INTRODUCTION

In Japan, the rice bugs *Leptocorisa chinensis* Dallas, *Lagynotomus elongatus* (Dallas), and *Stenotus rubroviittatus* (Matsumura) are important cosmetic pests of the rice *Oryza sativa* L. The occurrence patterns of rice bugs in rice fields are highly related to rice plant development; the bugs usually immigrate into the rice field after heading. Previous reports have described the occurrence patterns of rice bugs in rice fields in terms of “days after heading” or by stages of rice development (Ouchi, 1953; Ogawa et al., 1960; Nakasuji, 1973; Shimizu and Maru, 1978; Hayashi and Nakazawa, 1988; Nagano et al., 1988; Iimura, 1994; Nakada, 2000; Yokosuka, 2001). However, in order to analyze the correlation between the density of rice bugs and the occurrences of damaged grains, expression of a quantitative developmental stage of panicles is necessary.

Takeuchi et al. (2004) reported that the three species of rice bugs in this study mainly infest spikelets that have ovaries elongated lengthwise to sidewise. Therefore, we propose that the abundance of spikelets at a specific development stage may relate to the occurrence pattern of the rice bugs in rice fields.

Many reports have employed the cumulative daily temperature after heading to estimate the optimum harvest stage (Kudo et al., 1982; Kobayashi, 1983; Toriu, 1989; Hayashi et al., 2000). Their reports suggest that the abundance of spikelets at a
specific development stage can be expressed uniformly by cumulative daily temperature.

In this study, we described the stages of spikelet development, monitored the changes in the numbers of spikelets at each developmental stage, and recorded the incidence of three species of rice bugs in rice fields. Subsequently, the changes in spikelet development and the incidence of rice bugs were expressed in cumulative degree-days. Finally, we analyzed the relationship between the abundance of spikelets at a specific development stage and the incidences of the three species of rice bugs.

**MATERIALS AND METHODS**

All studies were conducted in the experimental paddy fields (36°00′00″N, 140°01′00″E) of the National Agricultural Research Center in Yawara, Ibaraki Prefecture, Japan. We studied the following issues.

**Spikelet development in the field.** Observations of spikelet development were carried out in 2003 using three paddy fields (plots). An early-maturing rice variety (Sainohana) was used in Plot A and a middle-maturing rice variety (Koshihikari) was used in Plots B and C. The dates of transplanting were on April 25, May 8, and June 19; areas were 280, 1,000, and 340 m² for Plots A, B, and C, respectively. Seedlings were transplanted with 30×18 cm spacing. Fertilizer was applied using the standard rate, 6.6 kg N per 10 a for Sainohana and 3.5 kg N per 10 a for Koshihikari.

Spikelet development was divided into three stages: Stage I (initial), characterized by spikelets with ovaries less than half of the hull length; Stage II (middle), characterized by spikelets with ovaries more than half of the hull length and the presence of a space between the ovary and the hull; and Stage III (fullness), characterized by spikelets with no space between the ovary and the hull, caused by the ovaries having reached their full length.

In each plot, rice hills were randomly sampled twice a week after the initial heading stage; the day when 10–20% of all panicles had headed (Hoshikawa, 1975). For Plots A, B, and C, dates of initial heading stage were July 13, August 6, and August 25, and the number of sampled hills was 6, 9, and 6, respectively. Sampling was carried out from 0830 to 1000 JST (Japan Standard Time). After sampling, headed panicles of each hill were cut at the neck node. The spikelets in these panicles were separated into Stage II and other stage spikelets. This was done visually with the aid of a transmitted light. The other spikelets were kept at 80°C for 48 h, and further separated into Stage I and Stage III spikelets. The numbers of spikelets for each stage were counted using an automatic grain counter (Fujiwara Scientific Co., KC-10) or manually.

Changes in the average number at each spikelet development stage were plotted against days after initial heading stage or the cumulative degree-days. Cumulative degree-day equals the cumulated daily average temperature above a base of 10°C after the initial heading stage. The low development threshold temperature of panicles is 10°C (Hanyu and Uchijima, 1962; Kanda et al., 2002). Daily temperatures were taken from a weather station near the plots.

