RESEARCH ARTICLE

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Temperature and Photoperiod influence on Biology of Grasshopper *Acridida exaltata* under Laboratory Conditions

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ABSTRACT

Insects are natural food for many vertebrates. Being nutritionally rich, acridids can be used to produce high quality feed for livestock industries. For a sustainable supply for the feed manufacturing companies, a huge acridid biomass must be obtained on a regular basis. Therefore, for successful acridid farming, a laboratory rearing system in semi-controlled conditions is proposed to produce a huge acridid biomass. Experiments were conducted to determine a favorable temperature and photoperiod for rearing the Acrida exaltata. For this purpose nymphal mortality, growth rate, fecundity, fertility, and adult dry weight were determined. Th e results revealed that, at 35±2 °C with a L: D photoperiod of 12:12, fecundity and fertility were maximum, while nymphal mortality, egg incubation period, nymphal duration, adult life span, and adult dry weight were favorable. It was concluded that 35±2 °C with a photoperiod of 12:12 is suitable for mass production of Acrida exaltata in acridid farms.

Key words: *Grasshopper farming, Acridida exaltata, photoperiod, temperature*

INTRODUCTION

There are major problem of acute shortage of animal protein in most underdeveloped and developing countries that adversely affects the protein intake level of the vast population and results in malnutrition. Therefore, enhancement of these livestock industries is becoming increasingly essential. However, livestock industries are facing difficulty to obtain a sufficient amount of feed due to a sharp rise in their price. Generally, feed accounts for more than 60% of the total cost of raising farm animals (Onimisi and Omage, 2006). Shortage of the conventional animal feedstuff s like fish, and plant feedstuff like maize and soybean, is occasioned by the competition between man and livestock for these feed sources (Vander, 1997). Hence, there is a need to look for an alternative, non-conventional, economic, protein rich, natural food source that is not competed by human population. Such replacement may include insects that can ultimately serve as a protein source for humans. In this regard Ramos-Elorduy (1984) reported that protein content of short-horned grasshoppers (acridids) varies from 52.1% to 77.1%. Recently, Wang et al. (2007) formulated high protein diets with the Chinese acridid, *Acrida cineria* and proved the insect to be an acceptable feed for broilers without any adverse effect on weight gain, feed intake, or gain: feed ratio. However, there should be a strategy for a continuous and sustainable supply of acridids to the livestock feed developing companies. In this context, Haldar, *et al.* (1999) proposed the idea of acridid farm establishment by their mass rearing with suitable food plant at optimum environmental conditions (i.e. temperature and photoperiod).

There is scanty information on any effort to use acridids as a food source for a wide variety of livestock despite their increasing farming potential in recent years. Thus, the aim of the present study was to find out the optimum temperature and photoperiod for mass rearing and high production of a common short horned Indian grasshopper to partial fulfillment of poultry feed. In this study, wide ranges of temperature and

photoperiodic regimes were selected and some biological traits of the chosen acridid species were observed.

METHODS AND MATERIALS

The acridid of interest, i.e. *Acrida exaltata*, was collected from nearby agricultural fields and grasslands of Gopalganj district from three different sites, using 30 cm diameter insect net. They were reared in the laboratory of Zoology department at Gopeshwar College, Hathua, Gopalganj, adopting the strategies proposed by Ewen and Hinks (1886) until they laid egg pods.

The nymphal mortality were studied with collection and separation of 300 newly hatched nymphs into 4 sets with 5 replicates, in transparent plastic jars of 3 L capacity (10×10×25 cm3), containing 15 nymphs per jar. The floor of each jar was covered with fine, sterilized sand of about 3-4 cm thickness and few drops of water were sprinkled regularly to keep it moist. The mouths of the jars were covered with fine nylon net. The insects were offered daily feed on different temperature and photoperiod and nymphal mortality percentage (NM%) of respective instar stages were calculated.

