Insecticide application and its effect on the density of rice planthoppers, *Nilaparvata lugens* and *Sogatella furcifera*, in paddy fields in the Red River Delta, Vietnam

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The brown planthopper, *Nilaparvata lugens*, and the white-backed planthopper, *Sogatella furcifera*, are significant pests for rice. Both species are able to survive year-round in northern Vietnam’s Red River Delta, which includes a large rice-producing region. This study aimed to evaluate insecticide use by farmers and its effect on the density of planthoppers in the region.

Through interviews conducted with farmers in study sites in Nam Dinh (ND) and Vinh Phuc (VP) Provinces, we learned that farmers frequently used imidacloprid, fipronil, and emamectin-benzoate in ND and pymetrozine and thiamethoxam in VP. Farmers applied insecticides when the local government announcements regarding plant protection were broadcast. Generalized linear model analysis indicated that the selective insecticides applied did not contribute to reducing the densities of planthoppers in the farmers’ fields. Our results indicate the possible development of insecticide resistance by planthoppers or improper insecticide application by farmers.

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Keywords: insecticide resistance, brown planthopper, white-backed planthopper, rice.

Electronic supplementary materials: The online version of this article contains supplementary materials (Supplemental Tables S1–S2), which are available at http://www.jstage.jst.go.jp/browse/jpestics/

Introduction

The brown planthopper (BPH), *Nilaparvata lugens*, and the white-backed planthoppers (WBPH), *Sogatella furcifera*, are significant pests for rice. BPH causes heavy yield losses in rice both through direct feeding and by transmitting two plant pathogenic viruses, rice ragged stunt virus and rice grassy stunt virus.1) WBPH can be a vector of southern rice black-streaked dwarf virus (SRBSDV). This virus causes stunted growth and twisting of leaves and leads to poor plant growth.2) There was an SRBSDV outbreak in the mid-2000s in southern China2) that spread to Vietnam and Japan.2–5) Both planthopper species are known as long-distance migratory insects that migrate from the central and northern parts of Vietnam to China and Japan every year. Due to their inability to overwinter in East Asia, Vietnam, where rice is available year-round, has been considered to be the migration origin of BPH and WBPH.6,7)

The Red River Delta is one of the main rice-producing areas in northern Vietnam, and the area used for rice cultivation consisted of 1,093.9 thousand hectares in 2016.8) Farmers in this region are able to cultivate rice twice a year, i.e., a winter crop and a summer crop, mostly for their own consumption. In order to control rice pest insects, insecticide is commonly used in Vietnam. The total import value of pesticides, including insecticides, has increased in the last decade,9) although some of the active ingredients in insecticides are produced domestically,10) suggesting that the amount of insecticide used has been increasing. Insecticides are distributed throughout the Red River Delta, and farmers can easily obtain them. Despite a recent increase in pesticide regulation, many farmers use pesticides improperly. For example, farmers may use high dosages, create pesticide cocktails, or apply pesticides at inadequate preharvest intervals.10) This behavior not only could have detrimental effects on human health and water resources in the Red River Delta11) but also could result in pest insects developing resistance to insecticides.12)

In Asia, resistance against several types of insecticides has been reported in BPH and WBPH.13–16) Matsumura et al. reported that BPH has a decreased susceptibility to imidacloprid and thiamethoxam, while WBPH remains susceptible to imidacloprid but not to fipronil in the Red River Delta and Japan.17) Among insecticides registered only for rice planters, 51 active ingredients and 773 commercial products are available in Vietnam.18) Recent investigation by Sattler et al. found that 29 active ingredients of insecticides were used for rice cultivation...
in rural areas in Vietnam, and one of these was not on the Vietnamese database of approved pesticides. However, reports on the use of insecticides by farmers are limited, and little information is available on the efficacy of insecticides in controlling the planthopper density in the Red River Delta. Repeated applications of different insecticides compounding an identical target site may lead to developing resistance to the insecticides of planthoppers. Therefore, in order to evaluate the use of insecticides against planthoppers in Vietnam, we aimed to describe the status of farmers’ insecticide use and its effect on planthoppers in agricultural fields in the Red River Delta.

