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ORIGINAL ARTICLE

Relationship of Starvation and Critical Weight on Final Moult in the Desert Locust, *Schistocerca gregaria*

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ABSTRACT

Effect of starvation on last instar nymphs on final moult have been investigated in the both the phases of the desert locust, *Schistocerca gregaria* (Forskal) (Orthoptera Acrididae). In gregarious phase feeding to newly moulted fifth instar nymphs up to four days resulted 100 % mortality of 5th instar in both male and female nymphs, whereas nymphs fed upto fifth day after initial moulting, achieved weight 0.915± 0.0716 g in male and 1.255 ± .0870 g in female moulted into adult stage. In solitary phase fifth instar nymphs required initial feeding of 2 days needed to achieve critical weight 0.97 ± 0.1094 g in male and 1.52 ± 0.01736 g in female to moulting into adult male and female. The present investigation suggest that the gregarious fifth instar individuals while marching if they need food for five days to metamorphose into adult, whereas solitary require 2 day of food to reach the stage where resultant individual is adult.

KEY WORDS: Acrididae, gregarious, metamorphosis, phase, solitary, *Schistocerca gregaria*

INTRODUCTION

In most of the insects metamorphosis is directly related with the proportion of juvenile hormone (JH) produced by CA. Onset of metamorphosis during final larval instar is triggered due to decline JH titre and increase in moulting hormone (Wigglesworth, 1970; Gilbert and King. 1973, Nijhout and Williams, 1974b; Johnson and Hill, 1973). It has been established in many insect species that the size play a critical role in the release of hormonal substance that inhibits corpora allata to stop further secretion of JH, ultimately the titre in the haemolymph and stimulates the production of PTTH (Nijhout, 1975; Williams, 1975; Ochieng-Odero, 1990). The time of the final moult of last instar larva is crucial since it ends at an active feeding phase hence it has direct influence on adult size and biological performance (Ochieng-Odero, 1990). The weight achieved by a larva above critical, dictates the reproductive performance and overall quality of the insect (Nijhout and Williams, 1974b; Safranek, 1984a,b). It was suggested that critical weight not dependent on diet quality, temperature and photoperiod and therefore this can be used in the development of descriptive indices of insect quality (Ochieng-Odero, 1994).

The relationship between threshold value and the stage of development attained by the nymph after feeding period during last nymphal instar have never been reported yet, in the different phases of desert locust. Therefore the present study undertaken to find out relationships between feeding period and threshold weight, crucial for last instar nymph final moult in the desert locust, *Schistocerca gregaria*.

MATERIALS AND METHODS

Experimental Insects

The crowded (gregarious and isolated (solitarious) individuals of the desert locusts, *S. gregaria* were collected from the locust colony maintained at Centre of Sericulture and Bioresource Management Research (CSBR), RTM Nagpur University, Nagpur using method as described earlier (Raina *et al*., 1987).

Rearing Environment

The make them solitary the individuals were reared in

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Table 1: Body weight achieved by the last instar nymphs of gregarious desert locust, *S. gregaria.*

Groups/Age	Feeding days followed by starvation	Weight of Male (g)		Weight of Female (g)	
		Moulting occurred	No Moulting	Moulting occurred	No Moulting
G_0	No feeding	-	0.44 ± 0.028	-	0.52 ± 0.041
G_1	1day feeding	-	0.56 ± 0.028	-	0.64 ± 0.042
G_2	2 days feeding	-	0.66 ± 0.028	-	0.70 ± 0.050
G_3	3 days feeding	-	0.70 ± 0.022	-	0.74 ± 0.036
G_4	4 days feeding	-	0.74 ± 0.036	-	0.96 ± 0.069
G_5	5days feeding	1.36 ± 0.067	0.96 ± 0.076	1.62 ± 0.091	1.54 ± 0.106
G_6	6 days feeding	1.08 ± 0.016	0.60 ± 0.065	1.43 ± 0.039	1.20 ± 0.054
G_7	7 days feeding	1.25 ± 0.041	0.90 ± 0.069	1.55 ± 0.056	0.60 ± 0.061
G_8	8 days feeding	1.28 ± 0.057	-	1.56 ± 0.091	-
G_9	9 days feeding	1.48 ± 0.014	-	1.60 ± 0.022	-

