

Fecundity, nymphal development and longevity of field-collected tropical bedbugs, *Cimex hemipterus*

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Abstract. This study examined the fecundity, oviposition, nymphal development and longevity of field-collected samples of the tropical bedbug, *Cimex hemipterus* (Fabricius) (Hemiptera: Cimicidae). Under environmental conditions of $26 \pm 2^\circ\text{C}$, $70 \pm 5\%$ relative humidity and a 12-h photoperiod, with bloodmeals provided by a human host, six strains of tropical bedbug had a fecundity of up to 50 eggs per lifetime, over 11–14 oviposition cycles. Increased feeding frequency improved fecundity. After feeding and mating, adult females normally took 2–3 days to produce a first batch of eggs. The oviposition period lasted 2–7 days before cessation of the oviposition cycle. The egg incubation period usually lasted 5–7 days before the emergence of first instars. The nymphs underwent five stadia (the first four of which each took 3–4 days, whereas the last took 4–5 days) before becoming adults at a sex ratio of 1 : 1. More than five bloodmeals were required by the nymphs to ensure a successful moult. Unmated adults lived significantly longer than mated adults ($P < 0.05$). Unmated females lived up to almost 7 months, but the longevity of mated males and females did not differ significantly ($P > 0.05$).

Key words. *Cimex hemipterus*, cast exoskeleton, egg incubation, fecundity, longevity, nymphal development, oviposition, preoviposition.

Introduction

The bedbug is an important insect pest that causes erythematous papules or haemorrhagic bulbous eruptions from its bite (Boase, 2004). Heavy and repeated bedbug bites have been reported to cause severe haemoglobin loss among patients in Hyderabad, India (Venkatachalam & Belavady, 1962). Bedbug infestations can also trigger delusional parasitosis in people who have been bitten (Hinkle, 2000).

The resurgence of bedbug infestation in many parts of the world, initially noticed in the early 1990s (Krueger, 2000), has been a major concern to the hospitality and tourism industry. It has received widespread coverage in various mass media (Potter, 2006). Pest management professionals in North America, Europe and Australia have recorded substantial increases in accounts of bedbugs (Doggett *et al.*, 2003, 2004; Boase, 2004; Hwang *et al.*, 2005). The causes of the resurgence of bedbug infestations have not been confirmed, but possibilities include

increases in international travel, changes in pest management practices and the development of insecticide resistance in bedbugs (Moore & Miller, 2006; Potter, 2006).

Over the past several years, pest management professionals in many countries in tropical Asia have recorded increased accounts of bedbugs (Lee, 2007). However, unlike the species encountered in temperate and subtropical regions (i.e. the common bedbug, *Cimex lectularius* L.), all infestations recorded in Malaysia and Singapore thus far involve the tropical bedbug, *Cimex hemipterus* (Fabricius) (How & Lee, 2010). Although several studies focusing on the management of *C. hemipterus* exist (Lindsay *et al.*, 1989; Kumar *et al.*, 1995; Myamba *et al.*, 2002), with the exception of the biological study carried out by Omori (1941), there is a dearth of information about the biological parameters of *C. hemipterus*.

We examined several biological parameters (fecundity, oviposition, nymphal development and adult longevity) of the tropical bedbug. Experiments were conducted using six dif-

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Table 1. List of the six field-collected strains of *Cimex hemipterus* used in this study.

| Strain | Location collected | Sampling site | Date of collection |
|--------------|--|---|--------------------|
| K Melayu5 | Kampung Melayu, Blok A, Level 5, Malaysia | Surrounding rattan chair, sofa cushion | 21 July 2005 |
| K Melayu14 | Kampung Melayu, Blok A, Level 14, Malaysia | Surrounding rattan chair, sofa cushion, bedding | 27 July 2005 |
| Dato Keramat | Jalan Dato Keramat, Penang, Malaysia | Bedding, wood cracks and cervices, cupboard | 28 July 2005 |
| Serangoon | Serangoon Ave 4, Singapore | Bedding, rattan chair | 10 August 2005 |
| Bukit Batok | Bukit Batok, Singapore | Worker quarter (bedding) | 1 August 2005 |
| Soon Lee | Soon Lee Road, Singapore | Bedding | 5 August 2005 |

ferent strains of *C. hemipterus* collected from the field in Malaysia and Singapore.

Materials and methods

Insects

Collections of field populations of *C. hemipterus* were made in Penang, Malaysia and on Singapore Island and were brought back to the laboratory for rearing. The following six field-collected strains of tropical bedbug were used in this study: K Melayu5, K Melayu14, Dato Keramat, Serangoon, Bukit Batok and Soon Lee (Table 1). They were cultured in the laboratory at $26 \pm 2^\circ\text{C}$ and $70 \pm 5\%$ relative humidity (RH) in glass jars (7 cm in diameter, 9 cm in height) in which folded brown paper provided harbours. The bedbugs were fed on a human host.

The F₁ generation was used in oviposition studies, and the eggs and progeny were then used for egg incubation and nymphal development studies until the emergence of adult bugs. The subsequent F₂ and F₃ generations were used in adult longevity and fecundity studies.

