EFFECT OF HEAT STRESS ON LIFE HISTORY OF PEA APHID, *Acyrthosiphon pisum* (HARRIS) (HEMIPTERA: APHIDIDAE) BASED ON LIFE-TABLE TECHNIQUE

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Aphids are ectothermic organisms; all their physiological processes largely depend on several climatic variables that include temperature. Therefore, in order to understand the heat stress effect on the pea aphid, *Acyrthosiphon pisum* (Harris), their life history parameters were studied at five constant temperatures 27, 30, 33, 36 and 39°C Con Chinese broad bean (*Vicia faba*) using life-tables technique. The larvae development period (from birth to adulthood) was highest at 27°C and minimum at 39°C. At all temperature, the larvae developed very rapidly, whereas as at 39°C, the development period recorded was very slow. The immature rate of development during 27°C to an optimum around 36°C increased fastly and after that declined to 37% at 39°C. The immature survival stage percentage within the range of 27-36°C significantly different from 79% to 89 %. Survival declined. The adult aphid longevity was 9.0, 9.1, 8.8, 6.9 days, offspring number normally produced was 37, 30, 16, 11, and 0, at temperatures of 27°C, 30°C, 33°C, 36°C, and 39°C, respectively. Furthermore, intrinsic rate of increase significantly higher from 27 to 36°C which indicated that at 39°C *A. pisum* growth recorded optimum. However, upper 39°C its limits its reproduction. These results were reflected in the population growth of the pea aphids on Chinese broad bean increased with increasing temperatures between 27°C and 36°C, and declining thereafter. This research outcome delivers important evidence and it might be very significant in progress and implementation programs for *A. pisum* management.

**Keywords**: *Acyrthosiphon pisum*, chinese Broad bean, development, heat stress, survival, fecundity, life table.

INTRODUCTION

The pea aphid, *Acyrthosiphon pisum* (Harris) (Hemiptera: Aphididae) distributed world-wide and considered as a significant pestiferous insect. After the crop emergence, aphid colonies rapidly increase and population of pest rise quickly causing significantly economical injury (Ahmet et al., 2018; 2019). However, economic threshold for pest have been determined, whereas for population of aphid development no method has been until predicted (Angilletta, 2009). The *A. pisum* rational management and effective development depend on an in-depth considerate of pest biology, and in specific of the prevailing temperature effect on main parameters of life history leading the population development rate and timing. However, the temperature was observed to be most effective. Population of insect such as mortality, fecundity, delay pre-reproductive and development effected by temperature. Life histories of pea aphid and effect of temperature on it has been published in several reports (Huffaker et al., 1999; Bayhan et al., 2005). Ecological high temperature spatially and temporarily fluctuates, therefore, many thermal stresses used to expose insects not individually throughout the day however also during their life-cycle (Feder et al., 2000). Due to ectothermic physiology and small in size, aphids are mainly weak to variation in temperature (Denlinger and Yocum, 1998; Angilletta, 2009). Most species of insects are altered to particular different ranges of temperature, and about extreme temperature it has been shown in many published papers, both cold and hot, can effect several their life history characters for example fecundity, mortality, reproductive success, longevity, survival of adult and development rate (Amice et al., 2008; Mironidis and Savopoulou, 2008; Mironidis and Savopoulou, 2010). However, up to now, regarding extreme range of temperatures, it has been reported in various studies that either heat stress at different small periods were equivalent to shocks of cold or heat temperature (Roux et al., 2010; Hance et al., 2007). Nevertheless, beneath ordinary situations, insects additional commonly come across fewer melodramatic circumstances. Certainly, they are repetitively exposed to variation in temperature however inside narrower assortments, henceforth signifying modest stresses...
MATERIALS AND METHODS

*Acyrthosiphon pisum* reared on different broad bean. These broad bean plants maintained the colony of *A. pisum* in the greenhouse. Fresh leaves of broad bean were selected for the experiment purpose. controlled room temperature at 25 ± 1°C, 65 ± 10% RH, and 14:10 (L:D) h photoperiod (Abdel-Rahman et al., 2011). Adult aphids were used for all experiments.