Note: Average weight of 10 individuals, ± - indicates standard error

Table 2: Body weight achieved by the last instar nymphs of solitary desert locust, *S. gregaria.*

Groups/Age	Feeding days followed by starvation	Weight of Male (g)		Weight of Female (g)	
		Moulting occurred	No Moulting	Moulting occurred	No Moulting
S_0	No feeding	-	0.43 ± 0.022	-	0.57 ± 0.041
S_1	1 day feeding	-	0.83 ± 0.037	-	0.97 ± 0.033
S_2	2 days feeding	1.34 ± 0.014	1.13 ± 0.038	1.81 ± 0.0	1.66 ± 0.031
S_3	3 days feeding	1.45 ± 0.022	1.27 ± 0.065	1.76 ± 0.084	1.28
S_4	4days feeding	1.46 ± 0.026	-	2.19 ± 0.057	1.62
S_5	5 days feeding	1.27 ± 0.033	0.75 ± 0.065	1.87 ± 0.056	1.21

Note: Average weight of 10 individuals, ± - indicates standard error

Table 3: Duration (day) for final moult into adult for the nymphs of gregarious and solitary phases of *S. gregaria.*

Group/ days	Gregarious					Group/ days	Solitary				
	Feeding days followed by starvation	Male		Female			Feeding days followed by starvation	Male		Female	
		M	NM	NM	M			M	NM	M	NM
G_0	No feeding	-	3.0	-	3.3	S_0	No feeding	-	3.8	-	4.0
G_1	1day feeding	-	3.6	-	4.0	S_1	1 day feeding	-	4.0	-	4.5
G_2	2 days feeding	-	4.2	-	4.3	S_2	2 days feeding	4.0	4.2	6.0	5.1
G_3	3 days feeding	-	7.6	-	6.3	S_3	3 days feeding	3.7	4	4.2	5
G_4	4 days feeding	-	3.8	-	4.4	S_4	4days feeding	2.5	3	3.4	3
G_5	5days feeding	3.6	-	3.9	-	S_5	5 days feeding	1.4	3	1.7	6
G_6	6 days feeding	4.0	-	5.0	-						
G_7	7 days feeding	3.6	-	3.5	-						
G_8	8 days feeding	2.4	-	2.8	-						
G_9	9 days feeding	1.4	-	0.8	-						

Note: M- successful moult; NM- no moult and nymphs died after starvation

small compartments (10 x 10 x 24 cm) made of aluminium described by Pener (Pener, 1992). These cages were surface sterilized using 2 % hypochlorite solution, fumed with the mixture of Ethenol and Formaldehyde dried and sterilized using hot air blower. Two cages with eight compartments in each cage placed on trolleys provided with four 25 W bulbs. The individuals were separated in such way in the compartments so that, they cannot see each other. The rooms were well ventilated to avoid any pheromonal communication between individual nymph of solitary phase to avoid grangerization (Saini *et al*., 1995; Rai *et al*., 1997). Gregarious phase insects were kept under crowded conditions using cage (18 x 18 x 24 inches) having sides and the roof of wooden ply sheet except front which had a removable glass door with an electric bulb fixed to the ceiling to provide light as described (Rai *et al*., 2012).

Newly moulted fifth instar nymphs of gregarious phase and sixth instar nymphs of solitary phase were selected. They were separated in different groups viz. for gregarious without feeding (G_0) and gregarious with 1 day feeding (G_1) and so on up to group G_9. Similarly for solitary six groups (S_0-S_5) were prepared. Each group of gregarious phase (G_0-G_9) had 10 individuals and groups of solitary (S_0 to S_5) had 6 nymphs.