Fecundity

All the adult bugs were segregated from the first day of emergence and kept for a few days to allow for acclimatization before being used in the study. The following two fecundity experiments were conducted: (a) 10 male/female pairs of each

of the six strains were kept at a sex ratio of 1 : 1, and (b) 10 sets of each of the six strains were kept at a ratio of 1 : 2 (two males were placed with four females). Numbers of new eggs were counted daily. Numbers of eggs that did and did not hatch were recorded. Adults were fed following cessation of ovipositioning. The experiment was carried out at room temperature of $26 \pm 2^\circ\text{C}$, at $70 \pm 5\%$ RH and under a 12-h photoperiod.

Oviposition

Preoviposition, oviposition and egg incubation periods and hatchability were measured in this study. The preoviposition period is defined as the interval between mating and the laying of eggs, whereas the oviposition period is defined as the interval between the initiation and cessation of one round of egg-laying activity. Daily observations were made of each egg to determine the incubation period and hatchability. In our studies, corrugated brown paper was used to provide a darker background to facilitate the easy detection of eggs, which were usually found glued either singly or in clusters to the paper substrate.

Nymphal development

At least three batches of nymphs collected from the previous egg incubation studies were used in this experiment. A total of 10–100 nymphs (depending on availability) were kept in glass jars for observation and data recording. The exoskeleton of

Table 2. Fecundity of the six field-collected strains of *Cimex hemipterus*.

| Strain | Pairing ratio 1 : 1 (one male, one female) | | | Pairing ratio 1 : 2 (two males, four females) | | |
|--------------|--|-------|----------------|---|-------|----------------|
| | No. eggs produced per female \pm SEM*† | Range | % sterile eggs | Mean no. eggs produced per female \pm SEM*† | Range | % sterile eggs |
| K Melayu5 | 26.63 \pm 4.24 ^{a(a)} | 15–42 | 0.87 | 27.84 \pm 2.35 ^{a(a)} | 17–39 | 2.36 |
| K Melayu14 | 23.63 \pm 3.62 ^{a(a)} | 15–45 | 0.47 | 46.08 \pm 4.77 ^{b(b)} | 21–70 | 1.29 |
| Dato Keramat | 21.86 \pm 2.90 ^{a(a)} | 12–35 | 2.86 | 32.25 \pm 3.08 ^{ab(b)} | 12–47 | 2.38 |
| Serangoon | 29.00 \pm 3.80 ^{a(a)} | 14–43 | 0.87 | 36.83 \pm 2.46 ^{ab(a)} | 21–48 | 4.69 |
| Bukit Batok | 26.13 \pm 4.11 ^{a(a)} | 15–50 | 2.75 | 37.58 \pm 3.06 ^{ab(b)} | 12–50 | 2.09 |
| Soon Lee | 20.11 \pm 2.57 ^{a(a)} | 13–33 | 1.57 | 46.42 \pm 2.77 ^{b(b)} | 28–61 | 5.35 |

*Means followed by different letters within the same column are significantly different among the strains (Tukey's HSD; $P < 0.05$).

†Means for the same strain followed by different letters in parenthesis are significantly different between the different sex ratios (t -test, $P < 0.05$). SEM, standard error of the mean.