Materials and Methods

1. Study sites
Our study was conducted in two provinces, Nam Dinh (ND) and Vinh Phuc (VP) in the Red River Delta region in the northern part of Vietnam, which are located on the coast of the South China Sea and in an inland region, respectively (Fig. 1A). Both provinces are dominated by farmed rice fields, and the area cultivated with rice was 1,531,000 ha in ND and 584,000 ha in VP.

Communities that frequently suffered from high densities of rice planthoppers were selected based on information provided by the Sub-Department of Plant Protection (Sub-PPD), which falls under the Ministry of Agriculture and Rural Development, in each province. Further, we obtained information on announcements to apply insecticides broadcast by the Sub-PPD in each province in order to evaluate when farmers were likely to apply insecticides.

1.1. Nghia Hung District, ND Province
We selected five or six farmers and their fields in eight randomly selected land areas in a community in Nghia Hung District, ND Province (42 farmers and their fields in total). In the community, several individual farmers own fields in a land area surrounded by a ridge, and they use sticks or rocks as marks to identify their fields. The farmers grow rice twice a year. The winter crop is sown in January, transplanted in February, and harvested in June, and the summer crop is sown in June, transplanted in July, and harvested in September or October. We conducted our studies on the same farmers and fields for the winter crop in 2016 and the summer crop in 2017. We obtained 38 valid interviews from the 42 farmers for both seasons in this community, because some farmers gave up their rice cultivation in the middle of crop seasons.

1.2. Lap Thach District, VP Province
Lap Thach District, in VP Province, is characterized by two rice crop types: one is grown only in the winter (which cultivation area is referred to hereafter as ‘one-crop area’), and another is grown in both winter and summer (which cultivation area is referred to hereafter as ‘two-crop area’). In the one-crop area, there are high water levels after the winter crop harvest, and farmers participate in fishery instead of rice cultivation during the summer season. During the winter crop season of 2016, five farmers

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Fig. 1. Map of study sites (A) and crop schedule (B). Squares show the periods of sowing (S), transplanting (T), and harvesting (H) (from left to right) for winter and summer crop seasons.
and their fields were selected in six land areas in two-crop area (30 farmers and fields in total), and five farmers and their fields were selected in two land areas in one-crop area (10 farmers and fields in total). The same farmers and fields in the two-crop area were included during both the winter and summer crop seasons. We obtained 37 valid interviews from 40 farmers during the winter season and 26 valid interviews from 30 farmers during the summer season.

2. Interviews with farmers
At the beginning of the crop season, the farmers confirmed the sowing date, cultivation variety, and field location of the selected land areas. Then they were asked to take note of their insecticide use, including the date of application, product name, and amount of insecticide applied in the selected field. They were also asked to keep the insecticide packages after use because, generally, farmers discard the used packages and rarely remember the product name or ingredients. Thus we were able to use the labels of packages kept by farmers to confirm the active ingredients in the used products. After the first contact with farmers, we interviewed them again in the middle and at the end of the crop season to confirm their insecticide use based on their notes and packages.

3. Field investigations
Using a beating method with yellow sticky paper (10.5 cm by 29.0 cm, Kamoi Kakoshi Co., Ltd.), we evaluated the density of planthoppers in rice fields owned by the farmers who were interviewed. We conducted this evaluation during the booting stage of rice, when planthopper densities are expected to be high. In the fields, we beat the stems of rice plants three times per hill and included a total of 10 hills per yellow sticky paper. We conducted two replicates of the beating survey in each field.

In the winter season in VP, because the insect density was very low in two-crop area, we included 20 hills per yellow sticky paper and used four replicates in each field. The sticky papers were placed into clear plastic pouches and kept in a freezer until analysis. The adult and nymph (3rd to 5th stage) BPH and WBPH, respectively, were counted under a microscope as needed. We counted nymphs in the 1st and 2nd stages as planthopper nymphs due to the fact that it was not possible to identify the species on the sticky paper. The spiders and mirid bugs, Cyrtorhinus lividipennis (Reuter) and Tythhus chinensis (Stål), were also counted because they are natural enemies of planthoppers.