The treatment were given as described, using newly moulted gregarious fifth instar nymphs; nymphs of G_0 group never provided food and they were starved till the end of the stage, G_1 nymphs provided food for 1 day and then starved till end of the stage, G_2 individuals provided food for 2 days followed by starvation, similarly G_3, G_4, G_5, G_6, G_7, G_8 and G_9 individuals were provided food for 3,4,5,6,7,8 and 9 days respectively and then kept on starvation till the next development stage. The nymphs of solitary group were also treated as in case of gregarious, where S_0 individuals starved for ever, individuals of group S_1 provided food for a day and then starved and groups G_2, G_3, G_4, G_5 and G_6 were given food for 2,3,4,5 and 6 days respectively.

Various parameter like weight of the nymphs on the day of starvation, period of starvation, day of moulting into immature adult and mortality in both the sexes and phases were recorded.

Experimental insects were provided seedlings of wheat (*Triticum* sp.) as a food. Nymphs of both the groups were maintained in two separate rooms having 32 ± 2^{0}C temperature, 40-50 relative humidity with 12:12 h light-dark regime (Raina *et al*., 1987).

Statistical analysis

The data were analyzed using growth model for the nymphal stages and represented as:

$$W(t) = \frac{K\,Wo}{Wo + (K - Wo)e^{-rt}}, t > 0 \quad ----1$$

Where, W(t)= weight of the nymph at time t
K = maximum weight achieved
Wo initial weight at time t=0
r = intrinsic weight increase rate
t = time in days

The critical time t(c) and the critical weight W(c) moulting to occur is determined as,

W(t) > Wc for any t >tc ----------2

Since the critical time t (c) occurs at the point of inflexion of the junction W (c), then it follows that from calculus

$$\frac{d2\,\mathbf{W}\,(\mathbf{t})}{dt\,\mathbf{2}} = \mathbf{0} \quad ------3$$

The critical time tc was obtained by simplifying equation 3 as,

$$tc = \frac{1}{r}\log\left(\frac{K - Wo}{Wo}\right) \quad --------4$$

Therefore the critical weight was calculated by substituting equation 4 into equation 1, an

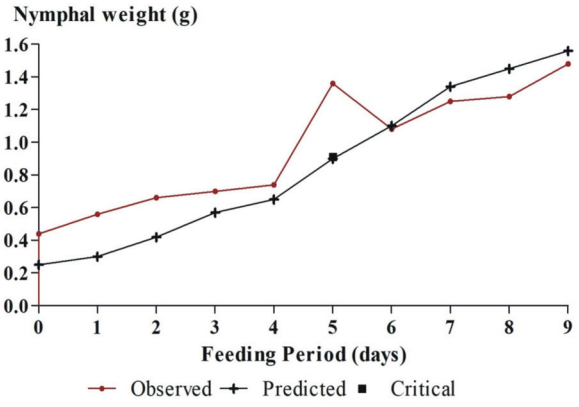
$$Wc = \frac{K\,Wo}{Wo + (K - Wo)e - rtc}$$

The values of K and Wo were predetermined from the data obtained from the experiments. The intrinsic growth rate It was estimated by using non-linear regression procedure PROC NLIW from the Statistical Package SAS (SAS Institute, 1987).

RESULTS

The body weight increase in relation to feeding duration for both male and female nymphs have been recorded. Weight of nymphs of fed and starved recorded up to their next moulting stage whether it was successful or unsuccessful for both gregarious and solitary phases have been presented in Table 1& 2.

Nymphs of gregarious starved for throughout their life G_0, food provided for 1 day Group G_1, and the nymphs consumed for day 2, 3 and 4 days did not moult in their life time whereas nymphs provided for 5 days and onwards resulted of metamorphosis (Table 1). In the case of nymphs of solitary phase at 6th instar, not received even a single day feeding resulted no moulting and similarly one day feeding also did not resulted next stage. Feeding given for two days, 3days, 4 days and 5 days onwards then starvation in each group resulted moulting into next stage (Table 2).



a

Fig. 1a. Observed, predicted and critical weight of the 5th and final instar gregarious male nymph of the desert locust, *S. gregaria*.