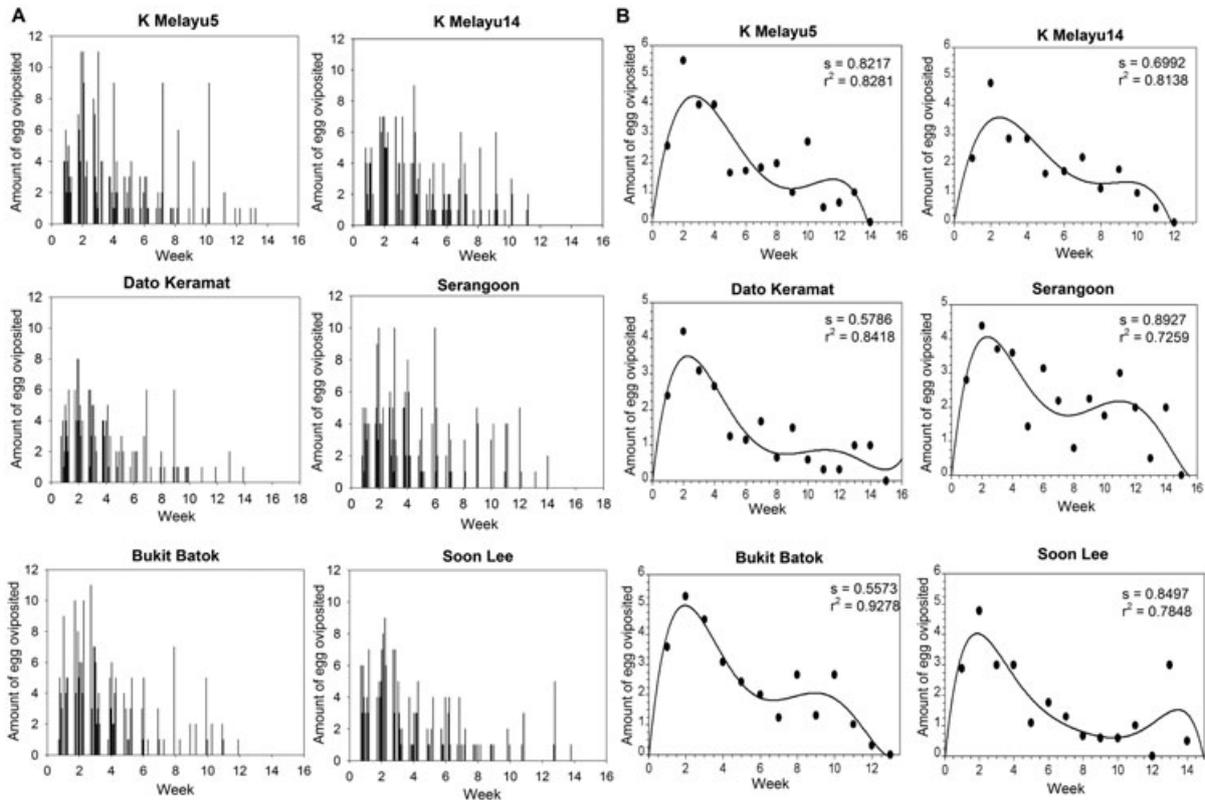


Fig. 1. Fecundity of the six field-collected strains of *Cimex hemipterus* under the 1 : 1 pairing regime (one male, one female). (A) Numbers of eggs oviposited per week. (B) Fitted polynomial curves for the average numbers of oviposited eggs per week ($n = 10$ females).

each nymph was used to signify a moulting event. Observations were made until all nymphs became adults. The emerged adults were sexed and a chi-squared test was conducted to determine any deviation from a 1 : 1 sex ratio.

Cast exoskeleton measurement

At least 20 cast exoskeletons of each stadium from each of the six strains were collected, viewed and measured under an Olympus SZ61 stereo microscope (Olympus Corp., Tokyo, Japan) connected to a computer using analysis[®] image processing software (Soft Imaging System GmbH, Münster, Germany). The cast exoskeletons were measured from the rostrum tip to the end of the anal pore. A comparison for each stadium was conducted to categorize means and the range of cast exoskeleton length to enable easy determination of nymphal stages.

Adult longevity

Adult longevity refers to the lifespan of adults. Longevity was estimated by observing 10–12 adult males and females that had been segregated from the day of emergence and kept under one of two conditions as either unmated (virgin) or

mated (paired up). A human bloodmeal was given once a week throughout the experiment until the natural death of the bugs.

Analysis

Data were subjected to a *t*-test or analysis of variance (ANOVA) and means were separated using Tukey's HSD (honestly significant difference). Percentage data were transformed into arcsine values before running the ANOVA. All analyses were performed using Statistix[®] Version 7.0 (Analytical Software, Tallahassee, FL, U.S.A.).

Results and Discussion

Fecundity

Johnson (1941) discussed the effects of three different bloodmeal regimes on bedbugs in terms of fecundity: (a) a bloodmeal at 3–4-day intervals; (b) a bloodmeal at 3–4-day intervals, followed by 7-day intervals, and (c) a bloodmeal on the second or third day after cessation of oviposition. Fecundity varied according to the feeding regime. In this study, we chose to use the third regime described by Johnson (1941).

The results of the fecundity study indicated no significant difference in the total number of eggs produced per lifetime

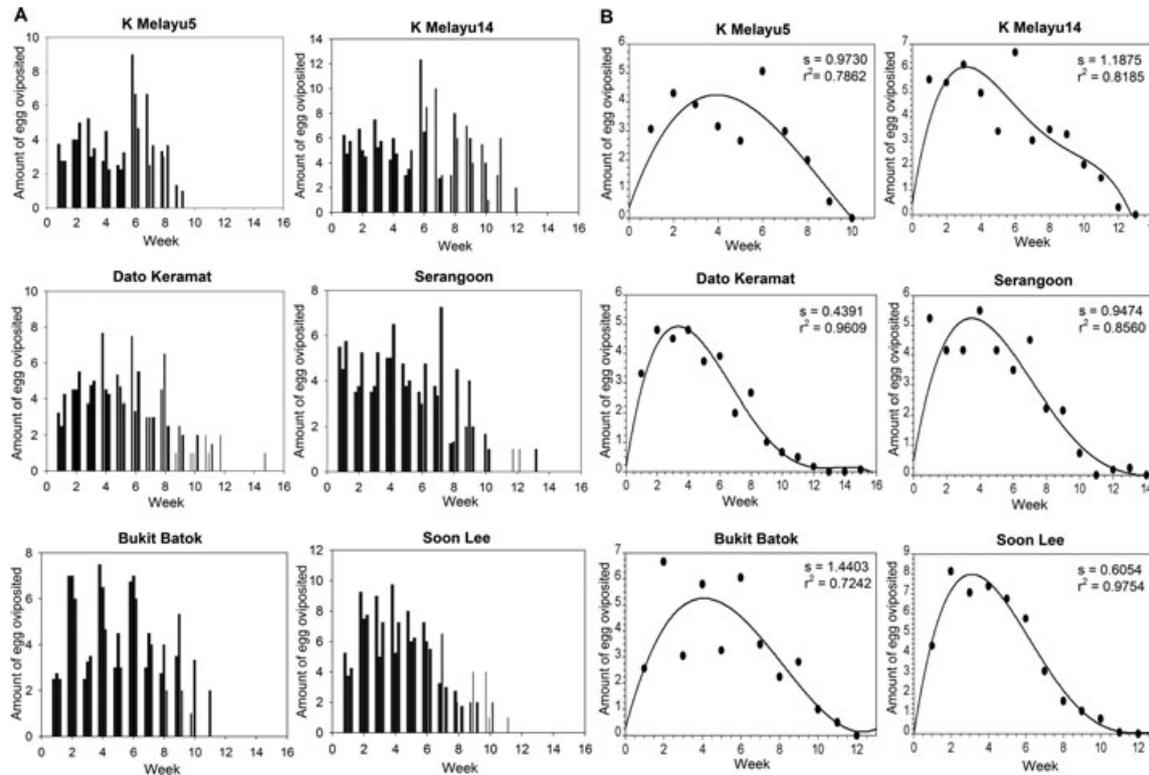


Fig. 2. Fecundity of the six field-collected strains of *Cimex hemipterus* under the 1 : 2 pairing regime (two males, four females). (A) Numbers of eggs oviposited per week. (B) Fitted polynomial curves of the average numbers of oviposited eggs per week ($n = 10$ females).