The growth rate study was performed with 4 different temperature and photoperiod regimes with 0-day-old and 1st instar nymphs in an environmental chamber following the above mentioned procedure. Nymphs were observed daily to observe molting, if any. Life spans of all of the intermediate instars were recorded. The instar wise growth rate (GR) was calculated by the following formula:

GR = (weight gained by the insect) × [duration of feeding period (days) × (mean weight of insect during feeding period)]–1

The neonate grasshopper were used in different regimes for egg pod/female during study with different temperatures and 12:12 photoperiod and different photoperiodic regimes on temperature restricted to 35±2°C, as their maximum fecundity was found at this temperature. The sand was examined regularly, every morning by sieving with a fine mesh to count the egg pods, if any.

To count the number of eggs per pod, the egg pods were kept in moist tissue paper on petridishes for a period of 48 h and were then placed in an environmental chamber at 32±2°C for 5 days to allow the eggs to swell. Then the frothy material was removed from the egg pods by nylon haired brushes and forceps, and the swollen eggs were separated out easily and their numbers per pod were counted accordingly (Das, *et al.,* 2001).

The egg pods laid per pair were divided into 2 groups with an equal number of individuals for fecundity and fertility. The fecundity was determined with 1st group by multiplying the mean number of egg pods laid per female to the mean number of eggs per pod. Fertility was calculated from the 2nd group by multiplying the mean number of egg pods laid per female to the mean number of fertile eggs per pod. To calculate the fertile eggs per pod, the eggs hatched per pod was calculated by the following experiment.

The Egg pods were placed inside the 1-cm thick sand of a 150 mL beaker and the mouths of the beakers were covered with nylon net for number of hatched eggs per pod. Thus 4 sets were prepared, each with 5 beakers and incubated at the 4 above mentioned temperature regimes. Then 5 other sets were prepared, each with 5 beakers and kept at 5 different photoperiod regimes and other parameters were restricted, as mentioned earlier. On emergence of the hatchlings (0 days old, 1st instar), they were counted. For these hatchlings, continuous day to day observation was done, as all of the viable eggs did not hatch on the same day.

To calculate adult dry weight, adult males, virgin females, and mated females were freeze killed and then the specimens were kept in thermo-resistant glass vials and placed in a microwave oven at 45°C for 72 h. The dried specimens were then weighed to calculate the dry weight.

STATISTICAL ANALYSIS

For each set, 5 replicates were carried out. For nymphal mortality percentage, the instar developmental period and dry adult body weight at different temperatures and photoperiods were compared via two-way analysis of variance (ANOVA). One-way ANOVA was carried out on growth rate, reproductive ability, and total nymphal developmental period at different temperatures or photoperiodic regimes. For adult life span at different temperatures, two-way ANOVA was done taking temperature and sexes as factors, but the two-way ANOVA did not show a significant difference for the adult life span at different photoperiodic regimes. Hence, one-way ANOVA was carried out for males, virgin females, and mated females individually. One-way ANOVA was carried out to observe if there was any significant effect of temperature and photoperiod on the reproductive ability of *Acrida exaltata*. Duncan's multiple range tests (DMRT) were carried out for each case followed by ANOVA in order to separate the mean values according to significance.

RESULTS AND OBSERVATION

When the jars were kept at different temperature regimes, the results showed that the nymphal mortality gradually increased with the rise of temperature from 25±2°C to 40±2°C (Table 1). Although for the 1st instar this increase was significant ($df = 3, 15$; $F = 24.63$; $P < 0.001$) for all of the temperature regimes, for the 2nd instar the results were insignificant between 30±2°C and 35±2°C (DMRT), whereas for the 3rd instar onwards, the nymphal mortality did not show any significant variation between the regimes of 25±2°C, 30±2°C and 35±2°C. When the mortality percentages were observed at different L: D photoperiodic regimes, it was recorded that the results gradually decreased up to 12:12 and then again gradually increased (Table 2).

