Development and Reproduction of the Mirid Bug, Cytorhinus lividipennis (Heteroptera: Miridae) and Its Functional Response to the Brown Planthopper

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The development, longevity, fertility, of the mirid Cytorhinus lividipennis and its predation on the brown planthopper (BPH), Nilaparvata lugens, were studied in a laboratory condition. The developmental period was 20 days with usually five instars. The adult longevity, fertility and the intrinsic rate of increase were higher when the mirid was fed with BPH eggs than without BPH eggs. The functional responses of the mirid to both egg and 1st-instar nymph of BPH were well described by a Hollino's (1959) type-II. The maximum number of BPH eggs eaten per day was 22, 18, and 6 by the female, male and 3rd-instar nymph of the mirid, respectively. The instantaneous search rate a and the handling time h, changed depending on the mirid age. BPH eggs were preferred to nymphs by the mirid.

INTRODUCTION

The brown planthopper (BPH), Nilaparvata lugens (Stål), has been an economic pest of rice in Malaysia since late 1977 (Lim et al., 1978). Currently much effort is devoted to its control, particularly by biological agencies.

Among natural enemies of the BPH, the mirid, Cytorhinus lividipennis is effective in reducing the populations in the field (Hinckley, 1963; Stapley, 1976; Chiu, 1979). This mirid, which occurs in most rice-growing countries, eats the egg, nymph and adult of the BPH (Bae and Pathak, 1966; Chiu, 1979). There is, however, little information on its development, survival, fertility, predation, and preference of BPH developmental stages, although information on these aspects is indispensable for a better understanding of the potential of C. lividipennis as a natural enemy of BPH.

MATERIALS AND METHODS

Adults and nymphs of the mirid Cytorhinus lividipennis were obtained from a laboratory culture maintained by BPH eggs within the rice plant. Eggs and nymphs of BPH were also obtained from laboratory culture. All the following experiments were done under the laboratory condition of 28±2°C and 75–85% relative humidity.

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Development, survival and fertility. The development of the mirid was studied using a cohort of eggs laid, within 24 hr before the beginning of experiment, in rice stem tissues ca. 5 cm in length. The eggs were placed in a plastic cup, 7.5 cm in height and 2.5 cm in diameter. The top cover of the cup was perforated and covered with muslin. After recording the incubation period, each of the newly-emerged nymphs of the mirid was transferred individually to a petri dish, 6.5 cm in diameter. First-instar nymphs were fed with 10% honey-water solution. The other instars were fed with BPH eggs 1 day after oviposition ad lib. The number of instars was determined based on nymphal exuviae under a binocular microscope.

The longevity and fertility of females and the longevity of males were determined using 15 pairs in transparent plastic cages 60.5 cm in height and 7.5 cm in diameter, under the following treatments. Treatment 1: one day old BPH eggs were daily given in excess which had been oviposited in 60-day-old rice plant (var. MR-7) in a pot. Treatment 2: a rice plant without BPH eggs; and Treatment 3: only water. The number of eggs laid was recorded daily until the death of the female, replenishing the males if they died. The oviposition substrate (rice plant) was replaced daily.

Predation. The functional responses of the adult male and female mirid to BPH eggs were studied at densities of 4, 6, 8, 16, and 32 of 2 hr old host eggs. The experimental arena for all predation studies was a plastic cup 7.5 cm in height and 2.5 cm in diameter. At the beginning of the experiment the mirid was one day old and starved for 8 hr. Early dissection shows that the number of host eggs laid within a rice stem equals the number of waxy circular oviposition marks specific to BPH. After 24 hr the stem was dissected under a binocular microscope and the number of BPH eggs attacked were recorded. The attacked egg was devoid of its contents with a shrivelled chorion. The partially consumed egg was also included in the 'attack' category. A control, without the mirid, was also tested for each host density. Each experiment was continued for one day with 10 replications of each density. The predation of BPH first-instar nymphs by the mirid females was studied with densities of 2, 4, 6, 8, 10, and 12. Predation of the BPH eggs by the third-instar mirid nymph was also determined under BPH densities of 2, 4, 6, 8, 10, and 12.

