Journal of Stored Products Research 47 (2011) 25–31

Contents lists available at ScienceDirect

Journal of Stored Products Research

journal homepage: www.elsevier.com/locate/jspr

Effect of temperature and humidity on the biology of *Attagenus fasciatus* (Thunberg) (Coleoptera: Dermestidae)

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ARTICLE INFO

Article history:
Accepted 27 July 2010

Keywords:
Attagenus fasciatus
Larval instars
Pupal duration
Fecundity
Adult longevity
Sex ratio

ABSTRACT

The effect of temperature and relative humidity (r.h.) on the biology of the carpet beetle *Attagenus fasciatus* was studied under laboratory conditions. The influence of two temperatures (30 °C and 35 °C) and three humidities (40, 60 and 80% r.h.) on the number, duration, mortality and pupation of larval instars, as well as on the biology of fed and starved adult beetles, was investigated. *Attagenus fasciatus* larvae were reared on dried milk. The mean duration of each successive larval instar generally increased slightly but there was much fluctuation, particularly for the later instars. The highest mortality was recorded during the first two or three instars. At 30 °C pupal duration decreased with increasing r.h. while at 35 °C there was a slight increase. However, the duration at 35 °C was always shorter than at 30 °C. There was 100% emergence of adults from pupae under all test conditions except 40 and 60% r.h. at 35 °C where it fell to about 90%. Humidity and starvation strongly affected egg hatchability under all conditions tested. At 35 °C, eggs took less time to hatch than at 30 °C and there was a positive correlation between egg duration and r.h. The duration of the egg stage was longer for eggs of starved females than those of fed ones. Adult longevity was longer at higher humidity, females lived longer than males and unmated beetles lived longer than mated ones. Starvation reduced adult longevity in all cases. The sex ratio was male biased at 30 °C except at 80% r.h. but the reverse was true at 35 °C.

1. Introduction

Most dermestid beetles are capable of feeding and developing on keratinaceous products and several are economically important pests on woollen textiles and museum specimens throughout the world (Veer et al., 1991). Larvae of *Attagenus fasciatus* (Thunberg) (Coleoptera: Dermestidae) attack cotton goods, leather, dried milk, grains, flour and many other animal and plant products (Metcalf and Flint, 1962; Abd El-Rahman et al., 1981a,b; Armes, 1990; Ali, 1992). Adults of the carpet beetle *A. fasciatus* are found outdoors feeding on bindweed flowers (*Convolvulus arvensis* L.) and are often found indoors resting on window curtains (Ali, 1992). The carpet beetle is a common name applied to any one of several species of small beetles belonging to the family Dermestidae, the larvae of which feed on wool carpets and rugs (Mallis, 1990). Larvae are elongate, carrot-shaped, golden to chocolate brown, and have a tuft of very long golden-brown hairs at the posterior end of their body. Hinton (1945) recorded *A. fasciatus* as a household pest in Egypt and Rao et al. (1987) reported *A. fasciatus* as a pest of stored groundnuts in India.

In a study made by Ali (1993) on *A. fasciatus* reared on dried milk, it was demonstrated that the number of larval instars ranged from 8 to 14 at 35 °C, 70–80% relative humidity (r.h.), and from 8 to 13 at 30 °C, 50–60% r.h. The number of larval instars ranged from 8 to 15 when reared on a mixture of dried milk and dried yeast at 35 °C, 70–80% r.h. The number of larval instars in the closely related *Attagenus scalaris* (Pic) reared at 30 °C, 50 ± 5% r.h. on dried yeast was 8–20 (Abd El–Rahman et al., 1981a) and at 35 °C, 75 ± 5% r.h. was 8–22. The number ranged from 12 to 24 on dried milk and 8–9 on the mixture of dried milk and yeast (Abd El–Rahman et al., 1981b).

In *A. fasciatus*, a larval period of 399 days was recorded on groundnuts at 25 °C, 75% r.h. and about one year on tobacco seeds at ambient laboratory temperature (Rao et al., 1987). Veer et al. (1991) recorded a larval period of 120 ± 140 days at 27 ± 0.5 °C, 65 ± 5% r.h. In *A. scalaris* a mean period of 149.30 ± 12.24 days with a range

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doi:10.1016/j.jspr.2010.07.002

Table 1
Number and duration of larval instars of *A. fasciatus* reared on dried milk at 30 °C; 40%, 60% or 80% r.h.

