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Effects of food and water deprivation on nymphal development, adult fecundity and insecticide susceptibility in German cockroaches, *Blattella germanica* (L.)

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Abstract. The effects of food and water deprivation on nymphal development, survivorship, and fecundity of adult German cockroaches, *Blattella germanica*, and insecticide susceptibility of adult males were studied in the laboratory. Nymphal development and percentage number of nymphs achieving adulthood were significantly affected by food or water deprivation, or both together, in all four different treatment regimes (food only, water only, no food and water, with food and water). Fecundity of female cockroaches was affected by food and water deprivation, but did not differ significantly among the starvation regimes ($P > 0.05$). Adult females produced the most number of nymphs under the presence of food and water (control), and nymphal production was significantly reduced ($P < 0.05$) upon removal of either one of the resources. Susceptibility of adult males to propoxur, upon starvation for three and six days increased between 1.1 – 1.9-fold. There appeared to be little effect of starvation on susceptibility to deltamethrin.

INTRODUCTION

The German cockroach, *Blattella germanica* (L.), is one of the most important insect pests in the urban environment. In Malaysia, they are pests in hotels and restaurants (Lee *et al.*, 1993; Lee *et al.*, 1999a). They have also been reported to be potential mechanical vectors of diseases (Brenner, 1995; Lee, 1997). Many pathogenic microorganisms had been isolated from German cockroaches (Brenner, 1995). Alcamo & Frishman (1980) surveyed for German cockroach in more than 40 sites including restaurants, bakeries, cafetarias, hospitals, prison, private homes and apartments in New York and isolated *Streptococcus*, *Staphylococcus*, *Bacillus* and *Clostridium* from the insects collected. Out of the cockroaches trapped, 89% of them harboured at least three species of pathogenic bacteria, which demonstrated a high level of exposure of residents to these pathogens. In addition to pathogens, the German cockroach has also been shown to cause household allergies (Kang, 1990; Brenner, 1995; Lee, 1997).

Establishment of German cockroach populations depends on environmental condition (Ogata, 1976), availability of food and water (Cornwell, 1968; Ross & Mullins, 1995) and presence of harbourages (Ross & Mullins, 1995). Recommendations for control of these populations often suggest removal of food, water and harbourages (Piper *et al.*, 1975; Bennett, 1978; Robinson & Zungoli, 1985; Zungoli & Robinson, 1986; Lee, 1998). Although many studies indicated that availability of food and water (Cochran, 1983; Durbin & Cochran, 1985) or bad sanitation (Wright, 1979; Sherron *et al.*, 1982; Schal, 1988) will provide a positive impact on population growth of cockroaches or level of cockroach infestations, several others have shown that there is no direct relationship between sanitation rate with the level of infestation (Bennett, 1978; Bertholf *et al.*, 1987; Lee & Lee, submitted).

One of the important factors that determined the impact of sanitation on level of infestation is the biological fitness of German cockroaches upon deprivation of food and water due to better sanitation practice. With a good understanding of the impact of sanitation on this factor, a better cockroach management programme can be designed for precision targetting and successful implementation. In this paper, we report the effects of food and water deprivation on nymphal development, survivorship, adult fecundity and insecticide susceptibility of the German cockroach, *Blattella germanica*. Food and water were provided once every six days to simulate their availability under good sanitary condition in the field.

MATERIALS AND METHODS

The laboratory susceptible strain (ICI) used in this study was previously obtained from Zeneca Agrochemicals, UK. They were reared under laboratory conditions of 12 hours photoperiod, 26 ± 2°C, 60 ± 5% relative humidity. Food (Pedigree Crunchy Bites) and water were provided *ad libitum*. Label claims on the food package indicated that it contained 21% protein, 10% lipid, 5% fiber and 1.3% salt.

Late gravid females were each segregated into a polyethylene container. Upon emergence of young nymphs, the nymphs were isolated and ten nymphs were introduced into a polyethylene cup (6.5 cm diam. x 10.6 cm height) with harborage. Food and water were provided according to treatment regimes. All nymphs were provided with food and water 24 hours prior to the initiation of the experiment. Four treatment regimes were tested: (1) food and water provided *ad libitum* (control) [FW], (2) food provided for 24 hours once every six days, and water provided *ad libitum* [W], (3) water provided for 24 hours once every six days, and food provided *ad libitum* [F], and (4) both food and water provided for 24 hours once every six days [no FW]. A total of 10 replicates were done for each treatment regime. Observation for moulting and mortality was done every morning. Dead nymphs and emptied skins were removed to ensure that there are no other food sources for the nymphs. The period taken for nymphs in each treatment regime to achieve adulthood was recorded.