**Experimental design:** From the stock population females were selected Randomly, and they were shifted to the bean leaf disk for nymphal production. For each temperature experiment newly born nymphs within 24 h were selected. New born nymphs were shifted to the lower ends of the detached bean leaves and placed in the petri dishes at the bottom along with moist filter papers. Only 1 aphid was permitted to stay in 1 petri dish at 27, 30°C, 33°C, 36°C and 39°C fix temperatures, in environmental chambers all the aphids were and kept with RH 60 ± 5% and 14 h:10 h a light: dark photoperiod. 30 nymphs (in 30 petri dishes) per temperature treatment. Replicates in which nymph’s mortality in first 24 hours were omitted. Regularly, in the Petri dishes with daily moistened filter papers were moistened regularly and after every 2-3 days in the new bean leaf disks aphids were transferred. Nymphs were observed daily for their mortalities and molting. The development time and the survivorship of immature were recorded. After the adult hatch and beginning of the nymphal production, all newly born nymphs number were recorded, and then remove the crowding potential influence of temperature (Audu et al., 2009). Data was recorded till the mortality of all the aphids.

**Data analyses and statistics:** The individual biological parameters (TPOP period of total pre-oviposition, duration of nymph, adult longevity and duration, nymphal mortality), and population parameters of population (T mean generation time, λ finite rate of increase, \( R_0 \) net reproductive rate, F fecundity, and \( r_m \) intrinsic rate of increase) and parameters of life table \( v_{xj} \) age-stage specific reproductive rate, \( e_{xj} \) age-stage specific life expectancy, \( f_{xj} \) age-stage specific fecundity, \( m_{xj} \) age-specific fecundity, \( l_x \) age-specific survival rate, \( (s_{xj} \) age-stage specific survival (where \( x = \) age of insect in days and \( j = \) stage), were calculated (Chi and Liu 1985; Chi 1988). The adult aphid reproductive period of, period of total preproduction (from birth to producing the first nymph), fecundity and period of longevity (from birth to death) and in four treatments were calculated and the collected data were subjected to statistical analysis. The population parameters \( R_0 \) values are calculated as:

\[
R_0 = \sum l_x m_x
\]

Iterative bisection method from the formula of Euler-Lotka was used to estimate \( r \) along with indexed of age from 0 (Goodman, 1982). The \( \lambda \) calculated as \( \lambda = e^r \). length of time defined by the mean generation time that a population requirement to upturn to \( R_0 \)-fold of its size of population at the distribution of stable age-stage, and calculated as \( T= (\ln R_0)/r \). According to Tuan et al., (2014a, b) The reproductive value \( (v_{xj}) \) was calculated. In the life table parameters, length
of time is denoted by the life expectancy (\(e_x\)) that an individual of stage \(j\) and age \(x\) is live expectedly to and calculated according to (Chi and Su, 2006). All analysis done by TWOSEX-MS Chart the computer program (Chi, 2017a). This is available online at http://140.120.197.173/Ecology/Download/Twosex-MS Chart. rar for operating window system and written as written in Visual BASIC. Since, Carter et al. (1978), and Hesterberg (2008), pointed out that potentially cause problems through simplified methods. Therefore, technique of bootstrap we used along-with re-sampling of 200,000 for the estimation of population parameters standard error and the variances of the (Efron and Tibshirani, 1993; Huang and Chi, 2012). Polat-Akköprü et al. (2015), explained bootstrap technique advantages. Comparing various treatment, at 5% significance level we used the paired bootstrap test.

RESULTS

The individual biological parameters on different treatment:

Statistical analysis revealed that the shortest pre-reproductive period (Nymph duration) was with the highest temperature of 39°C (\(F=16.5, df=3,187, P<0.05\)) and the longest reproductive periods (Adult duration) were observed on normal 27 and 30°C. However, High temperature could lead to a significant difference on aphid longevity (\(F = 1.8, df = 3,187, P > 0.05\)). Acyrthosiphon pisum developmental time significantly decreased with increase of temperature, starting from 27 to 39°C (Table 1).