Number of instar	No. of larvae			Duration (days)					
	40%	60%	80%	40%		60%		80%	
				Range	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE
1	93	20	32	15–25	19.4 ± 0.4	13–18	14.5 ± 0.4	10–15	13.4 ± 0.7
2	37	14	16	11–48	18.8 ± 1.04	12–25	18.8 ± 0.9	6–42	18.5 ± 2.4
3	31	13	15	7–59	24.1 ± 2.3	6–38	25.2 ± 2.7	3–71	25.4 ± 3.7
4	27	13	10	3–60	26.4 ± 2.4	22–35	30.2 ± 1.0	15–54	22.8 ± 3.8
5	24	13	10	15–71	39.0 ± 2.7	20–52	29.0 ± 2.3	16–139	50.7 ± 12.5
6	24	13	10	8–84	56.2 ± 3.9	14–39	29.8 ± 1.7	29–112	57.3 ± 9.6
7	24	13	10	23–58	41.3 ± 1.8	25–38	31.6 ± 1	23–63	40.9 ± 4.2
8	24	13	10	31–56	42.0 ± 1.3	15–134	38.7 ± 7.4	32–89	65.1 ± 6.3
9	24	13	7	30–110	48.9 ± 3.6	20–105	45.7 ± 7.4	13–63	44.6 ± 7.4
10	22	11	5	33–107	64.3 ± 5.2	24–139	58.3 ± 9.7	38–53	46.6 ± 4.4
11	22	10	1	30–158	82.8 ± 7.2	24–247	74.3 ± 20.2	–	17
12	21	9	1	37–203	93.1 ± 9.8	52–134	83.2 ± 9.4	–	13
13	18	8	1	63–198	106.1 ± 8.8	6–117	66.4 ± 13	–	74
14	16	6	–	36–217	114.4 ± 15.3	27–118	69.3 ± 14.1	–	–
15	12	4	–	30–217	87.5 ± 16.5	56–106	85.5 ± 11.8	–	–
16	8	1	–	30–148	70.1 ± 12.9	–	91	–	–
17	3	–	–	56–107	77 ± 15.4	–	–	–	–
18	2	–	–	40–48	44 ± 4	–	–	–	–
19	1	–	–	–	34	–	–	–	–

of 76–368 was recorded for larvae reared on dried yeast at 30 °C, 50 ± 5% r.h. (Abd El–Rahman et al., 1981a) and mean period of 133 ± 0.5 days with a range of 65–353 days was recorded at 35 °C, 75 ± 5% r.h. (Abd El–Rahman et al., 1981b).

Rao et al. (1987) noticed that the pupal stage of *A. fasciatus* lasted 17 days at 25 °C, 75% r.h. Veer et al. (1991) recorded 6–7 days at 27 ± 0.5 °C, 65 ± 5% r.h. At 35 °C, 70–80% r.h. on dried milk and on a mixture of dried milk and dried yeast the pupal period was 7.1 ± 0.7 and 7.3 ± 0.7 days, respectively, and at 30 °C, 50–60% r.h. on dried milk, the period was 7.7 ± 0.8 days (Ali, 1993). Also, females reared on dried milk had a higher fecundity at 30 °C, 50–60% r.h. than at 35 °C, 70–80% r.h. (Ali, 1993).

According to Rao et al. (1987) the incubation period of *A. fasciatus* was 7 days at 25 °C, 75% r.h. Veer et al. (1991) stated that eggs took 10–12 days to hatch at 27 ± 0.5 °C, 65 ± 5% r.h. Other studies on *A. fasciatus* indicated that the incubation period ranged from 5 to 7 days at 35 °C, 70–80% r.h. and from 7 to 9 days at 30 °C, 50–60% r.h. (Ali, 1993).

Abd El-Rahman (1981a) working with *A. scalaris* and Ali (1993) working with *A. fasciatus* concluded that mating decreases adult longevity. Similarly in *Anthrenus sarnicus* Mroczkowski, unmated females lived considerably longer than their mated counterparts (Armes, 1991). Fed, mated and unmated, males of *Anthrenus coloratus* Reitter tended to live longer than their starved counterparts (Ali, 1997). Ali (1993) reported that pupae obtained from larvae reared on the mixture of dried milk and dried yeast (plus woollen cloth) were sexed and out of 609, 51.4% were male giving a sex ratio of about 1: 1. This is similar to *A. scalaris* (Abd El–Rahman et al., 1981a) but differs from *A. unicolor* (Brahm) (=*Attagenus megatoma* (F.)) in which the sex ratio is 1: 4 (male: female) (Kiritani and Kawahara, 1963).

The aim of the present study was to obtain more information about the effect of temperature and humidity on the biology of the carpet beetle *A. fasciatus*.

2. Materials and methods

Adult beetles of *A. fasciatus* were obtained from an initial culture reared under laboratory conditions at the Department of Zoology, Faculty of Science, Minia University, Egypt. Two temperatures, 30 and 35 °C, combined with three humidities, 40, 60 and 80% r.h. were

Table 2
Number and duration of larval instars of *A. fasciatus* reared on dried milk at 35 °C; 40%, 60% or 80% r.h.

Number of instars	No. of larvae			Duration (days)					
	40%	60%	80%	40%		60%		80%	
				Range	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE
1	51	97	37	4–13	7.4 ± 0.4	4–11	8.2 ± 0.2	4–10	6.3 ± 0.3
2	36	82	17	5–14	7.4 ± 0.4	3–13	6.6 ± 0.2	5–15	8.5 ± 1.0
3	34	74	16	4–19	8.2 ± 0.8	2–10	6.4 ± 0.2	6–11	7.6 ± 0.3
4	34	71	16	4–24	10.8 ± 0.8	4–71	9.0 ± 0.9	7–16	9.3 ± 0.7
5	33	70	15	6–64	14.3 ± 1.9	4–35	11.9 ± 0.8	7–28	13.1 ± 1.6
6	32	70	13	5–80	15.3 ± 2.6	5–113	16.6 ± 2.0	8–94	21 ± 6.4
7	31	68	10	7–33	16.2 ± 1.3	6–70	18.9 ± 1.8	9–57	20.1 ± 4.3
8	30	64	9	7–56	19.4 ± 2.1	11–129	29.6 ± 3.1	15–56	32.8 ± 4.5
9	30	62	6	5–39	25.1 ± 1.2	15–202	34.5 ± 3.5	9–35	24.5 ± 3.9
10	30	57	–	10–42	28.1 ± 1.1	22–93	42.7 ± 2.2	–	–
11	30	49	–	8–50	30.2 ± 1.7	21–155	53.2 ± 3.4	–	–
12	30	32	–	18–79	34.7 ± 2.1	29–106	50.5 ± 3.8	–	–
13	28	23	–	23–78	40.4 ± 4.1	27–183	61.6 ± 7.8	–	–
14	22	14	–	9–120	43.7 ± 5.4	19–107	51.2 ± 7.0	–	–
15	15	3	–	19–115	40.4 ± 6.1	41–127	75.7 ± 26.2	–	–
16	10	–	–	21–51	32.1 ± 2.5	–	–	–	–
17	6	–	–	20–38	30.5 ± 2.7	–	–	–	–