Maximum mortality ($df = 4, 20$; $F = 21.76$; $P < 0.001$) was noted in the sets kept in total darkness, followed by the sets kept in total light. For the 1st instar, less nymphal mortality was observed at 12:12 and 6:18; however, from the 2nd instar onwards, less mortality was at 18:6, 12:12, and 6:18. When growth was compared within instars between the different temperature regimes, it was observed that all of the instars, except the 2nd one, had a similar trend, i.e. growth rate increased with the rise of temperature from 25±2°C to 35±2°C (Table 3). In contrast, in the case of the 2nd instar, the growth rate increased from 25±2°C to 30±2°C and then gradually decreased at 35±2°C and 40±2°C. Another notable observation was that at 40±2°C, the growth rate was significantly lower ($df = 15, 119$; $F = 200.42$; $P < 0.001$) for all of the instars. At different photoperiodic regimes, each instar, except for the 3rd, showed a similar trend; growth rate increased as the duration of light increased from 0 h to 12 h (i.e. 24:0 to 12:12), followed by a gradual decrease of growth for further increase of light duration. In the case of the 3rd instar, the growth rate initially increased from 24:0 to 18:6 and then a gradual decrease was observed (Table 3).

For egg pods laid per female, fecundity and fertility, the temperature regime 30±2°C to 35±2°C was recorded as the optimum range because the regimes below and above this range gave significantly lower values ($df = 19$, $F = 11.96$, $P < 0.001$; $df = 17.8$, $F = 75$, $P < 0.05$; $df = 19$, $F = 233.37$, $P < 0.001$, respectively) (Table 3). Number of eggs per pod ($df = 19$, $F = 14.15$, $P < 0.001$) and fertile eggs per pod ($df = 19$, $F = 233.37$, $P < 0.001$) were significantly lower at the highest temperature regime, i.e. 40±2°C. No significant variation was observed among the rest of the regimes. Egg incubation period decreased with increased temperature ($df = 3, 16$; $F = 50.02$; $P < 0.001$). However, no significant variation was observed between the 2 higher (i.e. 35±2°C and 40±2°C) and the 2 lower (i.e. 25±2°C and 30±2°C) temperatures. All of the chosen reproductive parameters, except for egg incubation period, arbitrarily gave better results along with increased light duration up to 12:12 and a further increase of light duration gave lower values (Table 3). However, egg pods per female showed no significant variation among the 5 different photoperiodic regimes. The other 4 parameters showed significantly higher values at 12:12 (eggs per pod: $df = 4, 20$; $F = 61.4$; $P < 0.001$, fertile eggs per pod: $df = 4, 20$; $F = 6.43$; $P < 0.01$,

fecundity: df = 4, 20; F = 292.08; P < 0.001, and fertility: df = 4, 20; F = 433.55; P < 0.001). The mean values of egg incubation period gradually decreased with the increased light duration, though the results of 12:12, 6:18, and 0:24 showed insignificant variation.

When the instar-wise variations of nymphal developmental period at different temperature regimes (Table 4) were considered, it was observed that the mean values of nymphal developmental periods were always high at 25±2°C. However, from the 3rd instar onwards, no significant variation was observed within the instars when the results were statistically compared between different temperature regimes, whereas the shortest (df = 4, 20; F = 3.88; P < 0.001) duration for the 2nd instar was observed at 40±2°C. Total nymphal duration was also calculated; however, no significant variation was observed (P > 0.05) between the selected temperature regimes.