4. Statistical analysis
To evaluate the effects of insecticide application and other variables on the density of planthoppers, generalized linear models (GLMs) were performed using JMP ver. 14 (SAS Institute Inc., North Carolina, USA). We assumed a Poisson distribution of the response variable and used log as a link function in the analysis. The collected numbers of total BPH and WBPH (which included adults and nymphs in the 3rd to 5th stage) and the total number of planthoppers (which included total BPH and WBPH and nymphs in the 1st and 2nd stages) per field were used as the response variables. The locations (ND or VP), seasons (winter or summer), number of natural enemies (spiders and mirid bugs), and number of applied active ingredients (non-selective and selective) before our field evaluations were conducted were used as the explanatory variables. In case the farmers used the same active ingredients at different times or in different products, each case was counted as 1. Collected active ingredients were classified by the mode of action from the Insecticide ResistanceAction Committee (IRAC). We divided the used active ingredients that are registered for controlling rice planthoppers in Vietnam into two groups, including non-selective active ingredients (which included carbamate (1A), organophosphates (1B), and pyrethroid (3A)) and selective active ingredients (which included phenylpyrazole (2B), neonicotinoid (4A), avermectin (6), pymetrozine (9B), and buprofezin (16)). Nereistoxin (14) and diamide (28) were not registered for controlling planthoppers in Vietnam as single agents, hence, we excluded these ingredients from the analysis.

Results

1. Crop system
In the study site in ND, the winter crop was sown starting in mid-January, transplanted between February 5 and 20, and harvested between June 1 and 15. Subsequently, preparation of the seedbed for the summer crop was started in mid-June, followed by transplanting in mid-July and harvesting in late October to mid-November (Fig. 1B). Eleven cultivated winter crop rice varieties were used, of which ‘Bac Thom 7’ was most commonly used (51.4%), followed by varieties ‘BC 15,’ ‘Thien uu 8,’ and ‘Nep Dai Loan.’ For the summer crop, ‘Nep Bac’ was the most common variety and was cultivated in 35 of the 38 fields (Supplemental Table S1).

Winter sowing in the one-crop area started earlier than in the two-crop area in the study site in VP, with sowing from Novem-

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<th>Table 1. The number of insecticide application per farmers’ fields in a crop</th>
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<sup>a</sup> Average and standard deviation of used product and active ingredients (a.i.) number per field in a crop season are shown in the column.
ber 20 to December 12, transplanting from January 1 to 10, and harvesting from May 10 to 15. The varieties used included the ‘P6’, ‘XT28’, and ‘Xi23’ (Supplemental Table S1). In two-crop area, sowing started in the middle of January, transplanting took place from late January to early February, and harvesting took place in late May (Fig. 1B). Subsequently, the summer crop was sown between June 1 and 15, transplanted after two weeks, and harvested from September 15 to 25 (Fig. 1B). In both seasons, ‘Khang Dan 18’ and ‘Khang Dan 28’ were the most commonly cultivated among 11 varieties (Supplemental Table S1).

2. The number of different insecticides and active ingredients applied

The frequency of insecticide application during the crop season, the product used, and the active ingredients were investigated through interviews with farmers, by reviewing their notes, and by collecting empty insecticide packages. In both ND and VP, the farmers used more insecticide for the summer crop than for the winter crop (Table 1). For the winter crop in VP, the farmers in one-crop area used a larger number of insecticides than in two-crop area (Table 1). As we only used the data that could be confirmed by interviews, this may underestimate the actual number of insecticide types applied.

Farmers in the northern part of Vietnam use a unit of land called a sao, which is equivalent to 360 m². Regarding the amount of insecticide applied, local farmers consider the amount applied per 360 m². The farmers spray insecticides using knapsack sprayer tanks containing 12 to 18 L, depending on the product, and use one sprayer tank per 360 m² according to our investigation. They pour several commercial products into a tank and dilute these with water, creating pesticide cocktails in the tank. In most cases, farmers used a single package of insecticide per tank, although they adjusted the amount of insecticide in the tank. For example, they would sometimes use half a package or two packages per tank, depending on the amount of insecticide in a package or the occurrence of insects and diseases.