Data were analysed by Royama's (1971) equation, which is the revised version of the Holling's (1959) type II equation for situations without replenishment of eaten prey:

\[ z = x_0 \left(1 - e^{-a(y_{t_0} - k_0)}\right) \]  \hspace{1cm} (1)

where, \(z\) = number of prey attacked; \(x_0\) = initial number of prey; \(a\) = instantaneous search rate; \(Y\) = number of predators; \(t\) = time available for search; and \(h\) = handling time. \(a, k, h\) and, in addition, the maximum possible number of prey eaten \((z_m)\) were estimated by the regression method.

Preference. The preference of one-day old mirid females between eggs and nymphs of BPH, was compared at combinations of 4 eggs and 20 nymphs, 8:16, 12:12, 16:8, and 20:4 respectively, with 5 replications. The experimental arena was the same as that used in the predation studies. Preference among BPH developmental stages was compared by a method proposed by Manly et al. (1972), which allows for prey consumption during the experimental period. The index of preference \(\beta\), which is the probability of the first prey (egg) eaten, is calculated from equations 2 and 3:

\[ \beta = 1/(1+\alpha) \]  \hspace{1cm} (2)
where the index \( \alpha \) is a factor describing the number of times the predator is likely to select one prey type \((\text{egg in this case})\) rather than another and

\[
\alpha = \log \left( \frac{N/(Z-\mu)}{\log (E/\mu)} \right)
\]

where \( E \) is the initial number of eggs, \( N \) is the number of nymphs and \( Z \) is the total number not eaten in one day. The value \( \mu \) is the mean number of eggs left in one day. When the mirid completely prefer BPH eggs, \( \beta \) is 1. When the mirid attacks both eggs and nymphs of BPH at random, \( \beta = 0.5 \). \( \beta \) approaches 0 when eggs are completely avoided (Cock, 1978).

RESULTS

Development, longevity and fertility

The egg of the mirid, laid within the leaf, was white and ellipsoidal, and the egg micropyle was visible as a whitish longitudinal mark on the leaf surface. The position of the egg inside the leaf was almost parallel to the leaf surface. The micropylar end was attached to the adaxial surface. The incubation period was ca. 8 days (Table 1), and the egg viability was 43%. Sixty percent of the nymphs passed through five instars, 31% through four instars and 9% through six instars. The mean nymphal duration was 12 days. The total developmental period was 20 days.

The longevity of the mirid females provided with BPH eggs (treatment 1) was

<table>
<thead>
<tr>
<th>Stage</th>
<th>Number examined</th>
<th>Days (mean±S.D.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egg</td>
<td>115</td>
<td>8.31±0.97</td>
</tr>
<tr>
<td>Nymph</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instar 1</td>
<td>19</td>
<td>3.50±0.84</td>
</tr>
<tr>
<td>Instar 2</td>
<td>15</td>
<td>2.50±0.71</td>
</tr>
<tr>
<td>Instar 3</td>
<td>15</td>
<td>2.00±0.52</td>
</tr>
<tr>
<td>Instar 4</td>
<td>15</td>
<td>2.00±0.23</td>
</tr>
<tr>
<td>Instar 5</td>
<td>15</td>
<td>2.50±0.92</td>
</tr>
<tr>
<td>Total developmental period</td>
<td></td>
<td>20.50±1.97</td>
</tr>
<tr>
<td>Sex-ratio (female/male)</td>
<td></td>
<td>1.28</td>
</tr>
</tbody>
</table>

Table 2. Longevity and fertility of the adult mirid under different food conditions

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Longevity (days)</th>
<th>Fertility*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>Rice plant with BPH eggs</td>
<td>8.20±3.49*</td>
<td>6.20±1.86*</td>
</tr>
<tr>
<td>Rice plant only</td>
<td>5.87±2.00**</td>
<td>4.93±1.79*</td>
</tr>
<tr>
<td>Control (water only)</td>
<td>5.00±1.96**</td>
<td>3.60±1.59**</td>
</tr>
</tbody>
</table>

Values followed by * and ** within a column differ significantly between treatments at \( P<0.05 \) by the MANN-WHITNEY \( U \)-test. Means of 15 replications.