Table 1: Nymphal mortality percentage of *Acrida exaltata* at different temperature regimes. Different letters within a row indicate difference between mean values (Two-way ANOVA, DMRT, p<0.001)

Instars	25±2⁰C	30±2⁰C	35±2⁰C	40±2⁰C
1	21.8±1.3 a	24.4±0.55 b	26.8±0.84 c	51.8±1.48 d
2	19.4±0.55 a	21.2±0.84 b	22±1 b	51.2±0.84 c
3	17.6±0.55 a	18.2±1.1 a	18.6±0.55 a	47.6±0.55 b
4	15.2±1.64 a	16.6±1.95 a	17.6±1.52 a	40.4±1.14 b
5	13.4±0.89 a	14.2±1.3 a	14.6±1.14 a	35.6±0.55 b
6	10±1.58 a	10.4±1.52 a	10.6±1.14 a	32.4±1.14 b

Table 2: Nymphal mortality percentage of *Acrida exaltata* at different temperature regimes. Different letters within a row indicate difference between mean values (Two-way ANOVA, DMRT, p<0.001)

Instars	24:0	18:6	12:12	6:18	0:24
1	60±1.58 d	29.4±1.14 b	24.6±1.94 a	26.6±0.89 a	52.6±0.55 c
2	55±0.71 c	26±0.71 b	22±1.41 a	23.2±148 a	46±0.71 b
3	50.2±0.84 c	22.2±0.84 a	19.4±0.89 a	20±1.58 a	38.6±1.95 b
4	44.2±0.84 c	19.4±1.14 a	17.4±1.14 a	17.6±1.34 a	35.6±1.52 b
5	38.4±0.89 c	17.4±1.34 a	15.4±0.89 a	15.6±1.14 a	32±1 b
6	34±1 c	11.4±1.14 a	10.6±1.14 a	11±0.71 a	29±1 b

Table 3: Reproductive ability of *Acrida exaltata* at different temperature regimes. Different letters within a column indicate significant difference between mean values (One-way ANOVA, DMRT, P<0.001)

Tempe rature	Egg-pods laid Per female	Egg per pod	Fertile egg Per pod	Fecundity	Fertility	Eggs incubation period
25±20C	8..6±0.89 a	13±1 b	11.8±0.84 b	111.2±5.93b	101±6b	32.6±1.14b
30±2⁰C	11..4±1.14 a	12.4±1.57	11.4±1.34 b	140±5.79 c	128.8±5.02c	32.2±1.3b
35±2⁰C	11.4±1.14 b	13.2±0.84 b	12.2±1.84 b	149.8±7.7 c	149.8±7.7d	27.2±0.84a
40±2⁰C	8.4±1.14 a	7.6±10.14 a	6.6±0.89 a	62.8±1.64 a	54.8±4.38 a	25.2±1.3a

Table 4: Reproductive ability of *Acrida exaltata* at different L:D photoperiodic regime. Different letters within a column indicate significant difference between mean values (One-way ANOVA, DMRT, P<0.001)

Photoperiod	Eggpods laid Per female	Eggs per pod	Fertile egg Per pod	Fecundity	Fertility	Eggs Incubation period
24:0	8..4±1.14 a	7.4±0.89a	5.6±0.55a	61.4±3.44a	46.6±3.13a	35.2±0.45c
18:6	9.4±0.55 b	11.4±0.55	10±1 b	107±4.58 c	93.6±4.93c	32.4±0.89b
12:12	10.6±0.55 a	13.4±0.55 b	12.4±0.55c	141.8±1.64d	137.8±1.1d	27.2±0.84a
6:18	9.6±0.55 a	10.6±0.55b	9.6±0.55b	101.6±4.72c	92±4.47c	26.6±1.67a
0:24	8.6±0.89 a	9.6±0.55b	8.4±0.89b	82.2±0.89b	71.6±0.89b	26.4±1.14a

Table 5: Instar-wise nymphal development period (days) of *Acrida exaltata* at different temperature and photoperiodic regimes. Different letters within a column indicate significant differences between mean values (two-way ANOVA, DMRT, P<0.05 for temperature, two-way ANOVA, DMRT, t-test P<0.05 for photoperiod)