Table 3
Total duration of the larval stage (days) of *A. fasciatus* reared on dried milk at 30 °C or 35 °C in combination with 40%, 60% or 80% r.h. The initial sample size was 60 in each set of conditions.

Temperature	30 °C		35 °C	
R.H. %	Range	Mean ± SE	Range	Mean ± SE
40	657–1060	889.8 ± 83.1[a,b]	321–432	356.8 ± 19.8[a]
60	535–610	583.8 ± 13.3[a,b]	226–295	255.2 ± 12.1[a]
80	254–374	341.0 ± 22.5[b]	101–150	122.4 ± 9.53
L.S.D 0.05 (RH)		155.01		44.15
L.S.D 0.01 (RH)		219.01		62.38
L.S.D 0.05 (T°)	197.07	41.55	56.46	
L.S.D 0.01 (T°)	288.36	60.80	82.62	
	(40%)	(60%)	(80%)	

RH: Values at each temperature. T°: Values at each relative humidity.
[a] Significantly different at the same relative humidity ($P < 0.05$).
[b] Significantly different at the same temperature ($P < 0.05$).

tested in this study. Experiments were carried out as described by Ali (1993). To determine the incubation period of eggs, a batch of newly-laid eggs was divided into groups of about 20, each of which was placed in a separate plastic tube (4 × 3 cm), and transferred to one of the experimental conditions. The duration and percentage of egg hatch were determined by daily observations. To determine the number and duration of larval instars, newly-emerged larvae were placed individually in plastic tubes (4 × 3 cm) covered with perforated plastic lids. The larvae were fed *ad libitum* on dried milk ("Bebelac 1" child milk) and kept at the required conditions. The tubes were examined every two days until pupation to record the larval moults and to remove the exuvia. The number and duration of larval instars as well as larval mortality and number of pupated larvae were recorded under each of the tested conditions.

Pupae were sexed according to the genital papillae present in female pupae but not in males. The tubes were examined daily and the pupal duration and adult emergence were noted at each of the tested conditions.

Newly-emerged adults were collected, paired (♀ × ♂) in small plastic tubes and grouped into two sets. The pairs of the first set were fed on tiny drops of honey placed on a small sheet of white paper when they were checked to record oviposition and adult mortality but the pairs of the second set were deprived of food (starved). The two sets were kept under each of the sets of conditions to determine female fecundity and reproductive periods as well as the adult longevity of fed and starved beetles. In a separate but similar experiment the longevity of unmated beetles was also recorded.

3. Results

3.1. Number and duration of larval instars

Data presented in Table 1 indicate that the number of larval instars ranged from 9 to 19, 9 to 16, and 9 to 13 at 30 °C; 40, 60 and 80% r.h., respectively. Generally the duration of each larval instar increased gradually to reach a maximum at the fourteenth, twelfth and eighth instar at 40, 60 and 80% r.h., respectively. At 60% r.h. the longest larval instar duration was in fact recorded for the last instar, represented by one individual which lived for 91 days.

The number of larval instars ranged from 12 to 17, 5 to 15, and 6 to 9 at 35 °C; 40, 60 and 80% r.h., respectively (Table 2). At 40% r.h., the duration of each of the first three instars was nearly equal. The duration then increased gradually up to the fourteenth instar, and then declined. At 60 and 80% r.h. the duration increased gradually with successive instars.

3.2. Total larval duration

Data presented in Table 3 indicate that at 30 °C larval duration decreased with increasing r.h. with a mean period of 889.8 ± 83.1 days, 583.8 ± 13.3 days and 341.0 ± 22.5 days at 40, 60 and 80% r.h., respectively. Also at 35 °C the larval duration decreased with increasing r.h. but the duration was shorter than that at 30 °C (mean periods of 356.8 ± 19.8 days, 255.2 ± 12.1 days and 122.4 ± 9.53 days for 40, 60 and 80% r.h., respectively).

3.3. Percentage mortality and pupation of larval instars

At 30 °C and 40% r.h. the highest mortality (60.2%) occurred during the first instar and then declined during the second, third and fourth instars, after which there was very little mortality in the larval stage. At 60% r.h. mortality occurred only in the first two instars and the fourteenth instar. At 80% r.h. mortality followed the same trend where most of the mortality occurred at the younger

Table 4
Percentage mortality and pupation of larval instars of *A. fasciatus* reared on dried milk at 30 °C; 40%, 60% or 80% r.h. The initial sample size was 60 in each set of conditions.