among the six strains of *C. hemipterus* studied under the paired sex ratio of 1 : 1 (Table 2). Females produced an average of 20–29 eggs per lifetime (range 13–50 eggs). In general, 11–14 ovipositions occurred per female and egg production peaked at the second and third ovipositions (Fig. 1). This finding agrees well with Johnson's (1941) report that peak oviposition of *C. lectularius* occurred at the fourth oviposition cycle and that females produced 6–10 eggs per cycle when they were fed on rabbit blood.

At a male : female ratio of 1 : 2, significant differences ($P < 0.05$) were detected among the six strains studied and in comparison with those paired at the 1 : 1 ratio within the same strain (Table 2). Egg production increased to an average of 27–47 eggs (overall range 12–70 eggs). The total number of ovipositions per lifetime also increased slightly. The peak oviposition occurred between the second and fourth cycles (Fig. 2).

Our values were comparatively lower than those reported by Omori (1941), in whose study one female *C. hemipterus* produced up to 323 eggs at 27°C. Variations in experimental methods are probably the cause for this discrepancy in results. In Omori (1941), the bedbugs were blood-fed almost every day during the oviposition period, but the sources of blood were not stated. Previously, researchers reported that a slight variation in egg production could occur when bloodmeals from different host animals were provided (Johnson, 1937; Bell & Schaefer, 1966).

In this study, between 0.47% and 5.35% of eggs did not hatch successfully. This result was comparatively lower than the 10.84% recorded by Omori (1941). The eggs that were categorized as unsuccessfully hatched may have been 'taube' (non-viable) eggs or may have failed to hatch because the first instars were unable to emerge through the operculum pit of the egg or because the egg caps were accidentally sealed by blood faeces. Cragg (1923) and Mellanby (1939a) reported that sterile eggs were often produced when the sperm were almost exhausted inside the female body, especially towards the end of egg production.

Oviposition

No significant difference ($P > 0.05$) in the preoviposition period was detected among the six strains studied (Table 3). Female bedbugs from most strains oviposited within 2–5 days of mating/feeding. Johnson (1941) reported that *C. lectularius* had a mean preoviposition period of 2.69 days at 28°C.

The Soon Lee strain showed a significantly shorter oviposition period compared with the other strains ($P < 0.05$). The Bukit Batok strain had the longest oviposition period (Table 3). Figure 3 shows the percentage of eggs laid per day during the first three oviposition cycles. The maximum number of eggs laid was observed on the second and third days of each cycle. This finding corresponds well with that reported by Davis

Table 3. Mean preoviposition, oviposition and egg incubation time for the six field-collected strains of *Cimex hemipterus*.

| Strain | Mean preoviposition period \pm SEM*, days | Range of preoviposition period, days | Mean oviposition period \pm SEM*†, days | Range of oviposition period, days | Mean egg incubation period \pm SEM*‡, days | Mean % egg hatchability \pm SEM*‡ |
|--------------|---|--------------------------------------|---|-----------------------------------|--|-------------------------------------|
| K Melayu5 | 2.60 \pm 0.25 ^a | 2–3 | 4.25 \pm 0.05 ^a | 2–6 | 5.64 \pm 0.07 ^{ab} | 97.2 \pm 1.4 ^a |
| K Melayu14 | 3.00 \pm 0.41 ^a | 2–4 | 4.39 \pm 0.10 ^a | 3–6 | 6.57 \pm 0.10 ^d | 100.0 \pm 0.0 ^a |
| Dato Keramat | 2.50 \pm 0.22 ^a | 2–3 | 4.45 \pm 0.05 ^a | 2–6 | 5.97 \pm 0.05 ^{bc} | 92.9 \pm 7.1 ^a |
| Serangoon | 3.00 \pm 0.41 ^a | 2–4 | 4.31 \pm 0.10 ^a | 3–7 | 6.14 \pm 0.07 ^c | 100.0 \pm 0.0 ^a |
| Bukit Batok | 3.25 \pm 0.63 ^a | 2–5 | 4.82 \pm 0.11 ^b | 3–7 | 5.45 \pm 0.10 ^a | 100.0 \pm 0.0 ^a |
| Soon Lee | 2.75 \pm 0.25 ^a | 2–3 | 3.83 \pm 0.05 ^c | 3–5 | 5.84 \pm 0.05 ^{bc} | 100.0 \pm 0.0 ^a |

*Means followed by different letters within the same column are significantly different (Tukey’s HSD, $P < 0.05$).

†Sample size = 65–302.

‡Sample size = 29–192.

SEM, standard error of the mean.