The minimum time was recorded at 36°C to complete a nymphal stage; however, the maximum temperature 39°C resulted in the decline of the developmental rate compared to the 36°C. The maximum temperature 39°C was found harmful for the immature stages survival at 27-36°C Aphids reared depicted highest survivorship whereas at high temperature of 39°C aphids exhibited the lowest survival where highest nymphal mortality was observed at high temperature of 39°C (Table 1).

Nymphal stage completed at 36°C which required minimum time. However, on the other hand, developmental rate recorded decline at 39°C because of high temperature. The extreme temperature 39°C was recoded harmful for the survival of aphid Immature stages. Survival ship was recorded highest among 27-37°C. However, survival ship was recorded lowest at 39°C. Meanwhile highest mortality rate was also recorded at 39°C The longevity and fecundity of the adult aphids were significantly affected by the temperature (Table 1, and 2). Exponential decrease in mean longevity was observed from 9.0 to 6.1 with the increase of temperature from 27 to 39°C (Table 1). Moreover, at different temperatures generation time (\(T_0\)), and \(r\) increase intrinsic rate of increase, (\(R_0\)) the net reproductive rate, \(\lambda\) were measured for the aphid (Table 1). However, at 36°C the \(R_0\) was highest 0.23. At 30°C, the net reproductive rate (\(R_0\)) was longer (23.0) than that for temperatures at 33°C (16.83), 36°C (15.20), and 39°C (14.60) (Table 1). Furthermore, Shorter generation times (\(T_0\)) resulted at due to increase in temperature for Acyrthosiphon pisum, which completed a generation at 27°C and 36°C (Table 1). On the other hand, at Temperature 27°C, the total longevity longest occurred which were significantly not different (\(F=4088.4, df=4, P < 0.01\)). Low temperature also had a significant effect on female fecundity (\(F= 18.8, df = 3,187, P < 0.05\)) significantly affected by low temperature. Whereas, with 27°C and 30°C per female produced offspring’s in higher number

The life-table parameters of Acyrthosiphon pisum on different treatment.

### Table 1. Population dynamic parameters of Acyrthosiphon pisum on different treatment.

<table>
<thead>
<tr>
<th>Treatments (°C)</th>
<th>(R_0) Mean ± SE</th>
<th>(r) Mean ± SE</th>
<th>(T) Mean ± SE</th>
<th>(F) Mean ± SE</th>
<th>(\lambda) Mean ± SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>16.30 ± 3.52a</td>
<td>0.27 ± 0.02a</td>
<td>10.30 ± 0.32a</td>
<td>27.17 ± 4.26a</td>
<td>1.31 ± 0.02a</td>
</tr>
<tr>
<td>30</td>
<td>23.03 ± 4.79a</td>
<td>0.33 ± 0.02a</td>
<td>9.40 ± 0.26b</td>
<td>38.38 ± 5.64a</td>
<td>1.39 ± 0.36a</td>
</tr>
<tr>
<td>33</td>
<td>16.83 ± 3.70a</td>
<td>0.29 ± 0.02a</td>
<td>9.61 ± 0.21ab</td>
<td>33.66 ± 4.20a</td>
<td>1.34 ± 0.03a</td>
</tr>
<tr>
<td>36</td>
<td>15.20 ± 4.60a</td>
<td>0.28 ± 0.03a</td>
<td>9.49 ± 0.21b</td>
<td>38.00 ± 7.95a</td>
<td>1.33 ± 0.04a</td>
</tr>
<tr>
<td>39</td>
<td>14.60 ± 4.10a</td>
<td>0.26 ± 0.04a</td>
<td>10.18 ± 0.21a</td>
<td>39.82 ± 5.96a</td>
<td>1.30 ± 0.04a</td>
</tr>
</tbody>
</table>