Number of instars	Mortality of larvae %			No. of pupated larvae			Pupation of larvae %		
	40%	60%	80%	40%	60%	80%	40%	60%	80%
1	60.2	30.0	50.0	0	0	0	0	0	0
2	16.2	7.6	6.2	0	0	0	0	0	0
3	12.9	0	33.3	0	0	0	0	0	0
4	11.1	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0
8	0	0	30.0	0	0	0	0	0	0
9	0	0	0	2	2	2	8.3	15.3	28.5
10	0	0	40.0	0	1	2	0	9.0	66.6
11	0	0	0	1	1	0	4.5	10.0	0
12	0	0	0	3	1	0	14.2	11.1	0
13	0	0	0	2	2	1	11.1	25.0	100
14	0	16.6	–	4	1	–	25.0	16.6	–
15	0	0	–	4	3	–	33.3	75.0	–
16	0	0	–	5	1	–	62.5	100	–
17	33.3	–	–	0	–	–	0	–	–
18	0	–	–	1	–	–	50.0	–	–
19	0	–	–	1	–	–	100	–	–

Table 5
Percentage mortality and pupation of larval instars of *A. fasciatus* reared on dried milk at 35 °C; 40%, 60% or 80% r.h. The initial sample size was 60 in each set of conditions.

Number of instars	Mortality of larvae%			No. of pupated larvae			Pupation of larvae%		
	40%	60%	80%	40%	60%	80%	40%	60%	80%
1	29.4	15.4	54.0	0	0	0	0	0	–
2	5.5	9.7	5.8	0	0	0	0	0	–
3	0	4.0	0	0	0	0	0	0	–
4	2.9	1.4	6.2	0	0	0	0	0	–
5	3.0	0	13.3	0	0	0	0	0	–
6	3.1	2.8	15.3	0	0	1	0	0	7.6
7	3.3	4.4	10.0	0	1	0	0	1.4	0
8	0	1.5	0	0	1	3	0	1.5	33.3
9	0	4.8	16.6	0	2	5	0	3.2	83.3
10	0	3.5	–	0	6	–	0	10.5	–
11	0	4.0	–	0	15	–	0	30.6	–
12	3.3	6.2	–	1	7	–	3.3	21.8	–
13	14.2	8.6	–	2	7	–	7.1	30.4	–
14	13.6	70.0	–	4	4	–	18.1	28.5	–
15	20.0	0	–	2	3	–	13.3	100	–
16	30.0	–	–	1	–	–	10.0	–	–
17	83.3	–	–	1	–	–	16.6	–	–

Table 6
Pupal duration of *A. fasciatus* reared as larvae on dried milk at 30 °C or 35 °C in combination with 40%, 60% or 80% r.h. The initial sample size was 100 in each set of conditions.

Temperature	30 °C		35 °C	
R.H. %	Range	Mean ± SE	Range	Mean ± SE
40	8–17	12.6 ± 0.7	6–9	7.6 ± 1.1
60	7–12	10.5 ± 0.5	7–9	8.0 ± 0.7
80	8–9	8.3 ± 0.3	8–10	8.5 ± 0.7

instars. At 40% and 60% r.h. larvae completed development and pupated from the ninth instar onwards. At 80% r.h. pupation of larvae occurred only after the 9th, 10th and 13th instars (Table 4).

At 35 °C and 40% r.h. mortality occurred throughout the larval instars except the middle ones (eighth to eleventh instars). However, most individuals which died before completing development did so during the five later instars. Larval mortality at 60% r.h. occurred at all instars except the fifth and fifteenth ones, but the highest number of dead larvae occurred during the first instar when 15 individuals out of 97 died. At 80% r.h. mortality occurred at all instars except the third and the ninth.

Most larvae pupated after the twelfth and seventh instars at 35 °C, 40% and 60% r.h. respectively (Table 5). At 80% r.h. most larval pupation occurred at the last instar (ninth) where 5 individuals out of 6 pupated, followed by the eighth instar (3 individuals out of 9). One individual out of thirteen pupated after the sixth instar.

3.4. Pupal duration and adult emergence

At 30 °C the pupal duration decreased from 12.6 ± 0.7 days to 8.3 ± 0.3 days as r.h. increased from 40 to 80% (Table 6). On the other hand at 35 °C the pupal duration showed a slight increase with increasing r.h., means of 7.6 ± 1.1 days, 8.0 ± 0.7 days and 8.5 ± 0.7 days at 40, 60 and 80% r.h., respectively, being recorded. At 30 °C the percentage of adult emergence from pupae was 100% at all humidities (Table 7). At 35 °C adult emergence was 100% at 80% r.h., but only 89.1% and 90.9% for pupae reared at 60 and 40% r.h., respectively.

3.5. Effect of temperature and humidity on the biology of fed and starved adult beetles

At both 30 and 35 °C the fecundity and egg hatch of fed and starved females alike increased with increasing r.h. (Table 8). Under each set of conditions, fed females always had higher fecundity and egg hatch than starved ones. Egg hatch at 35 °C was lower than that at 30 °C in all cases (Table 9). The mean time required for eggs laid by starved females to hatch at 30 °C was about 4 days longer at 40 and 60% r.h., and about 6 days longer at 80% r.h., than eggs laid by fed females (Table 9). At 35 °C, eggs took several days less to hatch than at 30 °C at each humidity, and again those laid by fed females hatched about 2 days earlier than those of starved ones.