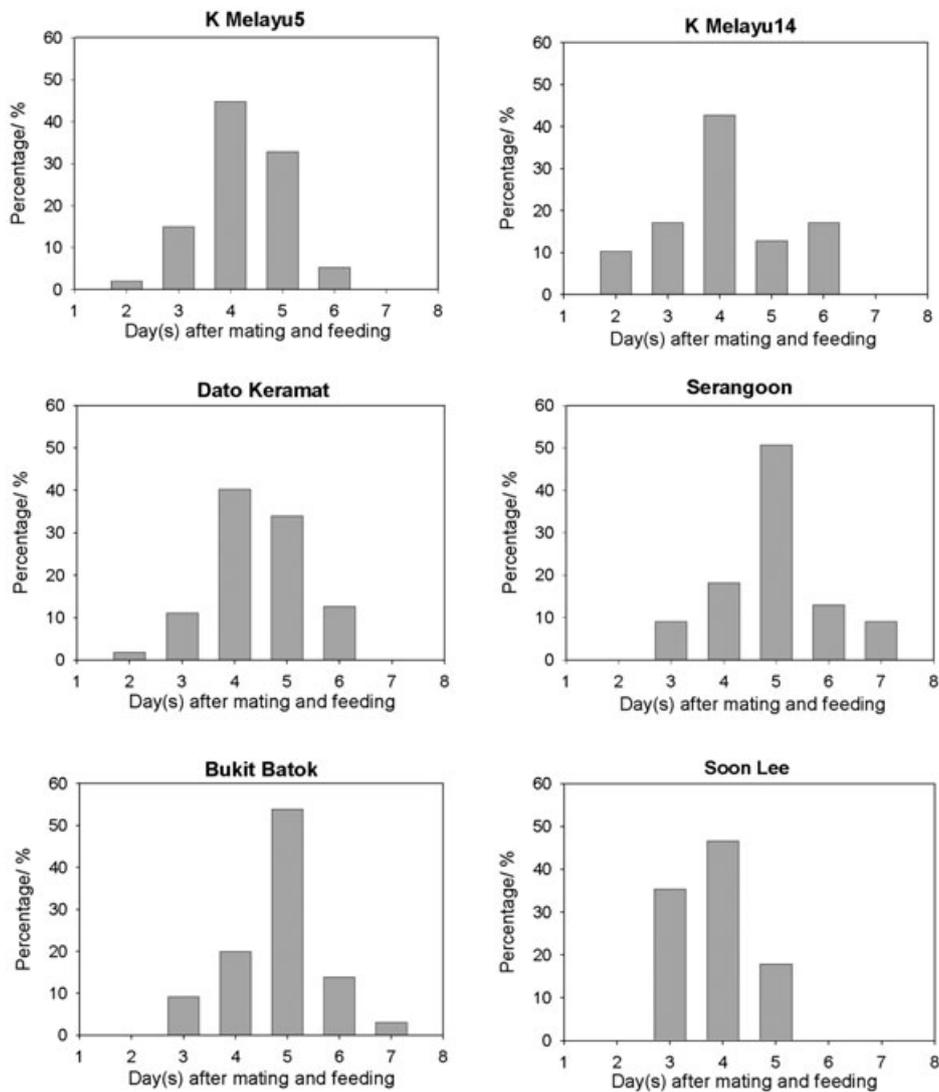


Fig. 3. Percentage of eggs laid daily during the first three oviposition cycles of the six field-collected strains of *Cimex hemipterus*.

Table 4. Nymphal development of the five stadia of the six field-collected strains of *Cimex hemipterus*.