Temperature	1	2	3	4	5	6
25±2⁰C	10±1.41b	12.8±1.3b	6±0.71a	9±1a	7±0.71a	10±1.58a
30±2⁰C	7.4±5.5a	12.4±0.89b	5.4±0.55a	8±1.22a	6.1±1.52a	8.6±1.34a
35±2⁰C	7±0.71a	12±1.58b	5±1a	8±1.22a	6.6±1.52a	8±1a
40±2⁰C	7±0.71a	9±1.22a	5±1a	7.6±1.34a	6±1.22a	8±1a
Photoperiod						
24:0	10.6±0.89b	13.6±0.55a	7±1a	9.6±0.55a	7.6±0.55b	10±1a
18:6	8±1a	12.5±0.55a	6±0.71a	9±1a	6.6±0.55b	9±0.71a
12:12	7±0.71a	12±1.58a	5±1a	8±1.71a	5.6±0.55b	8±1a
6:18	7±0.71a	12.4±0.55a	5.4±0.55a	8.4±0.89a	6.6±0.55b	8.4±0.55a
0:24	10±1.41b	12±1a	6.6±1.34a	9±1a	7±0.71b	9.6±0.55a

Table 6: Adult life-span (week) of *Acrida exaltata* at different temperature and photoperiodic regimes. Different letters within a column indicate significant differences between mean values (two-way ANOVA, DMRT, P<0.05 for temperature and P=0.799 for photoperiod).

Temperature	Male	Virgin female	Mated female
25±2⁰C	10.2±0.45a	11.4±0.55b	9.2±0.84b
30±2⁰C	10.6±0.55a	11.6±0.55b	9.2±0.84b
35±2⁰C	11.4±0.89a	12.4±0.55b	9.6±0.89b
40±2⁰C	9.2±0.84a	8.4±0.55a	7.6±0.55a
Photoperiod	**Male**	**Virgin female**	**Mated female**
24:0	9.2±0.84a	9.6±0.89a	7.4±0.55a
18:6	10.2±0.45a	10.6±0.55a	8.6±0.55a
12:12	11.4±0.89a	12.4±0.55a	9.6±0.89a
6:18	10.6±0.55a	11.4±0.89a	9.6±0.84a
0:24	9.6±0.89a	10±0.45a	7.6±0.55a

Table 7: Dry adult body weight (gm) of *Acrida exaltata* of acridid at different temperature and L:D photoperiodic regimes. Different letters within a column indicate significant differences between mean values (two-way ANOVA, DMRT, P<0.01 for temperature, two-way ANOVA, DMRT, P<0.05 for photoperiod)

Temperature	Male	Virgin female	Mated female
25±2⁰C	0.065±0.0025a	0.154±0.0032a	0.177±0.0017b
30±2⁰C	0.076±0.0026b	0.166±0.0027b	0.179±0.0022b
35±2⁰C	0.079±0.0042b	0.171±0.0054b	0.184±0.0013b
40±2⁰C	0.063±0.0028a	0.152±0.0019a	0.170±0.0032a
Photoperiod	**Male**	**Virgin female**	**Mated female**
24:0	0.059±0.0021a	0.148±0.0019a	0.166±0.0024a
18:6	0.0712±0.0017b	0.161±0.0025b	0.173±0.0025b
12:12	0.078±0.0019b	0.17±0.0023c	0.182±0.0026c
6:18	0.075±0.0033b	0.163±0.0021b	0.176±0.0025b
0:24	0.061±0.0027a	0.15±0.0019a	0.168±0.0031a

When the effect of different photoperiodic regimes on the instar wise nymphal developmental periods (Table 4) was observed, higher durations were recorded at the 2 extreme photoperiodic regimes (i.e. 24:0 and 0:24). Lower mean values were observed at the 18:6 to 6:18 photoperiodic range. When the data were statistically compared between 18:6, 12:12, and 6:18, significantly lower values ($df = 4, 20$, $F = 6.43$, $P < 0.05$) were observed at 12:12 for 5th instar only. Here also, the effect of photoperiod on the total nymphal duration was calculated. Though DMRT result did not show any significant variation between the results of different photoperiodic regimes, the t-test revealed that 24:0 has higher value than 12:12 and 6:18 ($P < 0.05$, t-test).