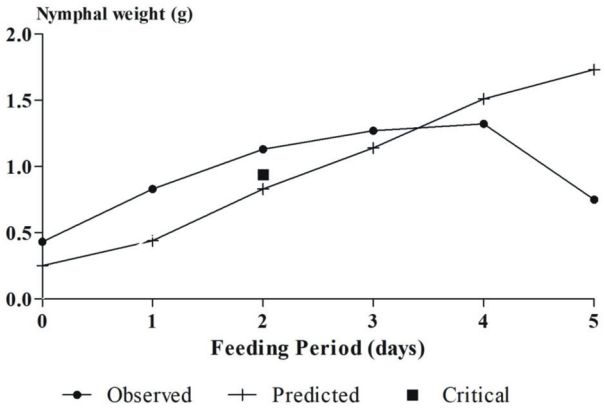
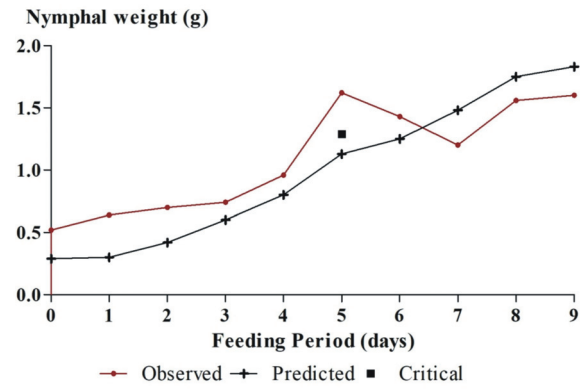


Fig. 2a. Observed, predicted and critical weight of the 6th and final instar solitary male nymph of desert locust, *S. gregaria*.



b

Fig. 1b. Observed, predicted and critical weight of the 5th and final instar gregarious female nymph of the desert locust, *S. gregaria*.

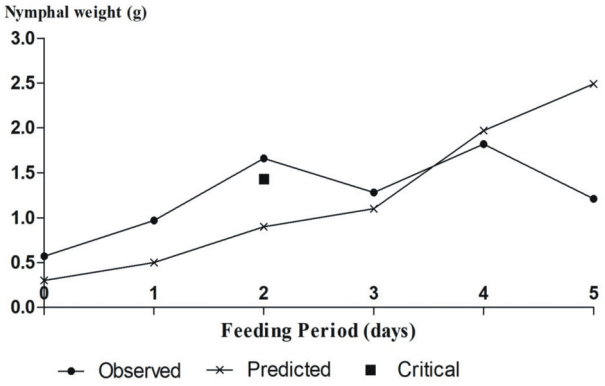


Fig. 2b. Observed, predicted and critical weight of the 6th and final instar solitary female nymph of desert locust, *S. gregaria*.

The average weight of the both moulted and un moulted nymphs was higher than the predicted weight both in gregarious (Figs. 1ab) and solitary (Figs. 2ab). Threshold weight for next moulting to occur in gregarious male and female was 0.915± 0.0716 g and 1.255± 0.087 respectively (Figs. 1ab). Similarly thresh hold weight for next moulting for solitary male and female was 0.97 ± 0.1094 g and 1.53 ± 0.1736 g respectively (Figs. 2ab).

In case of gregarious nymphs, nymphs never received food and those received food up to four days, did survived up to 3 to 7.6 days depending on different days of feeding but they died without moulting. Feeding provided to the nymphs up to five days or more and then starved moulted into adult and period required to metamorphose into adult for male nymphs 3.6, 4.0, 3.6, 2.4 and 1.4 days and for females 3.9,5, 3.5,2.8 and 0.8 days when of feeding given for 5,6,7,8 and 9 days respectively (Table 3).

