indicate positive correlation and red to white colors indicate negative correlation. The deeper the blue color the stronger the positive correlation and the deeper the red color the stronger the negative correlation.

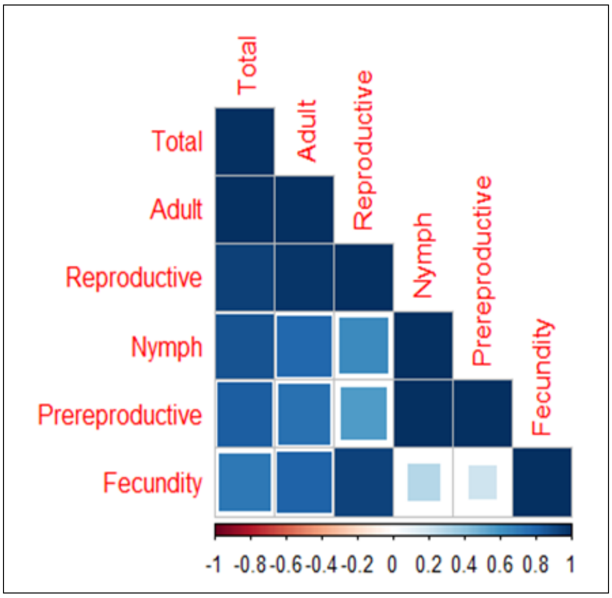


Fig 1: Correlation matrix among the different variables. Correlation plots represent the order wise relationship corresponding to color gradient between different variables

In this figure, all the variables are positively correlated. The highest positive correlation was between nymphal period and pre-reproductive period (99.47%) followed by adult and total longevity (86.71%) and between reproductive period and adult period (78.86%). The most weak positive correlation was between fecundity and pre-reproductive period (20.18%) followed by correlation between fecundity and nymphal period (28.11%).

Heatmap dendrogram is used to represent the result of a hierarchical clustering calculation of the variables (Figure 2). The result of a clustering is presented as the distance or similarities between the clustered rows or columns depending upon the selected distance measure.

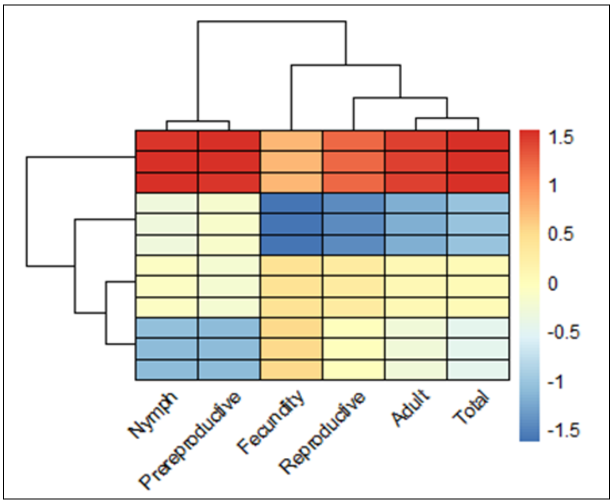


Fig 2: Heatmap dendrogram to visualize the result of a hierarchical clustering of the analyzed parameters

Total longevity is closely associated with adult period as they offer short distances followed by reproductive period and fecundity and they remain in same clade. Nymphal period and pre-reproductive period is closely associated and they remain in the same clade but distant from fecundity, reproductive period, adult period and Total longevity clade.

Principal component analysis (PCA) was done with the variables of data collection of life stages of aphid in 4 different treatments and it was found that the first two components could explain more than 99% of the variation presented in the Figure 3. So in the PCA biplot analysis, two dimensions were considered with referring to variance 1 and 2.