Among the 4 different temperature regimes, adult life span of males, virgin females, and mated females gradually increased with increased temperature from 25±2°C to 35±2°C, whereas the 40±2°C temperature regime showed the lowest values for all ($df = 2, 6$; $F = 3.08$; $P < 0.05$) (Table 5). Adult life span was longest ($df = 6, 59$; $F = 3.08$; $P < 0.05$) in virgin females and shortest in males at the first 3 temperature regimes.

Variations in photoperiodic regimes in the adult life span (Table 5) showed that mean values increased up to 12:12, and then shortened gradually. It varied between 7 to 12 weeks; however, they did not show any significant variation. Adult life span also did not vary significantly within photoperiods between males, virgin females, and mated females ($P= 0.799$, two-way ANOVA). Effect of temperature on adult dry body weight (Table 6) showed that both males and virgin females attained maximum weight at 30±2°C and 35±2°C, whereas the same of mated female was maximum at the first 3 temperature regimes, but the data did not show any significant variation.

Adult male and virgin female dry body weights were minimum at the 2 extreme temperature regimes, but the dry weight of mated female was significantly lower at 40±2°C ($df = 3, 6$; $F = 3.81$; $P < 0.01$). Mated female dry weight was significantly higher than virgin female and male dry weight at each temperature ($df = 6, 59$; $F = 3.81$; $P < 0.01$) and photoperiodic regime ($df = 8, 74$; $F = 2.76$; $P < 0.05$). Between different photoperiodic regimes, virgin females and mated females attained maximum ($df = 4, 8$; $F = 2.76$; $P < 0.05$) weight (Table 7) at 12:12, and adult male dry weight was maximum at 18:6, 12:12, and 6:18, where data did not show any significant variation. Lower dry body weight was observed at the 24:0 and 0:24 photoperiodic regimes for males, virgin females, and mated females.

DISCUSSIONS

Temperature and photoperiod affect different biological traits of insects (Malina and Praslicka, 2008). Hinks and Erlandson (1994) opined that temperature is a very important and determining factor for grasshopper rearing. Moreover, it has also been reported that reproductive potential in grasshoppers is highly temperature dependent (Blanford and Thomas, 2000). Post-embryonic development of grasshoppers and locusts is also dependent on temperature.

In the present study, during the development from 1st instar to 6th instar, it was observed that the highest nymphal growth rate was at the 3rd instar stage, in the case of both the temperature and photoperiodic regimes. Kohler, *et al.* (1987) observed the highest growth rate at the 3rd instar stage of 3 European acridids, namely *Chorthippus parallelus*, *C. biguttulus*, and *Gomphocerus* sp. Nymphal mortality has a great role on population size, structure, and dynamics. Nymphal mortality was maximum at the extreme temperatures of 4 different selected temperature regimes, possibly because *Acrida exaltata* could not tolerate the high temperature (i.e. 40±2°C). Therefore, it could be assumed that extreme high, and may be the extreme low temperatures were not favorable for the survival of the selected species. The temperature regime from 25±2°C to 35±2°C has been found to be the optimum zone for the survival of *Acrida exaltata.*

According to Robinson, *et al.* (1983), metabolic rate was directly influenced by temperature. An increase of temperature up to 35±2°C favored the growth rate, which might be due to enhanced metabolic activity with increased temperature. Giberson and Rosenberg (1992) found a similar trend of results for ephemeropteran insects. At the extreme high temperature (i.e. 40±2°C), decreased growth rate might have been observed due to normal metabolic activity hampered in *Acrida exaltata*. For the 1st and 2nd instars, though nymphal mortality was moderate at 35±2°C, at this regime, it was low for other instars, whereas the growth rate was high for all of the instars. Thus, it could be stated safely that the 35±2°C temperature regime was ideal for growth and survival. On the studies of *Locusta* sp. and *Schistocerca gregaria*, Uvarov (1966) reported similar observations. Information about influence of photoperiod on the biological traits of *Acrida exaltata* is very scarce.