In case of solitary, nymph never received food did not moult and male and female survived for 3.8 and 4 days respectively, one day feeding also produced the similar result. However, nymphs received food for 2 days or more did survived and transformed in to adult and the duration ranged from 1.4 to 4.0 days in case of male and 1.7 to 6 days in the case of female (Table 3).

In some cases 4.6% male and 9.5% females of gregarious and 18.5% male and 6.7% females of solitary did not moult even after they achieved weight required for the initiation of moulting. Starvation before the optimum feeding period (Ntc) resulted into death. Nymphs which received food up to the optimum days of feeding (Ntc)

achieved the "required Weight" (Nwc) have completed metamorphosis process. In few cases nymphs although fed upto the optimum days or even more could not achieve threshold weight and died before moulting. The Survival period was longer when nymphs starved before Ntc and most of them, died whereas it was shorter and moulted, beyond Ntc and most of them moulted but the nymphs which never moulted fed beyond the Ntc, their starvation time was also longer.

DISCUSSION

The weight of the nymph corresponds to the first release of PTTH from brain signals the onset of the pre-moulting phase (Nijhout & Williams, 1974a; Williams, 1975). Period before nymph attains Nwc is under the direct influence of environmental factors and quality of nutrition. An environmental factor such as temperature accelerates or slows down the post-Nwc development durations by affecting the rate of enzyme and hormonal action.

A threshold weight which induces the release of corpora allata- inhibiting factors from brain which inhibits the secretion of the juvenile hormone from CA is called critical weight (Nijhout, 1975; Williams, 1975; Ochieng-Odero, 1990).

Our results indicated that, in *S. gregaria* the activities before moulting (wandering, lightening of integument colours, increase in respiration rate and hanging upside down) initiated immediately after nymphs have achieved threshold weight" (Nwc). The nymphs starved before achieving Nwc never initiated moulting although they survived, but only for few days. Critical weight of the nymphs (Nwc) differed in both sexes and phases of *S. gregaria*. Nijhout & Williams (1974 a, b) reported that the moulting cycle is controlled by the JH, secreted by CA and any delay in inhibition of JH also delays the successive moulting process.

Nijhout (1979a,b) further reported that, nutrition has no significant role of in the moulting cycle, however, our results in the case of *S. gregaria* indicate the significance role of nutrition in the moulting. Similar control of moulting have been described in the house cricket *Acheta domesticus* (Woodring, 1983).

The amount of food consumed by an individual nymph during its active feeding period is directly related to their body-weight. The critical feeding period was longer in case of females than in males, which resulted into higher Nymphal critical weight (Nwc) in females.

The duration of Pre-Now (period between the day of moulting and achievement of New) and Pre-New (period between day 0 and achievement of New) was about 4.5-5.5 and 2.9-3.5 days for nymphs of both the sexes and phases (gregarious and solitary respectively) of *S. gregaria*. Nymphal maximum weight reduced gradually during pre moulting period and the required state which can produce a functional adult was marked by Now, and the active feeding period was same for the nymphs of both sexes.

The critical weight of the last instar is achieved by nymphs, only when they have been feeding for certain period helped in metamorphosis into adult stage. Insect fed below critical feeding time and achieved less than the required weight resulted into inhibition in moulting process and finally death of an individual. Thus it can be assumed that feeding time and weight achieved is critical for the last instar nymph to moult into and functional adult stage.

The laboratory rearing facilities although provide environment close to the original and tend to produce insects of similar quality of those which are found in the natural environment (Barlett, 1984), study requires further investigations using the insects reared under fluctuating environmental condition in order to compare and confirm the quality of the laboratory reared individuals.

In some cases, nymphs although they gained threshold weight before the optimum feeding periods or even after required feeding period, did not achieve the weight required and failed to moult. Therefore it is established that the critical weight of the last nymphal instar is crucial and can be achieved only after critical time of feeding during their early stage to moult into functional adult.

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