At 30 °C, humidity affected the preoviposition period particularly of fed adult females, the period significantly increasing with the r.h. level. In contrast, at 35 °C the preoviposition periods at 40, 60 and 80% r.h. of fed and starved females were not significantly different (Table 10). Also there was no significant difference between the preoviposition periods of fed and starved ones.

At 30 and 35 °C the oviposition or reproductive period increased with r.h. for both fed and starved adult females though less so for starved ones at 30 °C (Table 10). The postoviposition period followed the same general pattern as the preoviposition and oviposition periods for the various temperature and humidity conditions (Table 11). Both oviposition and postoviposition periods of fed females were always longer than the equivalent ones of starved females.

Data presented in Table 12 show that the longest life span of mated and unmated males and females occurred at 80% r.h. At all three test humidities, the females lived longer than males and the unmated ones lived longer than mated ones whether they were females or males. Longevity of starved mated and unmated adult males and females followed the same pattern as their fed counterparts at the three humidities. In all cases the starved beetles lived less long than fed ones and life spans were always less at 35 than at 30 °C (Tables 12 and 13).

3.6. Sex ratio

The sex ratio varied widely under the six different sets of experimental conditions. Table 14 shows that, at 30 °C at either 40 or 60% r.h. the ratio of males to females was nearly 2: 1 (males: females); but at the same temperature with higher humidity (80% r.h.) the reverse was true with a ratio of 1:4 (males: females). At

Table 7
Percentage of adult emergence of *A. fasciatus* reared as larvae on dried milk at 30 °C or 35 °C in combination with 40%, 60% or 80% r.h. The initial sample size was 40 in each set of conditions.

Temperature R.H. %	30 °C	35 °C
40	100	90.9
60	100	89.1
80	100	100

Table 8
Fecundity of fed and starved adult females of *A. fasciatus* and hatchability of their eggs at 30 °C and 35 °C; 40%, 60% and 80% r.h. (Sample size was 40 for each group of females).

Temperature		Fecundity				Hatchability %	
		30 °C		35 °C		30 °C	35 °C
R.H. %		Range	M ± SE	Range	M ± SE		
40	Fed	4–46	19.3 ± 2.4	6–20	13.7 ± 1.5	45.4	16.7
	Starved	3–30	13.8 ± 2.1**	6–15	10.1 ± 1.2**	19.3	13.1
60	Fed	8–76	22.7 ± 3.2	5–30	15.8 ± 2.8	64.5	41.2
	Starved	5–42	19.9 ± 2.5	5–20	11.3 ± 1.5*	30.4	19.4
80	Fed	17–43	26.1 ± 1.8	5–38	21.1 ± 3.7	68.6	45.4
	Starved	16–32	21.8 ± 1.5	5–22	16.3 ± 1.8	48.1	30.1
L.S.D	Fed		7.20		8.12		
0.05	Starved		5.93		4.37		
L.S.D	Fed		9.61		10.98		
0.01	Starved		7.96		5.91		

* Significant ($P < 0.05$).
** Highly Significant ($P < 0.01$).

Table 9
Egg incubation periods (days) of fed and starved adult females of *A. fasciatus* at 30 °C and 35 °C; 40%, 60% and 80% r.h. (Sample size was 40 for each group of females).

Temperature		30 °C		35 °C	
R.H. %		Range	M ± SE	Range	M ± SE
40	Fed	5–9	6.6 ± 0.3**	3–5	4.0 ± 0.3*
	Starved	6–15	10.6 ± 0.6**	5–8	5.9 ± 0.3**
60	Fed	5–10	7.4 ± 0.5	3–6	4.5 ± 0.4
	Starved	7–12	11.0 ± 0.2**	6–8	6.5 ± 0.2*
80	Fed	7–13	8.5 ± 0.5	4–6	5.1 ± 0.3
	Starved	6–20	14.7 ± 0.9	7–8	7.4 ± 0.2
L.S.D 0.05	Fed		1.30		0.95
	Starved		1.82		0.70
L.S.D 0.01	Fed		1.74		1.29
	Starved		2.43		0.94

*Significant ($P < 0.05$).
**Highly Significant ($P < 0.01$).

Table 10
Reproductive periods (days) of fed and starved adult females of *A. fasciatus* raised on honey at 30 °C or 35 °C, 40%, 60% or 80% r.h. (Sample size was 40 for each group of females).

Temperature		Preoviposition				Reproductive periods (Days)			
		30 °C		35 °C		30 °C		35 °C	
R.H. %		Range	M ± SE	Range	M ± SE	Range	M ± SE	Range	M ± SE
40	Fed	6–12	8.8 ± 1.9**	5–10	7.5 ± 0.5	1–10	5.2 ± 0.8 **	1–7	3.1 ± 0.7*
	Starved	11–16	12.8 ± 0.6	7–9	7.9 ± 0.3	1–6	5.4 ± 0.5 **	1–4	2.6 ± 0.4**
60	Fed	7–14	9.4 ± 0.5*	5–12	7.6 ± 0.6	5–14	7.6 ± 0.8**	1–10	5.7 ± 1.0
	Starved	10–18	13.2 ± 1.1	7–13	8.3 ± 0.7	1–7	5.8 ± 0.6**	3–7	4.7 ± 0.5
80	Fed	5–30	13.9 ± 0.7	5–16	8.0 ± 1.0	4–26	12.9 ± 1.6	1–14	6.3 ± 1.3
	Starved	11–18	14.4 ± 0.7	6–18	9.0 ± 1.5	3–13	9.6 ± 1.3	1–8	5.2 ± 0.6
L.S.D 0.05	Fed		3.43		2.9		3.24		2.98
	Starved		2.33		2.72		2.49		1.36
L.S.D 0.01	Fed		4.60		2.82		4.35		4.3
	Starved		3.15		3.68		3.37		1.84

*Significant ($P < 0.05$).
**Highly Significant ($P < 0.01$).