Improved knowledge of the relationship between photoperiod and selected biological parameters of *Acrida exaltata* might be useful in developing acridid farms and determining the best time of year for *Acrida exaltata* rearing. Musolin and Saulich (1997) reported that the nymphal growth rate of Orthoptera was accelerated by long days and retarded by short days. The present study also revealed a similar trend of observations, where the growth rate increased up to 12:12. From studies on *Locusta* sp. and *Schistocerca gregaria*, Hamilton (1950) found that the fastest development and highest survival was at the photoperiod of equal span of day and night. In the case of nymphal survival, the present study supports this observation. Therefore, the 12:12 photoperiodic regime was identified as optimum for the maximal growth and survival of *Acrida exaltata*.

Various reproductive traits gave the most favorable results at the 2 moderate temperatures of the 4 different temperature regimes. On the other hand, egg pod laying frequency increased with the increased temperature. Ali (1982) also reported that with the increase in temperature from 20 °C to 37 °C the egg pod laying capability increased in *Acrida exaltata*. Egg mortality increases with the increased temperature from 35±2°C onwards. Giberson and Rosenberg (1992) observed that the fecundity of mayfly was increased with the rise in temperature. In the present study, similar results for fecundity and fertility were found when the temperature was increased up to a certain level and then declined when the optimum range was exceeded.

The egg incubation period varied from 25 to 33 days at different temperatures, which was shortest at 35±2°C. A short egg incubation period might lead to early adult stage. Therefore, in a year, more life cycles might be completed and more acridid biomass could be obtained. Thus, it could be stated that the 35±2°C temperature regime is ideal for reproduction.

According to Lenteren (1999), when exposed to long photoperiod of light, the physiology of many adult insect species is directed to reproduction, whereas short-day conditions can deactivate the corpora allata, thereby reducing juvenile hormone secretion and consequently induce diapause. This explains the fact of increased number of eggs per pod, fertile eggs per pod, and fecundity and fertility with increased photoperiod from 24:0 to 12:12. However, the egg incubation period gave reverse results and was lowest at 12:12, which favors acridid rearing.

For nymphal duration, 35±2°C and 12:12 was considered optimum, as short duration is very important for the fitness and survival of the insects (Price, *et al.,* 1980). Adult life span was shortest at the highest temperature regime for males, virgin females, and mated females, which might be due to metabolic hazards. Different photoperiodic regimes did not show any variation in the adult life span for males, virgin females, and mated females. Adult males and mated females, which lived longer, had a better chance to copulate and laid a higher number of eggs. Adult dry body weight was higher at the two moderate temperatures and at equal span of light and dark. Mated female individuals attained higher dry weight than virgin females, possibly due to high consumption (Abdel-Rahman, 2001) and hormonal effect in mated acridid females. The dry weights of virgin females were greater than those of the males.

The temperature regime 35±2°C gave maximum values for growth rate, egg pod laying frequency, fecundity, fertility, adult dry body weight, and adult male life span, whereas the same regime gave minimum results for egg incubation period, nymphal mortality from the 3rd instar onwards and nymphal duration for the 2nd instar onwards. Nymphal mortality of the 1st and 2nd instars were minimum at 25±2°C and nymphal duration of the 2nd instar was minimum at 40±2°C, but most other parameters showed favorable results at 35±2°C, and remarkably worse at either 25±2°C or 40±2°C. All of the chosen biological traits showed better results at 12:12 except the growth rate of the 3rd instar.

Therefore, when all of the parameters were taken under consideration, 35±2°C and a photoperiod of 12:12 were identified as the optimum regimes for mass culture of *Acrida exaltata* under laboratory conditions. These results strongly support the idea of establishment of acridid farms where huge biomass of this acridid species could be

yielded to provide raw materials for the poultry, fish, and shrimp industry, and make them viable and attractive. Ultimately, sufficient animal protein will be easily available to the populace.