| Stadium | Strain | <i>n</i> * | Mean nymphal development ± SEM†, days | Mean % moulting success to next stage ± SEM‡ | Mean % moulting success after single bloodmeal ± SEM‡ | Range of % moulting success after single bloodmeal |
|------------------------------|--------------|------------|---------------------------------------|--|---|--|
| 1 (first–second) | K Melayu5 | 97 | 3.82 ± 0.08 ^a | 100.00 ± 0.00 ^a | 80.9 ± 9.6 ^a | 50–98% |
| | K Melayu14 | 70 | 3.38 ± 0.09 ^b | 90.97 ± 5.42 ^a | 71.3 ± 9.5 ^a | |
| | Dato Keramat | 189 | 3.04 ± 0.02 ^c | 97.43 ± 0.76 ^a | 78.3 ± 8.7 ^a | |
| | Serangoon | 76 | 3.36 ± 0.06 ^b | 96.75 ± 1.76 ^a | 79.3 ± 7.2 ^a | |
| | Bukit Batok | 52 | 3.33 ± 0.07 ^b | 97.22 ± 2.78 ^a | 67.9 ± 11.7 ^a | |
| | Soon Lee | 107 | 3.17 ± 0.04 ^{bc} | 97.50 ± 2.50 ^a | 59.2 ± 2.8 ^a | |
| 2 (second–third) | K Melayu5 | 97 | 3.49 ± 0.06 ^b | 100.00 ± 0.00 ^a | 66.7 ± 14.3 ^a | 16–96% |
| | K Melayu14 | 64 | 3.13 ± 0.04 ^a | 100.00 ± 0.00 ^a | 45.0 ± 17.1 ^a | |
| | Dato Keramat | 184 | 3.06 ± 0.02 ^a | 96.73 ± 1.85 ^a | 60.5 ± 12.9 ^a | |
| | Serangoon | 73 | 3.51 ± 0.07 ^b | 91.67 ± 8.33 ^a | 49.5 ± 15.2 ^a | |
| | Bukit Batok | 51 | 3.78 ± 0.07 ^c | 96.97 ± 3.03 ^a | 42.2 ± 20.4 ^a | |
| | Soon Lee | 104 | 3.12 ± 0.03 ^a | 97.04 ± 2.96 ^a | 49.6 ± 14.0 ^a | |
| 3 (third–fourth) | K Melayu5 | 97 | 3.42 ± 0.05 ^b | 96.67 ± 3.33 ^a | 56.5 ± 19.7 ^a | 13–96% |
| | K Melayu14 | 64 | 3.17 ± 0.05 ^a | 100.00 ± 0.00 ^a | 40.0 ± 13.3 ^a | |
| | Dato Keramat | 179 | 3.20 ± 0.04 ^a | 98.10 ± 1.24 ^a | 47.7 ± 7.9 ^a | |
| | Serangoon | 69 | 3.66 ± 0.06 ^c | 97.44 ± 2.56 ^a | 40.2 ± 14.5 ^a | |
| | Bukit Batok | 50 | 3.94 ± 0.07 ^d | 98.89 ± 1.11 ^a | 31.3 ± 19.4 ^a | |
| | Soon Lee | 100 | 3.14 ± 0.03 ^a | 100.00 ± 0.00 ^a | 51.3 ± 8.5 ^a | |
| 4 (fourth–fifth) | K Melayu5 | 93 | 3.30 ± 0.05 ^{ab} | 100.00 ± 0.00 ^a | 55.0 ± 9.4 ^a | 5–93% |
| | K Melayu14 | 64 | 3.59 ± 0.07 ^c | 96.97 ± 3.03 ^a | 46.9 ± 17.0 ^a | |
| | Dato Keramat | 175 | 3.50 ± 0.05 ^{bc} | 100.00 ± 0.00 ^a | 34.4 ± 3.6 ^a | |
| | Serangoon | 67 | 3.41 ± 0.06 ^{abc} | 100.00 ± 0.00 ^a | 23.3 ± 12.8 ^a | |
| | Bukit Batok | 49 | 3.90 ± 0.05 ^d | 100.00 ± 0.00 ^a | 25.6 ± 17.2 ^a | |
| | Soon Lee | 100 | 3.20 ± 0.04 ^a | 100.00 ± 0.00 ^a | 43.7 ± 5.7 ^a | |
| 5 (fifth–adult) | K Melayu5 | 93 | 4.51 ± 0.06 ^b | 100.00 ± 0.00 ^a | 46.8 ± 13.7 ^a | 6–63% |
| | K Melayu14 | 61 | 4.78 ± 0.06 ^c | 96.30 ± 3.70 ^{ab} | 16.5 ± 3.8 ^a | |
| | Dato Keramat | 175 | 4.35 ± 0.05 ^{ab} | 85.82 ± 5.75 ^b | 17.6 ± 8.1 ^a | |
| | Serangoon | 67 | 4.39 ± 0.08 ^{ab} | 88.44 ± 2.58 ^b | 22.5 ± 9.5 ^a | |
| | Bukit Batok | 49 | 4.49 ± 0.08 ^b | 100.00 ± 0.00 ^a | 27.9 ± 16.1 ^a | |
| | Soon Lee | 100 | 4.21 ± 0.04 ^a | 95.14 ± 1.34 ^{ab} | 37.1 ± 3.8 ^a | |
| Complete nymphal development | K Melayu5 | 97 | 18.60 ± 0.27 ^b | 96.67 ± 3.33 ^a | — | — |
| | K Melayu14 | 70 | 18.15 ± 0.26 ^{bc} | 84.49 ± 2.28 ^a | — | |
| | Dato Keramat | 189 | 17.24 ± 0.14 ^{cd} | 79.51 ± 6.80 ^a | — | |
| | Serangoon | 76 | 18.61 ± 0.31 ^b | 76.28 ± 6.96 ^a | — | |
| | Bukit Batok | 52 | 19.61 ± 0.27 ^a | 93.33 ± 5.09 ^a | — | |
| | Soon Lee | 107 | 16.88 ± 0.18 ^d | 89.97 ± 3.18 ^a | — | |

*The total number of nymphs from the previous stadium.

†Means followed by different letters within the same column of each stadium are significantly different (Tukey's HSD, $P < 0.05$).

‡Means followed by different letters within the same column of each stadium are significantly different (arcsine transformed, Tukey's HSD, $P < 0.05$).

SEM, standard error of the mean.

(1964) for *C. lectularius*. However, Johnson (1940) reported that *C. lectularius* appeared to possess a longer oviposition period (i.e. up to 8–10 days).

The K Melayu14 strain had the longest mean egg incubation period ($P < 0.05$), whereas the Bukit Batok and K Melayu5 strains had the shortest (Table 3). In general, all eggs required ≥ 5 days of incubation. These results are comparable with those for *C. hemipterus* at 27°C (Omori, 1941) and *C. lectularius* at 4–5 days at 30–35°C (Johnson, 1941; Kettle, 1984). There was no significant difference in the percentage of egg hatchability

among the six strains studied (Table 3) and all strains showed hatchability of $>90\%$.