**Incidence of three species of rice bugs in rice fields.** Incidences of *L. chinensis*, *L. elongatus*, and *S. rubrovittatus* were monitored from 2001 to 2003. Forty-seven plots were set up among nine rice fields (Table 1). The density of transplanted young seedlings was similar to that in the first experiment. Fertilizer was applied at 3.5 kg N per 10 a for Koshihikari and 6.6 kg N per 10 a for other varieties.

The incidence of rice bugs was monitored every 3 to 10 d starting from the initial heading stage. Insects were sampled with a 36-cm diameter sweep net, and a set of 20 or 30 sweeps was carried out in each plot. Samples were sorted just after the sweeping in the plots or brought to the laboratory and sorted. Whole sampled rice bugs were returned to each plot after the sorting. Adults of *L. chinensis*, *L. elongatus*, and *S. rubrovittatus*, and nymphs of *L. chinensis* and *L. elongatus* were counted. The nymphs of *L. chinensis*, the most important species in our study area, were sorted according to the instars. Nymphs of *S. rubrovittatus* were excluded in this study because their density was generally low in the rice fields (Goto et al., 2000; Nakada, 2000).

To analyze rice bug incidence, each sampling was classified into cumulative degree-days with 50 degree-day intervals. Because the density of rice bugs in the rice fields was generally low, we expressed rice bug incidence as the presence ratio of rice bugs based on the percentage of plots where the rice bugs were caught. Each set of sweeping
data was classified at each 50 degree-day interval, and incidence was calculated for each interval.

RESULTS

Spikelet development

The average number of spikelets in Stage I increased rapidly and reached peaks at 9, 6, and 5 d after the initial heading stage (DAI) (Fig. 1a), or at 95.8, 97.5, and 76.4 degree-days after the initial heading stage (DD) (Fig. 1b), in Plots A, B, and C, respectively. For Stage II, the peaks were at 16, 13, and 12 DAI, or at 168.8, 171.5, and 168.4 DD (Fig. 2). For Stage III, the plateau was reached approximately at 23, 20, and 19 DAI or at 274.1, 279.9, and 274.4 DD (Fig. 3). Variations in the number of spikelets expressed in cumulative degree-days were smaller than those expressed in days after initial heading stage.

The heading date or the day when 40–50% of all panicles had been headed was approximately 30–50 DD in these fields.

Incidences of three species of rice bugs

The maximum number of collected adults of L. chinensis per 20 sweeps was 6.0, 2.0, and 2.7 in 2001, 2002, and 2003, respectively. The figures for collected nymphs of L. chinensis were 5.0, 6.7, and 4.0; adults of L. elongatus were 15.0, 10.7, and 7.0; nymphs of L. elongatus were 7.0, 8.7, and 4.0; and the adults of S. rubrovittatus were 6.0, 6.0, and 6.0.

The peak of incidence of the three species of adult rice bugs occurred on specific cumulative degree-days (Fig. 4). Adult rice bug incidences were initially low at 0 to 50 DD, and then increased remarkably from 50 to 100 DD. The peaks of incidence of adult L. chinensis and S. rubrovittatus occurred from 100 to 150 DD. That of adult L. elongatus was observed from 50 to 100 DD (Fig. 4).

The incidence of nymphs of L. chinensis and L. elongatus started to increase on the same cumulative degree-days (Fig. 4). The incidence was low from 0 to 200 DD and began to increase from 200 to 250 DD. The peaks of incidence of nymphs of L. chinensis and L. elongatus were observed from 500 to 550 DD and from 400 to 450 DD, respec-