* Number of eggs per female until its death (\( 2 \Sigma M_x \)).
significant \((P \leq 0.05)\) longer than the other treatments without BPH eggs (Table 2). No significant difference was observed between treatment 2 with rice plant and treatment 3 only with water. The male longevity was not significantly different between treatments 1 and 2, but both treatments differed significantly \((P \leq 0.05)\) from treatment 3. The longevity of the female was longer than the male in each treatment. The daily survivorship of females in treatment 1 was higher than that in treatment 2 after the fifth day of emergence (Fig. 1a).

The female laid, in total, 21 eggs in treatment 1 with BPH eggs and 9 eggs in treatment 2 only with rice plant (Table 2), with significant statistical difference \((P \leq 0.05)\). The daily number of female eggs per female \((m_x)\) was higher in treatment 1 (Fig. 1b). Two peaks of \(m_x\) were observed in treatment 1 and 2. However, it is apparent that the second peak of \(m_x\) at nine days, resulted from experimental error caused by the small sample size \((n=4)\) of adult mirids. Assuming no death of immatures, the net reproductive rate \((R_0)\) was 11, the mean generation time \((T_g)\) 25 days and the approximate intrinsic rate of increase \((r)\) 0.1 in treatment 1 and \(R_0\) was 4.34, \(T_g\) 24.29 days and \(r\) 0.06 in treatment 2.

**Predation and preference**

The functional response equation of Royama (1971) fitted the data well (Chi-square values: \(P \leq 0.01\); Table 3) for all the combinations of predator and prey developmental stages. The results of the combinations of adult mirids and BPH eggs are shown

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**Fig. 1.** (a) Survival rates \((l_x)\) curves for the mirid *Cytorhinus lividipennis* female. (b) The mean number of female eggs laid per day \((m_x)\). Vertical lines show one standard error \((S.E.)\). ○: treatment 1, ●: treatment 2.

**Fig. 2.** The functional responses of the mirid adult to BPH eggs. Closed squares show mean and vertical lines S.D. The curves are fitted to the Royama (1971) equation shown in the methods. ○ shows proportion attacked at each density.
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Table 3. Estimated values of the searching efficiency $a$ (days$^{-1}$), the handling time, $h$ (days) and the maximum number eaten ($Z_{co}$), of the mirid which was fed on eggs and nymphs of BPH

<table>
<thead>
<tr>
<th>Developmental stages</th>
<th>Parameters</th>
<th>$Z_{co}$</th>
<th>$\chi^2_{0.10(5)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mirid</td>
<td>BPH</td>
<td>$a$</td>
<td>$h$</td>
</tr>
<tr>
<td>Female Egg</td>
<td></td>
<td>2.21</td>
<td>0.034</td>
</tr>
<tr>
<td>Male Egg</td>
<td></td>
<td>2.03</td>
<td>0.033</td>
</tr>
<tr>
<td>3rd instar nymph Egg</td>
<td></td>
<td>1.13</td>
<td>0.195</td>
</tr>
<tr>
<td>Female 1st instar nymph</td>
<td></td>
<td>1.54</td>
<td>0.320</td>
</tr>
</tbody>
</table>

$^a$ Values in parenthesis show actual maximum number of BPH eggs and nymphs eaten in the laboratory by the mirid.

$^b$ $\chi^2$ values between observed and expected numbers of prey attacked. Expected number for each density in each treatment was calculated from Royama’s (1971) equation. Not significant (ns).

Fig. 3 (a) The index of preference ($\beta$) of the mirid to BPH egg plotted against the proportion of the number of eggs to total number of eggs and nymphs. (b) The percent of BPH eggs and nymphs eaten by the mirid at different proportions of BPH eggs and nymphs in the diet.

in Fig. 2. Females attacked slightly more eggs per day (max. 22) than the male (max. 21). The mirid nymph ate fewer BPH eggs (max. 6) than the adult and the mirid female ate a maximum of 4 BPH nymphs per day (Table 3).