Nymphal development

Cimex hemipterus went through five stadia to achieve adulthood. Each stadium took an average of 3–4 days (with the exception of the final stadium, which required 4–5 days) (Table 4). The mean total length of the nymphal development period was 17–20 days. Omori (1941) reported that

C. hemipterus nymphs took 4 days for the first four stadia, whereas the final stadium could last as long as 6 days, and the total development period ranged from 21.8 to 32.3 days at 27°C. However, *C. lectularius* exhibited a shorter nymphal development period of 14 days at 28°C, with intervals of 2–3 days for the first four stadia and 3–4 days for the last stadium (Johnson, 1941).

In general, the Soon Lee strain showed the shortest mean nymphal development period (<17 days), whereas the nymphs of the Bukit Batok strain took as long as 20 days to achieve adulthood (Table 4). No significant difference was detected among the six strains in terms of the percentage of nymphs that successfully achieved adulthood (all >75%). The lifecycles of the six strains were relatively similar, ranging between 24 and 32 days.

Some nymphs did not initially feed or fed partially when exposed to a human. Johnson (1941) and Krueger (2000) made similar observations about *C. lectularius*. In some instances, the nymphs needed to be exposed to the host up to eight times before they finally fed and then moulted to the next stage. The percentage of successful moults after a single bloodmeal for each stadium varied widely (i.e. from <10% to >90%) (Table 4). In the final stadium, >50% of the nymphs required more than a single bloodmeal to moult.

The emerging adults from all six strains were sexed and the results showed no deviation from the expected 1 : 1 sex ratio. This finding corresponds well with those reported by Johnson (1941) for *C. lectularius* and Omori (1941) for *C. hemipterus*. The K Melayu5 strain showed an emergence that was 60% male and 40% female, whereas the Soon Lee strain showed the reverse ratio; however, the difference was not statistically significant (chi-squared test).

Cast exoskeleton measurement

Nymphal instars of *C. lectularius* and *C. hemipterus* have been identified by size, number of rows of spines on abdominal tergites, appearance of the hind margin of the mesonotum, length of antennal segments and number of bristles along the

Table 5. Comparison of cast exoskeleton length for each stadium of the field-collected strains of *Cimex hemipterus*.

| Stadium | Length, mean \pm SEM* \ddagger , mm | Range of length, mm |
|------------------|---|---------------------|
| 1 (first–second) | 1.19 \pm 0.01 ^a | 1.0–1.5 |
| 2 (second–third) | 1.68 \pm 0.01 ^b | 1.5–2.0 |
| 3 (third–fourth) | 2.38 \pm 0.01 ^c | 2.0–2.6 |
| 4 (fourth–fifth) | 3.21 \pm 0.02 ^d | 2.6–4.0 |
| 5 (fifth–adult) | 4.4421 \pm 0.02 ^e | 4.0–5.0 |

* $n = 120$ (20 replicates from each of the six strains).

\ddagger Means followed by different letters within the same column are significantly different (Tukey's HSD, $P < 0.05$).

SEM, standard error of the mean.

edge of the pronotum (Usinger, 1966; Newberry, 1990). In our study, measurements of cast exoskeletons from the apical end of the rostrum to the anal pore were found to distinguish all five instars (Table 5). Thus, cast exoskeletons, which are easily collected in the field, can be brought to the laboratory and measured to determine the age distribution of populations.

Adult longevity

The longevity of mated males and females was similar in all six strains ($P > 0.05$) (Table 6). Mated males and females lived 11–99 days and 11–109 days, respectively. Unmated females lived significantly longer than unmated males ($P < 0.05$). Unmated females lived 82–216 days and unmated males lived 47–129 days. Figure 4 shows a scatterplot of the longevity of both mated and unmated males and females. The longevity patterns of unmated males and females were distinct, whereas those of mated males and females overlapped. In addition, the longevity distribution of mated males and females displayed larger variation compared with that of unmated males and females.

These results differ from those reported by Omori (1941), who found that males lived longer than females when they were placed together. Our results, however, agree with those of Melanby (1939b), who observed that naturally captured females

Table 6. Longevity of unmated and mated adults of the six field-collected strains of *Cimex hemipterus*.

| Strain | Longevity, mean \pm SEM* \ddagger , days | | | |
|--------------|--|-------------------------------------|-----------------------------------|----------------------------------|
| | Unmated \ddagger ¶ | | Continuous mated \S ¶¶ | |
| | ♂ | ♀ | ♂ | ♀ |
| K Melayu5 | 93.60 \pm 3.89 ^{a(a)} | 157.40 \pm 3.5 ^{b(ab)} | 70.67 \pm 4.52 ^{a(a)} | 57.36 \pm 4.23 ^{a(a)} |
| K Melayu14 | 87.00 \pm 10.0 ^{a(a)} | 139.00 \pm 13.5 ^{b(a)} | 54.14 \pm 6.04 ^{a(a)} | 62.18 \pm 6.07 ^{a(a)} |
| Dato Keramat | 95.00 \pm 2.98 ^{a(a)} | 168.30 \pm 6.71 ^{b(abc)} | 67.50 \pm 7.76 ^{a(a)} | 77.50 \pm 5.44 ^{a(a)} |
| Serangoon | 99.60 \pm 4.17 ^{a(a)} | 182.80 \pm 6.85 ^{b(bc)} | 62.71 \pm 8.56 ^{a(a)} | 59.08 \pm 8.16 ^{a(a)} |
| Bukit Batok | 99.10 \pm 2.58 ^{a(a)} | 203.67 \pm 3.08 ^{b(d)} | 50.83 \pm 10.40 ^{a(a)} | 61.08 \pm 8.41 ^{a(a)} |
| Soon Lee | 96.60 \pm 4.05 ^{a(a)} | 190.00 \pm 6.31 ^{b(cd)} | 49.00 \pm 9.50 ^{a(a)} | 53.92 \pm 5.98 ^{a(a)} |

*Means followed by different letters within the same row of the same mating status are significantly different (t -test, $P < 0.05$).