---

Table 1. Plots where sweep sampling were carried out in 2001–2003

<table>
<thead>
<tr>
<th>Plot No.</th>
<th>Year</th>
<th>Variety</th>
<th>Area of plot (a)</th>
<th>Date of transplanting</th>
<th>Date of initial heading stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2001</td>
<td>Sainohana</td>
<td>3.0</td>
<td>Apr. 26</td>
<td>Jul. 7</td>
</tr>
<tr>
<td>2</td>
<td>2001</td>
<td>Sainohana</td>
<td>5.2</td>
<td>Apr. 26</td>
<td>Jul. 10</td>
</tr>
<tr>
<td>3, 4</td>
<td>2001</td>
<td>Akitakomachi</td>
<td>1.1</td>
<td>May 9</td>
<td>Jul. 15</td>
</tr>
<tr>
<td>5, 6</td>
<td>2001</td>
<td>Akitakomachi</td>
<td>1.1</td>
<td>May 9</td>
<td>Jul. 18</td>
</tr>
<tr>
<td>7, 8</td>
<td>2001</td>
<td>Kokoromachi</td>
<td>0.7</td>
<td>May 30</td>
<td>Jul. 27</td>
</tr>
<tr>
<td>9, 10</td>
<td>2001</td>
<td>Hatsuboshi</td>
<td>0.7</td>
<td>May 30</td>
<td>Jul. 30</td>
</tr>
<tr>
<td>11, 12</td>
<td>2001</td>
<td>Chiyonishiki</td>
<td>0.7</td>
<td>May 30</td>
<td>Aug. 2</td>
</tr>
<tr>
<td>13, 14</td>
<td>2001</td>
<td>Hitomebore</td>
<td>0.7</td>
<td>May 30</td>
<td>Aug. 2</td>
</tr>
<tr>
<td>15, 16</td>
<td>2001</td>
<td>Kinuhikari</td>
<td>0.7</td>
<td>May 30</td>
<td>Aug. 6</td>
</tr>
<tr>
<td>17, 18</td>
<td>2001</td>
<td>Koshihikari</td>
<td>0.7</td>
<td>May 30</td>
<td>Aug. 6</td>
</tr>
<tr>
<td>19</td>
<td>2001</td>
<td>Koshihikari</td>
<td>2.0</td>
<td>May 30</td>
<td>Aug. 10</td>
</tr>
<tr>
<td>20–23</td>
<td>2001</td>
<td>Asanohikari</td>
<td>1.1</td>
<td>Jun. 20</td>
<td>Aug. 23</td>
</tr>
<tr>
<td>24–26</td>
<td>2002</td>
<td>Sainohana</td>
<td>1.7</td>
<td>Apr. 26</td>
<td>Jul. 14</td>
</tr>
<tr>
<td>27</td>
<td>2002</td>
<td>Akitakomachi</td>
<td>2.2</td>
<td>May 30</td>
<td>Aug. 6</td>
</tr>
<tr>
<td>28</td>
<td>2002</td>
<td>Koshihikari</td>
<td>2.2</td>
<td>May 30</td>
<td>Aug. 9</td>
</tr>
<tr>
<td>29</td>
<td>2002</td>
<td>Hitomebore</td>
<td>2.2</td>
<td>May 30</td>
<td>Aug. 9</td>
</tr>
<tr>
<td>30</td>
<td>2002</td>
<td>Nipponbare</td>
<td>2.2</td>
<td>May 30</td>
<td>Aug. 16</td>
</tr>
<tr>
<td>31–34</td>
<td>2002</td>
<td>Akitakomachi</td>
<td>2.3</td>
<td>Jun. 20</td>
<td>Aug. 18</td>
</tr>
<tr>
<td>35–38</td>
<td>2002</td>
<td>Hitomebore</td>
<td>2.3</td>
<td>Jun. 20</td>
<td>Aug. 23</td>
</tr>
<tr>
<td>42–44</td>
<td>2003</td>
<td>Hitomebore</td>
<td>1.7</td>
<td>May 8</td>
<td>Aug. 1</td>
</tr>
<tr>
<td>45–47</td>
<td>2003</td>
<td>Koshihikari</td>
<td>1.7</td>
<td>Jun. 19</td>
<td>Aug. 25</td>
</tr>
</tbody>
</table>

All fields were in the village of Yawara, Ibaraki Prefecture, Japan.
The peaks of the incidence of the first instar of *L. chinensis* were observed from 200 to 250 DD, those of the second and third instars were observed from 250 to 300 DD, and those of the fourth and fifth instars from 500 to 550 DD (Fig. 5). The peaks of incidence appeared successively, based on nymphal development stage.