3. The active ingredients used by farmers

Twenty-one active ingredients in 11 insecticide types were found in our study. Most ingredients were registered as single agents for the control of planthoppers in rice fields in Vietnam, while indoxacarb and chlorantraniliprole were registered for the control of leaf folders, Cnaphalocrocis medinalis (Guenée), and stem borers. In ND, 14 active ingredients in eight insecticide types and 16 active ingredients in 10 insecticide types were used in winter and summer crops, respectively. Imidacloprid was the most commonly used, followed by fipronil and emamectin benzoate, in both crop seasons (Fig. 2). The number of active ingredients applied during the winter crop season in VP was lower than that during the summer crop season. During the winter crop season, 21.6% of farmers used pymetrozine, while during the summer crop season, thiamethoxam, chlorantraniliprole, abamectin, and permethrin were the most commonly used among 10 active ingredients (Fig. 2). The Sub-PPD recommended seven and eight active ingredients for controlling planthoppers in ND and VP, respectively. However, the active ingredients commonly used by farmers were not consistent with these recommendations (Fig. 2, Supplemental Table S2).

4. Timing of insecticide application

The farmers tended to spray insecticide around the same time as other farmers sprayed in each study site (Fig. 3). In ND, recommendations to spray insecticides were announced three times during the winter crop season and eight times during the summer crop season. In VP, the Sub-PPD recommendations to spray insecticide for the control of planthoppers, leaf folders, and stem
Borer were announced twice in each crop season, including in late March and mid-April (winter crop season) and during the seedbed time and in mid-July (summer crop season, Supplemental Table S2). Farmers tended to follow announced recommendations for when to spray insecticides in both provinces, although some farmers applied additional insecticides at times other than those recommended in the announcements (Fig. 3).

5. Effect of insecticide application on planthopper density

The densities of BPH and WBPH infestation were affected by locations and crop seasons (p<0.05; Tables 2, 3). The application of non-selective active ingredients tended to reduce the number of both BPH and WBPH, while the selective active ingredients did not reduce the density of BPH (Tables 2, 3). Similarly, the application of non-selective active ingredients tended to reduce the total number of planthoppers, while selective active ingredients did not seem to affect their density (Table 4). The number of mirid bugs increased the numbers of both planthopper species (Tables 2, 3), while the number of spiders increased the numbers of BPH (p<0.05, Table 2).

Discussion

This study clarifies the status of insecticide use, applied active ingredients, and timing of insecticide application by farmers and their effects on the density of rice planthoppers in the Red River Delta. The farmers applied several active ingredients...
to their fields, although there were regional and seasonal differences (Fig. 2). Most farmers followed the announced recommendations from the Sub-PPD for when to apply insecticides (Fig. 3). However, the active ingredients used by farmers were not consistent with those recommended by the Sub-PPD (Fig. 2, Supplemental Table S2). This may be because farmers generally select insecticide products based on suggestions made by retailers. The effect of selective insecticide application on planthopper density was not detected in this study, but the location and crop season influenced rice planthopper densities (Tables 2, 3).

Insecticide resistance in planthoppers has been reported in Asia. Imidacloprid and fipronil were commonly applied in ND, and thiamethoxam and pymetrozine were commonly applied in VP to control planthoppers (Fig. 2). Imidacloprid, a neonicotinoid insecticide, has been widely used since the 1990s. However, the susceptibility of BPH to imidacloprid has decreased since 2005 in China and other Asian countries. Furthermore, the susceptibility of BPH to imidacloprid has decreased since 2005 in China and other Asian countries. Although WBPH remains susceptible to two ingredients, imidacloprid and thiamethoxam, they have developed a resistance to fipronil, a phenylpyrazole insecticide. A reduction in BPH susceptibility to pymetrozine was reported in China. Although there are a large number of reports about the insecticide resistance of planthoppers in East Asia, limited information is available from the northern part of Vietnam, where planthoppers can survive year-round. GLM analysis results suggest that the application of selective insecticides (types 2B, 4A, 6, 9B, and 16, based on the IRAC classification) did not contribute to reducing the density of BPH (Table 2). BPH susceptibility to imidacloprid may be restored if application is suspended for several generations, implying that farmers continued to use the same ingredients despite their low effectiveness. To avoid or delay a further increase of insecticide resistance in Vietnam, it is necessary to regularly monitor the status of insecticide resistance and to avoid using certain active ingredients.