The adult mirid had strong preference for the BPH egg (Fig. 3a). The value of $\beta$ was always greater than 0.5, irrespective of the relative proportion of BPH eggs to total number of eggs and nymphs. $\beta$ ranged from 0.958 at the lowest proportion of eggs presented (16.67%) to 0.767 at the highest (83.33%). At equal presentation of BPH eggs and nymphs, $\beta$ was 0.88.

DISCUSSION

In this study, 60% of the mirid nymphs passed through five instars when we gave BPH eggs in excess. Reyes and Gabriel (1975) obtained four instars by giving as food
eggs of the green leafhopper, *Nephotettix virescens* (Dist.). Specific differences in food may be attributed to the variation in the number of instars.

The feeding of the BPH eggs, which may be a source of protein, by the mirid adults resulted in at least 2.5 times greater egg production in treatment 1 with BPH eggs compared to treatment 2 without BPH eggs. The source of the eggs produced by the mirids in treatment 2, could have resulted from nymphal reserves if we assume that the mirid does not feed on the rice plant. In spite of the similar mean generation times, the larger net reproductive rate ($R_0$) resulted in a higher intrinsic rate of increase ($r_0$) in treatment 1 than in treatment 2 (Table 2).

The type-II functional response of Holling (1959) obtained in this study has commonly been reported for arthropod predators (Hasell et al., 1976; Hasell, 1978). Adult mirids search BPH eggs more effectively, as shown by $a$ and handle the eggs more quickly, as shown by $h$, than nymphs. Little difference was observed in the searching efficiency ($a$) and the handling time ($h$) between the males and females. However, when the adult female mirids were given BPH nymphs as prey $a$ decreased and $h$ increased, compared with egg as prey. The BPH egg is sedentary but the nymph is mobile and thus likely to escape, thus increasing the $h$ value. The reason for the decrease in $a$ is not clear but nymphal escape could be one of the reasons, as suggested by Hasell et al. (1976).

Although the mirid was able to attack both eggs and nymphs of BPH, it preferred eggs, as shown by higher values of $\beta$ than 0.5 (Fig. 3a). The preference of the mirid could be influenced by the difference in handling times between the BPH egg and nymph; probably the time for consumption of a BPH egg is relatively shorter than that of the BPH nymph. In addition, escape by the BPH nymph, when found by the mirid may also affect the mirid's preference for the nymph. The value of $\beta$ decreased with the increasing proportion of BPH eggs. This was due to the increasing number of eggs left uneaten ($\mu$) as the proportion of BPH eggs increased in the diet. The adult mirid requires a larger $h$ for nymphs, at least $9 \times$ more than the eggs, as shown by the studies on functional responses. Since the number of nymphs eaten was not much affected by the proportion of nymphs in the diet (Fig. 3b), time spent on nymphs will be constant irrespective of the proportion of prey types. However, this would reduce the time spent on eggs. As a result, the proportion of eggs attacked became smaller with the increasing proportion of eggs in the diet (Fig. 3b).

For the use of the mirid as a control agent of BPH, there are several problems. Firstly, there is poor phenological synchrony between the mirid and BPH populations in the field. The mirid tends to be most abundant for <40 days after transplanting of rice (Dyck and Orlindo, 1977), whereas BPH peaks about 2 months after transplanting (Bae and Pathak, 1969). Secondly, the mirid is polyphagous; the green leafhopper *N. virescens* (Hinkley, 1963; Reyes and Gabriel, 1975), and the white-back planthopper, *Sogatella furcifera* (Horváth) are also hunted. Thirdly, BPH has greater fertility and intrinsic rate of increase (Kisimoto, 1977) than the mirid. Therefore, the necessary number of mirids to control BPH populations is more than $20 \times$ number of BPH (Stapley, 1976). In some instances, the mirid has been a successful predator of the BPH, especially in drilled rice fields (Hinkley, 1963). Further quantitative field studies on the effect of the mirid on the population dynamics of BPH are needed to confirm this.
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