\ddagger Mean longevity is significantly different between all unmated and mated males or unmated and mated females (t -test, $P < 0.05$).

\ddagger The sample size is 10.

\S The sample size is 6–12.

¶¶Means followed by different letters within the same column are significantly different (Tukey's HSD, $P < 0.05$).

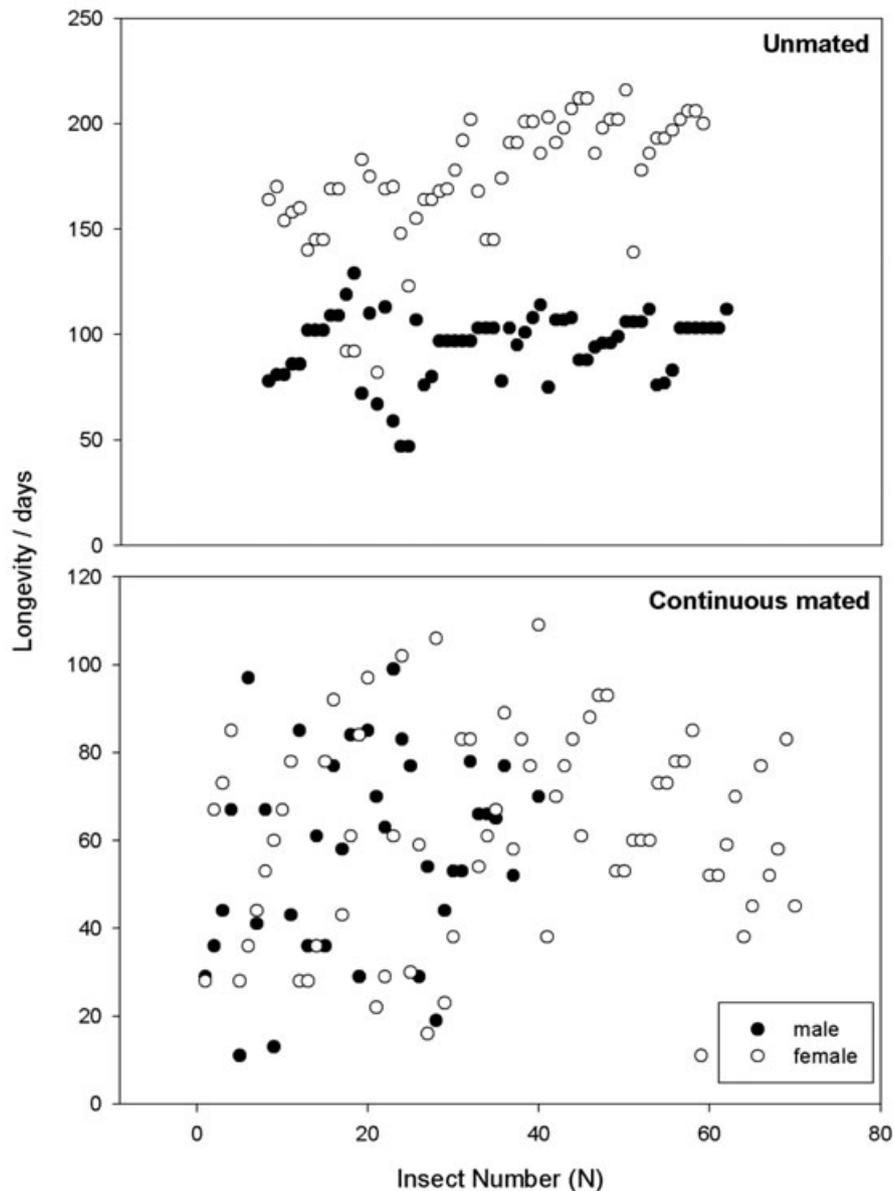


Fig. 4. Relationship between longevity of mated and unmated *Cimex hemipterus*.

lived longer than males. Both Omori's (1941) results and our findings show that unmated females lived up to four times as long as or >100 days longer than mated females (Table 6). We also found that unmated males had longer longevity than mated males (Table 6). On average, the mean longevity of unmated males surpassed that of mated males by a factor of 1–2. The significant difference ($P < 0.05$) between unmated and mated male longevity found in our study, however, disagrees with findings by Kemper (1930) and Johnson (1940), who reported that the longevity of male bedbugs was not affected by copulation. The reduction in longevity in mated individuals, especially in females, probably reflects traumatic insemination during copulation (Morrow & Arnqvist, 2003).

Mellanby (1939b) reported that the length of feeding and egg fertilization may also influence the longevity of bedbugs and the nutrients from bloodmeals are known to be used by females for egg production (Johnson, 1940). The cause of the reduction in longevity in mated males compared with unmated males is unknown and warrants further investigation.

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