### Table 2. Effects of different treatment on development duration of Acyrthosiphon pisum

<table>
<thead>
<tr>
<th>Treatments (°C)</th>
<th>n</th>
<th>Nymph Mean ± SE</th>
<th>Adult Mean ± SE</th>
<th>Longevity Mean ± SE</th>
<th>Nymph mortality Mean ± SE</th>
<th>TPOP Mean ± SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>30</td>
<td>7.0 ± 0.2a</td>
<td>5.7 ± 0.9a</td>
<td>9.0 ± 1.0a</td>
<td>0.40 ± 0.09a</td>
<td>7.1 ± 0.2a</td>
</tr>
<tr>
<td>30</td>
<td>30</td>
<td>7.2 ± 0.3ab</td>
<td>5.2 ± 0.8a</td>
<td>9.1 ± 0.9a</td>
<td>0.40 ± 0.09a</td>
<td>7.2 ± 0.3a</td>
</tr>
<tr>
<td>33</td>
<td>30</td>
<td>7.2 ± 0.3ab</td>
<td>5.7 ± 0.8a</td>
<td>8.8 ± 0.9a</td>
<td>0.50 ± 0.09a</td>
<td>7.2 ± 0.3ab</td>
</tr>
<tr>
<td>36</td>
<td>30</td>
<td>6.3 ± 0.1c</td>
<td>5.0 ± 0.9a</td>
<td>6.9 ± 0.8a</td>
<td>0.60 ± 0.09a</td>
<td>6.3 ± 0.1c</td>
</tr>
<tr>
<td>39</td>
<td>30</td>
<td>7.9 ± 0.3b</td>
<td>4.6 ± 0.7a</td>
<td>6.9 ± 0.9a</td>
<td>0.63 ± 0.08a</td>
<td>7.9 ± 0.3b</td>
</tr>
</tbody>
</table>
Figure 1. The age-stage specific survival rate ($s_{xj}$) of *Acyrthosiphon pisum* at 27°C to 39°C

Figure 2. The cumulative age-specific survival rate ($l_x$) of *Acyrthosiphon pisum* at 27°C to 39°C

Figure 3 life expectancy and reproductive value, ($l_xm_x$) the cumulative age-specific maternity, ($l_x$) age-specific survival rate, ($f_x$) age-stage specific fecundity, ($m_x$) age-specific fecundity, and ($l_xm_x$) age-specific maternity of *Acyrthosiphon pisum* at 33°C

The survivor curves and all individual’s aphid’s differentiation in stage which were reared on various temperature represented by the age-stage specific survival rates ($s_{xj}$) plotted in (Fig.1). Probability $sxj$ symbolizes by $sxj$ which shows that aphid individually survive to stage $j$ and age $x$ (Fig.1). The curve $l_x$ is the age-specific survival rate which denote simple curve version Fig.1. Its possibility
that emerged newly nymph will survive to age \( x \) whereas disregarding nymph development and stages differentiation (Fig.3). Peaks of \( (lxmx) \) age-specific maternity and \( (mx) \) the age-specific fecundity and were greater as compared to other. The expected lifespan of individual aphids of stage \( j \) and age \( x \) on various temperatures described by \( (exj) \) the age-stage specific life expectancy describes (Fig.2). At various temperature, the aphid life expectancy was different, correspondingly. The value indicates the Individual contribution at stage \( j \) and age \( x \) for population in future indicated by values of age-stage specific reproductive (Fig.4.)