REFERENCES

1. Abdel-Rahman K.M. (2001): Food consumption and utilization of the grasshopper *Chrotogonus lugubris* Blanchard (Orthoptera, Acridoidea, Pyrgomorphidae) and its effect on the egg deposition. J. Central Eur. Agric. 2: 263-270.
2. Anand H., Das S., Ganguly A. and Haldar P. (2008): Biomass production of acridids as possible animal feed supplement. *Environ. Socio. Biol.,* **5** (2): 181-190.
3. Blanford S. and Thomas M.B. (2000): Thermal behavior of two acridid species: effect of habitat and season on body temperature and potential impact on biocontrol with pathogens. Environ. Entomol. 29: 1060-1069.
4. Das S., Das A. and Haldar P. (2001): Fecundity and fertility of a pestiferous Acridid *Oxya fuscovittata* (Marschal). Indian J. Environ Ecoplan. 5(1): 19-23.
5. Ewan A.B. and Hinks C.F. (1986): Rearing a non-diapause strain of the migratory grasshopper, Melanoplus sanguinipes (F.) (Orthoptera: Acrididae) in the laboratory. Proc. Pan. Am. Acrid. Soc. 4: 169-173.
6. Giberson D.J. and Rosenberg D.M. (1992): Eff ects of temperature, food quantity and nymphal rearing density on life-history traits of northern population of *Hexagenia* (Ephemeroptera: Ephemeridae). J. N. Am. Benthol. Soc. 11(2): 181-193.
7. Haldar P., Das A. and Gupta R.K. (1999): A laboratory based study on farming of an Indian grasshopper *Oxya fuscovittata* (Orthoptera: Acrididae). J. Orth. Res. 8: 93-97.
8. Halmilton A.G. (1950): Further studies on the relation of humidity and temperature to the development of two species of African Locusts-*Locusta migretoria migratorioides* (R & F) and *Schistocerca gregaria* (Forsk). Trans. R. Ent. Soc. Lond. 101: 1-58.
9. Kohler G., Brodhun H.P. and Schaller G. (1987): Ecological energetic of central European grasshoppers (Orthoptera: Acrididae). Oecologia. 74: 112-121.
10. Malina R. and Praslicka J. (2008): Effect on temperature on the developmental rate, longevity and parasitism of *Aphidius ervi* Haliday (Hymenoptera: Aphidiidae). Plant Protect. Sci, 44:19-24.
11. Musolin D.L. and Saulich A.K. (1997): Photoperiodic control of nymphal growth in true bugs (Heteroptera). Entomol, Rev 77: 768-780.
12. Onimisi P.A. and Omage J.J. (2006): Evaluation of poultry litter as feedstuff for growing rabbits. Livest. Res. Rural. Dev. 18(11): 26-29.
13. Price P.W., Bouton C.E., Gross P., Mc Pherson B.A., Thompson J.N. and Weis A.E. (1980): Interactions among three tropic levels: Infl uence of plants on interactions between insect, herbivores and natural enemies. Annu. Rev. Ecol. Systematics. 11: 41-65.
14. Ramos-Elorduy J. (1984): Edible insects in Mexico and their protein content. J. Ethnobiol. 4: 61-72.
15. Robinson WR, Peters RH and Zimmerman J (1983): The effect of body size and temperature on metabolic rate of organisms. Can. J. Zool. 61: 281-288.
16. Uvarov B.P. (1966): A handbook of general acridology, Cambridge University Press, Cambridge.
17. Wang D., Zhai S.W., Zhang C.X., Zhang Q. and Chen H. (2007): Nutritional value of the Chinese grasshopper *Acrida cinerea* (Thunberg) for broiler. Anim. Feed. Sci. Technol. 135(1-2): 66-74.