Table 11
Postoviposition periods[a] (days) of fed and starved adult females of *A. fasciatus* raised on honey at 30 °C or 35 °C, 40%, 60% or 80% r.h. (Sample size was 40 for each group of females).

Temperature		30 °C		35 °C	
R.H. %		Range	M ± SE	Range	M ± SE
40	Fed	6–17	10.0 ± 1.0**	4–14	9.2 ± 1.2**
	Starved	5–15	8.9 ± 1.2**	3–10	6.7 ± 0.6*
60	Fed	8–23	12.6 ± 1.2**	5–19	12.6 ± 1.5**
	Starved	7–13	8.8 ± 0.7**	6–18	8.7 ± 1.2
80	Fed	10–42	18.8 ± 2.1	8–27	15.8 ± 1.9
	Starved	9–20	13.6 ± 1.2*	6–12	9.6 ± 0.7
L.S.D 0.05	Fed		4.31		4.49
	Starved		2.97		2.56
L.S.D 0.01	Fed		5.79		6.07
	Starved		4.02		3.45

*Significant ($P < 0.05$).
**Highly Significant ($P < 0.01$).
[a] The postoviposition period is defined as the number of days that the female survives after oviposition has terminated.

35 °C with 40 and 60% r.h. the proportion of males decreased as compared to that at 30 °C, the sex ratio being nearly 1: 1 with a bias towards females. At the higher humidity (80% r.h.) and 35 °C the proportion of males was much higher than that at 30 °C, with a sex ratio of nearly 2: 1 (males: females).

4. Discussion

The results obtained indicate that both temperature and humidity influence the number of larval instars of *A. fasciatus*. An increase in either temperature or humidity decreases the number of larval instars which can range from 6 at 35 °C, 80% r.h., to 19 at 30 °C, 40% r.h. These results are similar to those obtained with the same species by Ali (1993) and (Abd El–Rahman et al., 1981a,b). In *A. unicolor* the number of instars is similar to the minimum number for this species, having an average 7 in males and 8 in females (Baker, 1977). In *Anthrenus coloratus*, a related species, when reared on dried milk plus pure wool textile at 33–35 °C, 70–80% r.h., the number of larval instars ranged from 7 to 9 (Ali, 1997). In general, the earlier instars each lasted for shorter periods than the later ones in the present study, though the duration tended to decline in later instars when there was more than the usual number. These results are in accordance with those obtained on *A. scalaris* by Abd El–Rahman et al. (1981a,b).

Larval mortality was highest in the younger instars in all cases though there was some further mortality in the later ones at 35 °C.Similarly, in *A. coloratus,* high larval mortality occurred in the early instars but some continued later (Ali, 1997).

The present study confirms that increases in temperature and r.h. decrease the larval duration. The same trend was observed by Ali (1993) who worked on the same beetle at 30 °C, 50–60% r.h. and at 35 °C, 70–80% r.h. though larval duration was shorter than that obtained in this study. This difference may be due to the difference in the type of dried milk used, "SMA" dried milk being used in the former study rather than the "Bebelac 1" dried milk used here.

The environmental conditions of humidity and temperature had a considerable effect on pupal duration. In this study, it was evident that the effect of humidity was strong at 30 °C, a finding previously obtained by Rao et al. (1987), Veer et al. (1991) and Ali (1993). The

Table 12
Longevity of mated and unmated males and females of *A. fasciatus* fed on honey at 30 °C or 35 °C, 40%, 60% or 80% r.h. The initial sample size was 40 in each set of conditions.

R.H. %		Male				Female			
		30 °C		35 °C		30 °C		35 °C	
		Range	M ± SE	Range	M ± SE	Range	M ± SE	Range	M ± SE
40	Mated	12–38	23.4 ± 1.8**	11–21	15.2 ± 0.6**	16–41	22.7 ± 1.9**	11–34	19.7 ± 1.3**
	Unmated	20–53	30.3 ± 2.2**	10–22	17.0 ± 0. 8**	26–61	38.8 ± 2.7**	11–32	22.0 ± 1.0**
60	Mated	14–37	23.7 ± 1.6**	16–35	22.8 ± 0.9	20–44	28.5 ± 1.6**	16–38	27.2 ± 1.1
	Unmated	18–51	37.2 ± 2.0**	17–36	25.6 ± 1.2	28–68	41.2 ± 3.0*	22–45	31.5 ± 1.6*
80	Mated	26–73	40.6 ± 3.4	18–45	25.9 ± 1.7	28–75	42.5 ± 3.1	20–46	30.6 ± 1.6
	Unmated	35–74	47.8 ± 2.8	21–41	27.9 ± 1.2	32–89	53.0 ± 3.7	30–49	39.2 ± 1.4
L.S.D 0.05	Mated		6.81		3.21		6.43		3.70
	Unmated		6.72		2.98		9.01		3.51
L.S.D 0.01	Mated		9.8		4.29		8.57		4.93
	Unmated		8.96		3.97		12.02		4.69

* Significant ($P < 0.05$).
** Highly Significant ($P < 0.01$).