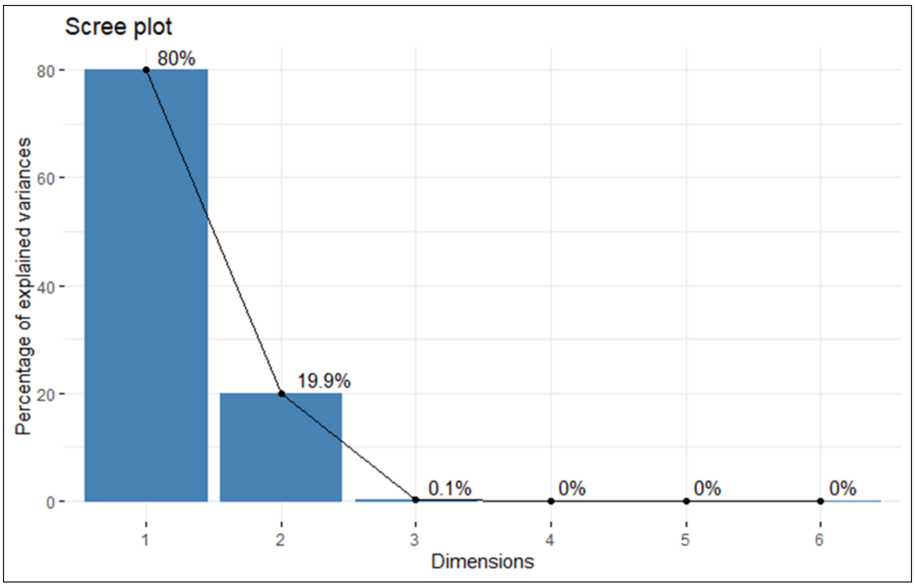
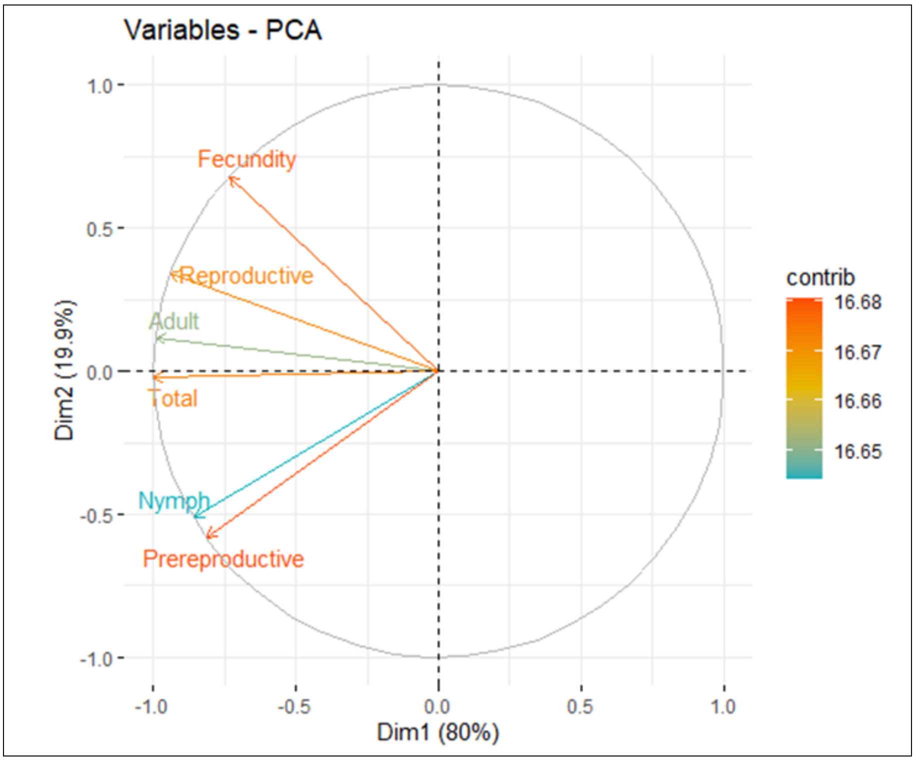
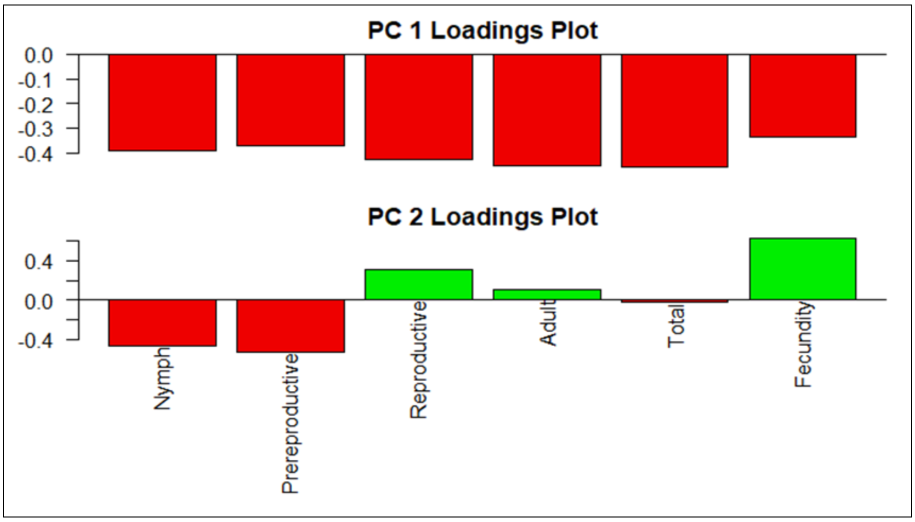


Fig 3: Principal component analysis (PCA) among the life stage variables of Aphid in 4 different treatments

The contribution of different variances in PCA is presented in Figure 4(a, b). Here dimension 1 alone contributed 80% and dimension 2 contributed 19.9%.