**DISCUSSION**

Population dynamics of particular insect species under controlled conditions might be valuables and could be useful
Different insect species living in different areas of the world according to their tendency of bearing of temperature (Morgan et al., 2001; Frei et al., 2003; Gao et al., 2013; Tazerouni and Talebi, 2014; Ramalho et al., 2015). This experiment delivered full original and innovative regarding A. pism biology parameters like, survival, reproduction, and reproduction. Favorable conditions increase the population of insects as compared to unfavorable conditions. It is vital to recognize these important aspects, the insect population growth provided by demographic parameters, and thus to develop an integrated pest management strategy. Life tables are important tools for examining and understanding the external factors impacts for example insect population growth, reproduction, survival, and temperature on the growth (Ballou et al., 1986; Kontodimas et al., 2004; Stathas et al., 2011). Rate of development was decreased at high temperature in our study, immature stages with high mortality (73%), and no progeny production (Table I and Table 2). Different aphid species i.e. the pomegranate aphid, Aphis punicae, the spirea aphid, Aphis spiraeola, the rice root aphid, Rhopalosiphum rufiabdominalis (Sasaki), the grain aphid, Metopolophium dirhodum (Wlk.) and water lily aphid, Rhopalosiphum Nymphaeae L. showed similar results (Summers et al., 1984; Zhou and Carter 1992; Tsai and Liu, 1998; Wang and Tsaï, 2000; Bayhan et al., 2005). At all constant temperatures, A. pism Fourth instar period of development was quietly longer as compared to rest of other three instars (Table 1). However, fourth instar showed significantly mortality in higher range and delay development comparatively to other three stages when showing to extremes great temperature (30°C), indicating that instar of fourth stage at extreme temperature has low tolerance (Tables 1, 2). Aphid species like the pomegranate aphid, Aphis punicae, brown citrus aphid, Toxoptera citricida (Kirkaldy) and the English grain aphid, Sitobion avenue (Fabricius) showed similar phenomena (Tsai and Wang, 1999; Ozder, 2002; Bayhan et al., 2005). Moreover, when temperature increase from 27 to 39°C reproduction of nymphs and longevity of adult gradually decreased (Fig. 2; Table 2). In between 18 and 27°C, Satar et al., (2008) showed lower Acrystosiphon gossypii (14–46 nymphs) reproduction as compared to Aphis gossypii (59–68 nymphs). In aphid reproductive rates between any of the temperatures, there were no consistent changes with the increased temperatures among 25°C and 31°C, in the life of the adult aphids, Age-specific fecundity occurred earlier. Markkula and Roukka, (1971), found same variation in A. pism fecundity rates when kept on different pea cultivars. Even though, between the six tested varieties no differences were founded by Bieri et al. (1983). Mortality adult pea aphid’s, at extreme high temperatures, instant rates of were greater. Harrison and Barlow (1973), reported Similar Results Venomous special effects of temperature on survival was obvious, although the effect was greater. Bieri et al. (1983) reared adults on various cultivars of pea and found no variation in adult survivals which is in contrast to our finding. Adult aphid Median adult life-span with increasing temperature tended to decrease and median life-span values of were lower consistently as compared to previously published papers. Our life span results supported by Bieri et al. (1983). 23.5 days, at 15°C median life-span was recorded by Bieri et al. (1983), and 37 days founded by Siddiqui et al. (1973). However, Frazer (1972), Siddiqui et al., (1973), Campbell and Mackaue (1975) and Morgan et al., (2001) previously estimated intrinsic rates of increase, rm of 0.329 at 20°C reported by Campbell and Mackaue (1975), rm of 0.404 by Frazer (1972), rm 0.364 by Siddiqui et al. (1973), and rm 0.364 reported greater values as compared to here. In the current work, relatively longer pre-reproductive period described by these differences found. Andrewartha and Birch (1954) described herbivores physiological qualities comparative to increased capacity summarized by intrinsic rate of increase (r). It’s understood that production of nymph was temperature dependent. With temperature the values of (r) for various species aphid wide-ranging. at 30°C The intrinsic rate of increase (r) between all constant temperatures examined was the highest at 0.33 (Table 1), due to quicker growth (Table 1) and greater immature stages survivorship of (Table 2). The A. pism (r), at 30°C was lesser as compared to Aphis gossypii which was 0.360 (van Rijn et al., 1995). However, (r) showed sensitivity specifically to comparative variations to the period of the pre-reproductive duration (Xia et al., 1999 and Ahmed et al., 2018). While its proposed that variation in parameters of life history parameters among various studies might be recognized to aphids adjusting to conditions of local climates (Lamb, et al., 1987), different methods of rearing might have influenced (Campbell, et al., 1974; Hutchinson and Hogg, 1984). In this study, the variation among recorded results and previously reported results in study of North American and continental European indicates that while data comparing from disparate geographical sources care must be taken. 

Conclusion: It is understood that insect have the ability to tolerate the temperature. They increase their population according to tolerance to temperature which they required. Different region of the world has different temperature. Therefore, every specie in different parts of the world have their tolerance ability of the temperatures according to that region. Hence, The A. pism statistics of life table in this study for the constant temperature could be used to help interpret
population dynamics. *Aphid A. pisum* fecundity and population growth rate influenced by various temperature shown in this study results.

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