Table 13
Longevity of starved, mated and unmated males and females of *A. fasciatus* at 30 °C and 35 °C, 40%, 60% and 80% r.h. The initial sample size was 40 in each set of conditions.

R.H. %		Male				Female			
		30 °C		35 °C		30 °C		35 °C	
		Range	M ± SE	Range	M ± SE	Range	M ± SE	Range	M ± SE
40	Mated	10–25	19.0 ± 1.8**	9–16	11.0 ± 0.8**	12–30	21.1 ± 2.5*	10–23	16.9 ± 1.6**
	Unmated	13–25	20.0 ± 1.6**	12–18	13.0 ± 2.7**	20–33	27.2 ± 1.6	13–21	19.2 ± 2.6**
60	Mated	12–28	19.7 ± 2.0**	12–20	18.1 ± 0.9	15–32	24.8 ± 2.2	15–28	23.3 ± 1.4
	Unmated	15–32	22.8 ± 1.7**	14–23	20.0 ± 2.7*	22–36	29.1 ± 2.2	17–26	25.0 ± 2.8**
80	Mated	20–35	27.7 ± 1.5	15–23	20.5 ± 1.1	20–37	28.3 ± 2.2	17–35	25.3 ± 1.8
	Unmated	20–38	29.7 ± 1.7	18–25	22.5 ± 2.5	25–44	32.8 ± 2.0	18–33	29.8 ± 4.7
L.S.D 0.05	Mated		5.07		2.74		6.69		4.64
	Unmated		4.85		2.43		5.64		3.22
L.S.D 0.01	Mated		6.86		3.70		9.04		6.27
	Unmated		6.56		3.29		7.62		4.35

*Significant ($P < 0.05$).
**Highly Significant ($P < 0.01$).

pupal stage of the related species *A. scalaris* and *Anthrenus sarnicus* lasted 8.08 ± 0.12 days with a range of 7–9 days at 30 °C, 50 ± 5% r.h., and 8.6 ± 0.2 days with a range of 8–10 days at 30 °C, 70% r.h., respectively (Abd El–Rahman et al., 1981a; Armes, 1991). A mean period of 5.4 ± 0.1 days with a range of 4–7 days was recorded for *A. coloratus* at 33–35 °C, 70–80% r.h. (Ali, 1997).

Humidity had no effect on the pupal survival at 30 °C but some effect was evident at 35 °C. In *Oryzaephilus surinamensis* (L.), the pupal survival of each strain decreased with decreasing humidity even at a temperature favorable for development (Jacob and Fleming, 1990).

The present data show that temperature and humidity strongly affect female fecundity and fertility as there was a negative correlation between temperature and fecundity, while the correlation was positive with humidity, indicating that lower temperature (30 °C) and higher humidity (80%) were more favorable than the higher temperature (35 °C) and the lower humidity (40% and 60% r.h) for this species. A similar result was obtained by Ali (1993). Patel and Chari (1977) found that *A. fasciatus* laid an average of 192 eggs while Veer et al. (1991) obtained up to 70 eggs per female. The fecundity of *A. fasciatus* is apparently far higher than that of *A. scalaris*. Mated females of the latter species laid a mean of only 9.50 ± 1.97 eggs during their life (Abd El-Rahman et al., 1981a). In *A. fasciatus* only mated females were able to oviposit whereas in both *A. scalaris* (Abd El-Rahman et al., 1981a) and *A. unicolor* (Kiritani and Kawahara, 1963) virgins can lay eggs. Also *Anthrenus coloratus* unmated females were not able to oviposit (Ali, 1997), unlike those of *A. sarnicus* (Armes, 1991).

Higher temperature resulted in lower egg hatchability, while raising the r.h. increased hatch. Similar results were obtained with *A. sarnicus* where egg hatch was lower (21.1%) at 32.5 °C, 70% r.h. but was much higher (85.3%) at 25 °C, 70% r.h. (Armes, 1990). Starvation of adult females was another factor strongly reducing fecundity and fertility. Also starved, mated females laid smaller eggs than fed mated ones under all test conditions.

High temperature shortened the incubation period but an increase in r.h. slightly increased it. Eggs laid by starved females had a longer incubation period than those laid by fed ones under all conditions. Ali (1997) working with *A. coloratus* stated that eggs incubated at 33–35 °C, 70–80% r.h., had a mean incubation period of 8.3 ± 0.1 days with a range of 7–9 days. A mean period of 10.3 ± 0.1 days with a range of 10–11 days at 35.5 °C, 70% r.h. was recorded for *A. sarnicus*, the period increasing at lower temperature (Armes, 1990).

The r.h. had a strong effect on adult longevity where beetles lived longer at higher humidities than at lower ones. Also starvation and mating had a strong effect where starved and mated beetles died sooner than fed and unmated beetles with females living longer than males. These results are in accordance with those obtained by Abd El-Rahman et al. (1981a), Armes (1991) and Ali (1993, 1997). At 20 °C, the longevity of starved males and females of *A. sarnicus* was similar to those fed on water only or on water plus either albumen or pollen, but was shorter than those fed on sugar with or without albumen or pollen (Armes, 1991). Starved males and females of *Anthrenus verbasci* (L.) had only half the longevity of *A. sarnicus* under the same conditions (Kunike, 1939; Blake, 1961; Armes, 1991). Thus the longevity of adult beetles appears to be dependent on environmental conditions, mating and sex.