The fact that applied selective insecticides did not reduce planthopper density (Tables 2, 3) could be attributed not only to the development of insecticide resistance in planthoppers but also to the application method used by farmers. Based on our observations, the farmers apply insecticides by walking through their fields at regular intervals, with small distances between rice hills, using electric or manually powered knapsack sprayers. Due to the fact that it is hard work carrying a heavy knapsack sprayer tank for insecticide application, it is possible that the active ingredients do not reach the target pests or are not sprayed uniformly in the field, although this depends on the type of insecticide. In addition, the number of mirid bugs increased the number of planthoppers (Tables 2, 3), indicating that populations of mirid bugs, which are susceptible to several insecticides, were maintained in the farmers’ fields. This further suggests that the insecticides may not have reached either pests or their natural enemies.

In Vietnam, the Sub-PPD monitors pest species and makes recommendations to farmers on how to control pests. Plant Protection Stations in districts and Plant Protection Offices in communities work to provide information to farmers. Most farmers in this study depended on announcements from the Sub-PPD to decide on the timing of insecticide application (Fig. 3). Although we could not evaluate the efficacy of the announcements

| Table 3. Results of GLM analysis on variables affecting the density of WBPH |
|-----------------|-------|-----------------|-----------------|-------|
| Variables       | d.f. | Estimated value | Likelihood ratio ($\chi^2$) | p value |
| Location (ND)   | 1    | 1.383           | 1986.241          | <0.0001 |
| Crop season (summer) | 1    | −0.704          | 563.419           | <0.0001 |
| Number of selective insecticides$^{(a)}$ | 1    | 0.003           | 0.102             | 0.749  |
| Number of non-selective insecticides$^{(b)}$ | 1    | −0.077          | 17.724            | <0.0001 |
| Number of spiders | 1    | −0.004          | 6.606             | 0.0102 |
| Number of mirid bugs | 1    | 0.045           | 331.783           | <0.0001 |

$^{(a)}$ Active ingredients classified as phenylpyrazole (2B), neonicotinoid (4A), avermectin (6), pymetrozine (9B) and buprofezin (16).

| Table 4. Results of GLM analysis on variables affecting the density of total number of planthoppers |
|-----------------|-------|-----------------|-----------------|-------|
| Variables       | d.f. | Estimated value | Likelihood ratio ($\chi^2$) | p value |
| Location (ND)   | 1    | 0.644           | 4599.409          | <0.0001 |
| Crop season (summer) | 1    | −0.296          | 751.344           | <0.0001 |
| Number of selective insecticides$^{(a)}$ | 1    | 0.043           | 161.476           | <0.0001 |
| Number of non-selective insecticides$^{(b)}$ | 1    | −0.136          | 325.393           | <0.0001 |
| Number of spiders | 1    | 0.017           | 3447.151          | <0.0001 |
| Number of mirid bugs | 1    | 0.065           | 6708.457          | <0.0001 |

$^{(a)}$ Active ingredients classified as carbamate (1A), organophosphates (1B) and pyrethroid (3A).

$^{(b)}$ Degrees of freedom
directly because our field investigations were conducted in the middle of the crop season, the announcements seemed to function as an important information resource for farmers to decide on the timing of insecticide applications. However, regarding the selection of insecticides, it is important to improve the farmers’ knowledge on insecticide use rather than depending on retailers to select products. Based on our evaluation of insecticide resistance and insecticide application methods, we recommend that future efforts to manage insecticide resistance in rice planthoppers in Vietnam need to include sharing information with the Sub-PPD so that this information can be easily communicated to farmers.

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