Upon achieving adulthood, adults were paired and similar treatment regimes resumed. Observation was made daily for events in reproduction (according to methods described in Lee *et al.*, 1996a; 1998) up to the fourth ootheca, as follow: preoviposition period, incubation period, total nymphs per ootheca, total number of nymphs produced up to fourth ootheca. Data obtained were analyzed with analysis of variance and means were separated with Tukey's HSD ($P < 0.05$), using SPSS Version 9.5 computer software.

Insecticide susceptibility of adult males deprived from food or water, or both together, for 3 and 6 days were determined using a modified W.H.O. glass jar method (Lee *et al.*, 1999b). Technical grade propoxur and deltamethrin, diluted in analytical grade acetone were pipetted into the jar to layer the base evenly with a concentration of 20 µg cm^{-2}. Ten insects were then introduced into the jar and mortality was recorded at selected time interval up to 2 hours. The experiment was repeated 4 – 5 times, depending on the availability of the insects. Data were pooled and subjected to probit analysis using POLO-PC software program. Susceptibility ratios and their 95% fiducial limits were calculated according to procedures described by Robertson & Preistler (1992) using a locally developed computer program (Lee, unpublished).

RESULTS AND DISCUSSION

Nymphal development and survivorship. Generally, nymphal development was longest when cockroaches were deprived of food and water (Table 1). Mean nymphal developmental period when food and water were provided (47.8 ± 0.6 days) was comparable with that obtained by Lim (1994) (49.3 ± 0.3 days) and Lee *et al.* (1996c) (45.6 ± 0.3 days). However, the period was longer than those demonstrated in VPI strain (33 days) (Perkins & Grayson, 1961), UCR strain (38 days) (Archbold *et al.*, 1987) and an unknown strain (40.1 ± 0.6 days [male] and 41.3 ± 0.5 days [female]) (Willis *et al.*, 1958). On the contrary, Ross (1991) reported a longer nymphal developmental period (53.9 – 58.6 days). Variation in these findings are most likely due to differences in cockroach strain (Ross, 1991; Lee *et al.*, 1996) and experimental conditions such as temperature (Gunn, 1935; Gould, 1941), food (Hamilton & Schal, 1988; Cooper & Schal, 1992), etc. Nymphal developmental period for male and female cockroaches that were provided with food and water (FW) were found to be significantly different, when compared with the three other treatments (Table 1). The first female in the FW category emerged 23, 25 and 34 days earlier than those in F, W and no FW categories, respectively, compared to 21, 18 and 34 days for the males in the same categories.

Kunkel (1966) had reported that there is a need for the presence of food for at least 12 hours to initiate the moulting process in the German cockroach. He concluded that initiation of moulting cycle was related to the beginning of feeding phase. As intermittent feeders, German cockroach nymphs only need a short feeding period of 12 hours to begin the moulting process. This explains why the nymphs that were starved in this study were still capable of becoming adults.

Deprivation from food and water affects nymphal survivorship. It was shown in this study that only about 14% of the total nymphs reared under no FW were capable of achieving adulthood (Table 1). About 30% of cockroaches that were provided either F or W emerged as adults.

Preoviposition and incubation periods. The number of paired cockroaches used for each starvation regime varied due to differences in number of nymphs achieving adulthood in the earlier experiment. Overall, there appeared to be no significant difference in both preoviposition and incubation periods among the four starvation regimes,

Table 1: Nymphal development and survivorship of German cockroaches subjected to different treatment regimes

Treatment regime	mean nymphal development ± S.E.M. (days)[1]							% achieving adulthood	Sex ratio (male: female)
	n	male	range	n	female	range	combined		
Food & water (control)	30	46.7 ± 0.9 a	39 – 60	29	48.9 ± 0.9 a	38 – 64	47.8 ± 0.6	59.0	1.0 : 1.0
Food only[2]	11	70.2 ± 2.1 b	60 – 82	16	69.1 ± 1.3 b	61 – 80	69.6 ± 1.1	27.0	0.7 : 1.0
Water only	14	77.1 ± 2.3 bc	57 – 84	17	77.9 ± 2.5 c	63 – 97	77.6 ± 1.7	31.0	0.8 : 1.0
No food & water[2]	5	85.8 ± 5.4 c	73 – 103	9	88.8 ± 4.2 d	72 – 114	87.7 ± 3.2	14.0	0.6 : 1.0

[1]Mean values followed by different letters within the same column are significantly different (Tukey's HSD, $P < 0.05$).
[2]Only single survivor which yet to reach adulthood after 120 days experimental period.

except for the preoviposition period of the third ootheca under W only category, and the incubation period of the first ootheca for both W only and no FW categories (Table 2). Mean preoviposition period for the first ootheca for FW category [8.4 ± 0.2 days] was comparable to that reported earlier by Lee *et al.* (1996) [8.4 ± 0.2 days] and Lee *et al.* (1998) [8.8 ± 0.3 days] on the same strain.