**DISCUSSION**

In previous reports, qualitative developmental stages, which were characterized as the milk ripening stage, optimum harvest stage, etc., were employed to express the developmental stage of panicles in rice fields. These stages were estimated based on factors such as cumulative temperature (Kudo et al., 1982; Toriu, 1989; Hirota, 1992; Hasegawa et al., 1995; Kanda et al., 2002). On the other hand, quantitative developmental stages, which were young panicle length, weights of panicles, and ratio of greenish unhulled rice, were employed to express the developmental stages of panicles in rice fields (Hoshikawa, 1975; Koyama et al., 1985). Changes in young panicle length were expressed in terms of cumulative temperature (Nakazono and Inoue, 2001). However, these qualitative and quantitative developmental stages were not suitable to continuously express the stages occurring from the initial to middle ripening stages of rice fields.

In this study, the abundances of three separate stages of spikelets were employed as quantitative developmental stages to express the developmental stage of panicles in rice fields. For the three stages of spikelet development, variations in the number of spikelets expressed in DD were smaller than those expressed in DAI (Figs. 1–3). These results indicate that the quantitative developmental stage of rice can be expressed with greater accuracy in DD than in DAI. Thus, cumulative degree-days can be used to uniformly express the changes in the abundance of the three spikelet stages.

The three species of rice bugs in this study mainly infested Stage II spikelets in a panicle in the cage experiment (Takeuchi et al., 2004). In this...
study, the incidence of nymphs of *L. chinensis* and *L. elongatus* began to increase from 200 to 250 DD, and remained high until Stage III spikelets reached a plateau (Fig. 4). The incidence of *L. chinensis* nymphs appeared successively along with nymphal development (Fig. 5). The low threshold temperature for development of nymphs in *L. chinensis* is 12.0°C; the effective cumulative degree-day of nymphs is 316.2 degree-days (Ishizaki et al., 2002); and the developmental period of nymphs of *L. elongatus* is about 30 d in a rice field in Ibaraki Prefecture (Ouchi, 1953). These findings indicate that the high abundance period of Stage II spikelets is very short compared with the developmental period of the rice bugs or the ripening period of panicles; nevertheless, the young nymphs of these rice bugs can occur exactly near the high abundance period of Stage II spikelets.

The incidences of adult rice bugs reached their peaks at similar DD (i.e. 50–150 degree-days after the initial heading stage, which is near the peak of Stage I spikelets) (Fig. 4). The low threshold temperature for the development of eggs in *L. chinensis* is 13.5°C; the effective cumulative degree-day of eggs is 147 degree-days (Ishizaki et al., 2002); and the incubation period of *L. elongatus* is 5 to 7 d.
in a rice field in Ibaraki Prefecture (Ouchi, 1953). Based on these results, it is suggested that the peaks of incidence of eggs for *L. chinensis* and *L. elongatus* is near the peak of Stage I spikelets, and this oviposition timing is necessary for young nymphs to occur near the high abundance period of Stage II spikelets.

The qualitative development stage and number of days after heading were used to express the developmental stages wherein adults of *L. chinensis* and *S. rubrovittatus* show the highest density in the rice field (Shimizu and Maru, 1978; Hayashi and Nakazawa, 1988; limura, 1994; Nakada, 2000; Yokosuka, 2001). However, the qualitative development stage cannot be closely related to the developmental stage of panicles in the rice field. Thus, it was difficult to express the detailed occurrence pattern of these insects in rice fields among different varieties, seasons, and fields.

In this study, we accurately expressed the changes in the abundance of three stages of spikelets with cumulative degree-days, and then showed that the incidence of three types of rice bugs was closely related to the abundance of the three stages of spikelets. Therefore, cumulative degree-days can be used to uniformly express the changes in the incidence of rice bugs among different rice varieties, seasons, and fields.

ACKNOWLEDGEMENTS

We thank Naoyuki Sugiura, Kumamoto Plant Protection Office, and Takashi Owashi, Miyagi Prefectural Plant Protection Office, for their cooperation in the field census, and Takashi Noguchi, Haruo Yoshida, and other staff of the rice fields at the National Agriculture Research Center for planting and maintaining our study sites. We also thank E. Rubia-Sanchez for reading and improving our manuscript. This research was partly supported by a Grant-in-Aid for the Research Project on the Development of Integrated Pest Management Systems to Reduce Environmental Load, the Ministry of Agriculture, Forestry and Fisheries, Japan.

REFERENCES


Nakasuji, F. (1973) The characteristics of occurrence of rice