(a)

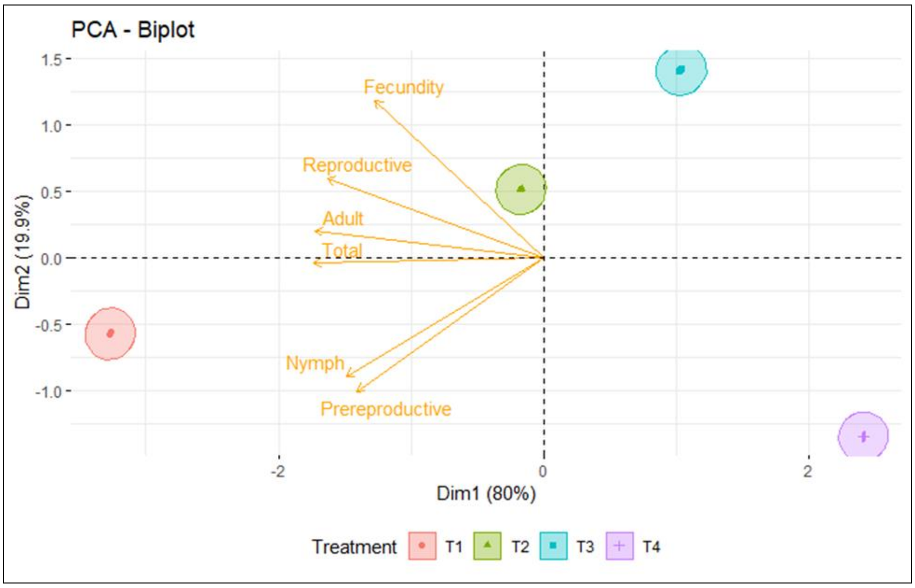


(b)

Fig 4 (a, b): Principal component analysis representing different variables for 4 different treatments

Among the 6 parameters of which the data have been collected to evaluate the treatment effect on the different life stages of aphid (variables), all the variables showed negative correlation with dimension 1. Fecundity, reproductive period and adult period showed positive correlation and among them fecundity has highest positive correlation with dimension 2 (67.92%); while total longevity, nymphal period and pre-reproductive period showed negative correlation with dimension 2.

The contribution of different variables in PCA with its corresponding treatment is presented in Fig 5.



(Dim1 = Dimension 1, Dim2 = Dimension 2, T_1 = 15 °C, T_2 = 20 °C, T_3 = 25 °C and T_4 = 30 °C)

Fig 5: Biplot generated through principal component analysis corresponding with different treatments.

The contribution of different variables in PCA with different temperature is presented in this figure. In this figure we can see that there 4 distant clusters. The clusters represent the significant effect of different temperature on the life table of aphid as they are not overlapped each other. Here fecundity, reproductive period and adult period are influenced by T_2 = 20 °C. Whereas, total longevity, nymphal period and pre-reproductive period are influenced by T_1 = 15 °C. Higher temperatures (25 °C and 30 °C) have deleterious effects on life table parameters of aphid.

Discussion

The developmental dynamics of aphids, specifically *Aphis fabae*, in response to temperature variations reveal intricate patterns with significant implications for their survival and reproductive success. Generally, aphids require more developmental time at lower temperatures before they can initiate reproduction. However, our study highlights an extended pre-reproductive period at 30 °C, which, counter intuitively, demonstrated deleterious effects at higher temperatures.

The influence of temperature on aphid survivability is a critical factor, and higher temperatures were found to have a detrimental impact, consistent with observations across various aphid species (Asin & Pons, 2001; Wang & Tsai, 2001) [2, 5]. The life table parameters in our study exhibited a consistent trend, with a decline in all aspects except fecundity after 20 °C. Notably, the lowest fecundity was recorded at 30 °C (4.11), emphasizing the temperature sensitivity of reproductive output.

Our findings align with the work of McCornack *et al*. (2004) [8], who reported similar temperature-dependent declines in net fecundity, gross fecundity, generation time, and life expectancy for aphids. This concurrence underscores the robustness of our results and the broader applicability of temperature-driven impacts on *A. fabae*.

Life table studies at varying temperatures provided comprehensive insights into the effect of temperature on the survival, development, and fecundity of *A. fabae*. The duration of immature/nymphal phases exhibited a significant decrease as the temperature rose from 15 °C to 25 °C. However, a notable increase was observed when the temperature further rose from 25 °C to 30 °C. This complex pattern in nymphal development aligns partially with the findings of Din (1976) [5], who noted an increase in the rate of nymphal development up to 29 °C, with fecundity peaking at 25 °C. Interestingly, our study indicates that the highest fecundity occurred within the range of 15-20 °C, showcasing the nuanced temperature preferences influencing reproductive outcomes.

As temperatures increased from 15 °C to 30 °C, both adult duration and total longevity exhibited considerable decreases. This trend is consistent with the findings of Akca *et al*. (2015) [1] for *Aphis fabae*, highlighting the general sensitivity of aphid life history traits to temperature variations.

Conclusion

Temperature emerged as a significant factor influencing the developmental rate, survivorship, reproduction, and longevity of *A. fabae*. According to our comparative life table study, temperatures of 20 °C and 25 °C appeared most conducive for population expansion among the evaluated temperature ranges (15 °C, 20 °C, 25 °C, and 30 °C). The insights gained from this study can contribute to the development of climate-resilient pest management strategies, which can aid in mitigating potential losses in crop yield and ensuring food security amidst changing climatic conditions.

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