Generally, incubation period reduced with increasing oothecal number in all starvation regimes (Table 2). Deprivation from food or water, or both together appeared not to affect the incubation period of the German cockroaches. This may be due to cessation of feeding by gravid females during oothecal incubation (Cochran, 1979). The oothecal incubation period under control category (FW) obtained from this study is comparatively shorter than that obtained from earlier studies (Lee *et al.*, 1996; Lee *et al.*, 1998) [about 25 days].

Number of nymphs produced. Overall, the mean number of nymphs produced per ootheca was the highest in the control (FW) category [34.9 ± 0.8 nymphs], while the lowest was among the groups that were deprived of food and water (no FW) [22.5 ± 0.8 nymphs]. Nevertheless, there was no significant difference in the first ootheca, compared to the second ootheca where a significant difference between the two categories was detected (Table 2). Earlier, it was reported that during oothecal formation, female cockroaches were very susceptible to food and water deprivation (Cochran, 1983), and if food and water deprivation

Table 2: Effects of different treatment regimes on several reproductive parameters of the first four oothecae in German cockroaches

Oothecal no.	Treatment regime	Preoviposition period			Incubation period			No. nymphs per ootheca		
		n	mean ± SEM[1] (days)	range	n	mean ± SEM[1] (days)	range	n	mean ± SEM[1] (days)	range
1	Food and water (control)	27	8.4 ± 0.2 a	7 – 11	27	20.2 ± 0.1 a	7 – 44	27	33.7 ± 1.7 a	7 – 44
	Food only	7	10.3 ± 2.1 a	5 – 20	7	19.9 ± 0.3 a	18 – 21	7	31.4 ± 0.8 a	28 – 34
	Water only	11	11.1 ± 1.1 a	6 – 16	11	18.3 ± 0.2 b	17 – 19	11	29.8 ± 1.8 a	19 – 39
	No food and water	3	10.7 ± 2.3 a	6 – 13	3	17.7 ± 0.3 b	17 – 18	3	25.0 ± 4.6 a	19 – 34
2	Food and water (control)	23	7.2 ± 1.3 a	4 – 34[2]	23	18.5 ± 0.3 a	14 – 20	23	35.4 ± 1.5 a	16 – 45
	Food only	10	7.9 ± 1.1 a	3 – 15	10	18.9 ± 0.2 a	18 – 20	10	29.2 ± 1.7 ab	18 – 36
	Water only	11	7.1 ± 0.6 a	4 – 10	11	17.9 ± 0.3 a	15 – 19	11	29.9 ± 2.1 ab	18 – 38
	No food and water	3	6.3 ± 0.9 a	5 – 8	3	18.3 ± 0.3 a	18 – 19	3	20.0 ± 4.6 b	12 – 28
3	Food and water (control)	22	5.1 ± 0.2 a	4 – 9	22	18.1 ± 0.3 a	14 – 19	22	35.7 ± 1.7 a	15 – 43
	Food only	8	5.6 ± 0.5 a	4 – 7	8	18.6 ± 0.4 a	17 – 21	8	25.1 ± 1.9 b	17 – 31
	Water only	4	7.5 ± 0.9 b	5 – 9	4	17.0 ± 0.9 a	15 – 19	4	29.0 ± 4.6 ab	16 – 36
	No food and water	–	–	–	–	–	–	–	–	–
4	Food and water (control)	19	4.8 ± 0.2	4 – 6	19	18.5 ± 0.1	18 – 20		34.8 ± 1.4	18 – 43
	Food only	–	–	–	–	–	–	–	–	–
	Water only	–	–	–	–	–	–	–	–	–
	No food and water	–	–	–	–	–	–	–	–	–

[1]Mean values followed by different letters within the same column were significantly different (Tukey's HSD, $P < 0.05$).
[2]Only one ootheca had a preoviposition period of 34 days (range = 4 – 11 days, upon exclusion of this ootheca).