The sex ratio fluctuated widely under the different experimental conditions, that at 30 °C differing from that obtained at 35 °C at each of the three humidities for reasons which are unclear. Similar results were obtained by Abd El-Rahman et al. (1981a) and Ali (1993).

As a result of the above findings, it can be concluded that, the biology of the carpet beetle *A. fasciatus* is influenced in many ways by both temperature and humidity. Generally, the r.h. had a strong positive correlation on the reproductive capacity of both starved and fed adult females and adult longevity was longer at higher humidity levels.

Table 14
The sex ratio of adult males and females of *A. fasciatus* reared on dried milk at 30 °C or 35 °C in combination with 40%, 60% or 80% r.h., based on sample sizes of 40 in each set of conditions.

Temperature	Sex ratio %			
	30 °C		35 °C	
R.H. %	Males	Females	Males	Females
40	65.3	34.7	46.5	54.5
60	66.6	33.4	44.5	56.5
80	20	80	62.5	37.5

Acknowledgment

This work was gratefully supported by Center of Excellence for Biodiversity Research, College of Science, King Saud University, Riyadh, Saudi Arabia.

References

Abd El–Rahman, H.A., Zenab, A.S., Ali, M.F., 1981a. Biological study on the black carpet beetle, *Attagenus scalaris* (Pic) (Coleoptera: Dermestidae). Bulletin of the Entomological Society of Egypt 63, 231–241.
Abd El–Rahman, H.A., Zenab, A.S., Ali, M.F., 1981b. Ecological study on the black carpet beetle, *Attagenus scalaris* (Pic) (Coleoptera: Dermestidae). Bulletin of the Entomological Society of Egypt 63, 243–252.
Ali, M.F., 1992. Food preference and effect of starvation and high temperature on *Attagenus fasciatus* (Thunberg) (Coleoptera: Dermestidae). Journal of the Egyptian German Society of Zoology, Comparative Physiology 7 (A), 287–296.

Ali, M.F., 1993. Biological studies on immature and adult stages of *Attagenus fasciatus* (Thunberg) (Coleoptera: Dermestidae). Journal of Stored Products Research 29, 237–242.

Ali, M.F., 1997. Development and heat tolerance of *Anthrenus coloratus* (Reitter) (Coleoptera: Dermestidae) reared on a laboratory diet. Journal of Stored Products Research 33, 251–255.

Armes, N.J., 1990. The biology of *Anthrenus sarnicus* Mroczkowski (Coleoptera: Dermestidae): 1. Egg and larval development. Journal of Stored Products Research 26, 11–22.

Armes, N.J., 1991. The biology of *Anthrenus sarnicus* Mroczkowski (Coleoptera: Dermestidae) – 2. Pupal and adult stages. Journal of Stored Products Research 27, 57–64.

Baker, J.E., 1977. Synchronized pupation in starved and fed larvae of the black carpet beetles. Annals of the Entomological Society of America 70, 299–302.

Blake, G.M., 1961. Length of life, fecundity and oviposition cycle in *Anthrenus verbasci* (L.) (Col., Dermestidae) as affected by adult diet. Bulletin of Entomological Research 52, 459–472.

Hinton, H.E., 1945. A Monograph of the Beetles Associated with Stored Products, vol. I. British Museum (Natural History), London.

Jacob, T.A., Fleming, D.A., 1990. The effect of humidity on the development and survival of the immature stages of strains of *Oryzaphilus surinamensis* (L.) (Coleoptera: Silvanidae) at constant temperatures. Journal of Stored Products Research 26, 163–167.

Kiritani, K., Kawahara, S., 1963. Effect of adult diet on the longevity, fecundity, oviposition period and phototaxis in the black beetle, *Attagenus megatoma* (F). Japanese Journal of Ecology 13, 21–28.

Kunike, G., 1939. Neure Ergebniss Über die Eiablage and Generation folage der *Anthrenus* Arten. Vorlaüfige Mitteilungen Anzeiger fur Schädlingskundte 15, 80–84.

Mallis, A., 1990. Handbook of Pest Control the Behavior, Life History and Control of Household Pests, Seventh Edition. Frank Foster & Co, Cleveland, Ohio.

Metcalf, C.L., Flint, W.P., 1962. Destructive and Useful Insects; Their Habits and Control (Revised by Metcalf, R.L.), fourth ed. McGraw-Hill Book Company, New York, San Francisco, Toronto, London.

Patel, G.M., Chari, M.S., 1977. Bionomics of tobacco seed beetle, *Attagenus fasciatus* (Thunberg). Gujarat Agricultural University Research Journal 2, 69–75.

Rao, G.V.R., Surender, A., Wightman, J.A., Varma, B.R., 1987. *Attagenus fasciatus* (Thunberg) (Coleoptera: Dermestidae) a new pest of stored groundnuts. International Arachis News Letter 2, 12–13.

Veer, V., Prasad, R., Rao, K.M., 1991. Taxonomic and biological notes on *Attagenus* and *Anthrenus spp.* (Coleoptera: Dermestidae) found damaging stored woollen fabrics in India. Journal of Stored Products Research 27, 185–198.