Table 3: Effect of different starvation regimes on the total nymphal production[1] per female

Treatment regimes	n	Mean total nymphs per female (± S.E.M)[2]
Food and water	28	114.0 ± 9.5 a
Food only	10	71.3 ± 5.9 b
Water only	12	64.4 ± 5.9 b
No food and water	3	48.3 ± 6.8 b

[1]Total number of nymphs up to 4[th] ootheca.
[2]Mean values followed by similar letters within the same column were not significantly different (P > 0.05; Tukey's HSD).

continued for a longer period of time, less numbers and smaller sizes of oothecae will be produced (Mueller, 1978). This will probably lead to a decrease in total nymphal production.

Females that were provided food and water *ad libitum* (FW) throughout their lives had a higher fecundity, with significantly more total number of nymphs produced up to fourth ootheca, than those from the other treatment regimes (Table 3). This may be due to their longer longevity periods, because a substantial proportion of the starved females (F, W or no FW) died after producing the third ootheca.

Insecticide susceptibility. Overall, adult males starved for 3 and 6 days were more susceptible to propoxur than the control insects (Table 4). Those that were deprived of both food and water (no FW) showed the highest susceptibility to propoxur, followed by W only and F only categories. This supported findings reported earlier by Gordon (1961), Vance (1983), Kramer et al. (1990) and Lee *et al.* (1996). No incremental effect was seen in propoxur susceptibility when starvation period was increased from 3 to 6 days. According to Kramer *et al.* (1989), propoxur induced water loss in affected insects through increased metabolism and loss of spiracle control. Propoxur is metabolized by hydroxylation which requires an input of a hydroxyl group, possibly from the body water (Matsumura, 1985). As such, the impact of hydration would have been greater in those cockroaches that were deprived of water, rather than of food (Lee *et al.*, 1996). There appeared to be little effect of starvation on susceptibility to delta-

Table 4: Effects of different treatment regimes on the susceptibility of adult male German cockroaches to propoxur and deltamethrin

Insecticide (concentration)	Starvation period (days)	Treatment regime	n	LT_{50} (95% fiducial limit)	Slope ± S.E.M.	Susceptibility ratio (95% fiducial limit)	χ^2 (df)
propoxur (20 µgcm $^{-2}$)	0	Food and water	50	17.8 (17.2 – 18.7)	13.0 ± 1.3	–	2.23 (4)
	3	Food only	50	15.7 (15.3 – 16.2)	17.1 ± 1.7	1.13 (1.09 – 1.18)	1.68 (3)
		Water only	50	13.8 (13.2 – 14.5)	8.5 ± 1.1	1.38 (0.64 – 2.98)	0.91 (3)
		No food and water	50	9.3 (8.4 – 10.3)	9.6 ± 1.0	1.91 (1.80 – 2.03)	4.30 (3)
	6	Food only	50	13.2 (12.6 – 13.8)	9.6 ± 1.1	1.35 (1.28 – 1.42)	2.26 (3)
		Water only	50	12.6 (12.2 – 13.0)	14.6 ± 1.7	1.58 (1.44 – 1.73)	1.28 (2)
		No food and water	47	10.7 (9.2 – 12.3)	13.9 ± 1.6	1.70 (1.60 – 1.81)	7.42 (2)
deltamethrin (20 µgcm $^{-2}$)	0	Food and water	50	4.8 (4.3 – 5.5)	5.7 ± 0.4	–	4.94 (10)
	3	Food only	50	4.3 (3.3 – 5.3)	3.5 ± 0.3	1.12 (1.02 – 1.23)	64.85 (11)
		Water only	50	5.1 (4.3 – 6.7)	3.6 ± 0.3	0.94 (0.85 – 1.04)	38.33 (10)
		No food and water	50	4.7 (4.2 – 5.3)	5.0 ± 0.4	1.02 (0.95 – 1.10)	27.26 (9)
	6	Food only	45	5.1 (3.7 – 6.3)	4.7 ± 0.9	0.95 (0.83 – 1.08)	13.57 (7)
		Water only	40	4.4 (3.8 – 5.4)	3.7 ± 0.7	1.09 (0.91 – 1.30)	4.98 (9)
		No food and water	40	5.4 (5.0 – 5.9)	5.6 ± 0.6	0.87 (0.80 – 0.95)	11.58 (8)

methrin. This finding is likely due to differences in metabolism of deltamethrin, compared to that of the propoxur.

This study demonstrated that nymphal development, adult fecundity and insecticide susceptibility of the German cockroach were affected by food and water deprivation. It was shown that under good sanitation, the insect's biological fitness can be reduced, besides increasing its susceptibility to insecticides. In addition, good sanitation practice will also encourage starved cockroaches to explore more often, thus increasing the chance of these insects of coming into contact with residual insecticides or baits (Lee & Lee, submitted), which will directly improve the overall control programme.

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