JARQ 44 (3), 225−230 (2010) http://www.jircas.affrc.go.jp

REVIEW
Recent Status of Insecticide Resistance in Asian Rice Planthoppers

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Abstract
Since 2005, outbreaks of rice planthoppers have occurred in East-Asian countries such as Vietnam, China and Japan. These outbreaks are closely related to the development of insecticide resistance in these regions. The susceptibilities of the brown planthopper (BPH) and the whitebacked planthopper (WBPH) to four insecticides were evaluated by a topical application method on insects collected from Japan, China, Taiwan, Vietnam, and Philippines in 2006. Species-specific changes in insecticide susceptibility were found in Asian rice planthoppers: imidacloprid resistance in BPH and fipronil resistance in WBPH. Topical LD_{50} values for imidacloprid in the BPH strains from East Asia (Japan, China and Taiwan) and Vietnam were significantly higher than those from the Philippines, suggesting that resistance to imidacloprid has developed in BPH in East Asia and Indochina, but not in the Philippines. Almost all the WBPH populations collected had extremely large LD_{50} values for fipronil, suggesting that resistance to this insecticide is widespread in WBPH populations throughout East and Southeast Asia. Possible reasons for species-specific development of insecticide resistance are identified and discussed.

Discipline: Insect pest
Additional key words: fipronil, imidacloprid, susceptibility, topical application

Introduction

The brown planthopper (BPH), *Nilaparvata lugens* (Stål), and the whitebacked planthopper (WBPH), *Sogatella furcifera* (Horváth) (Homoptera: Delphacidae), are serious pests of rice throughout Asia. The northern limit of continuously breeding populations of these species is around the Red River Delta in Vietnam and Hainan Island in China, where rice (*Oryza sativa*), their only host plant, is cultivated all year round. Neither of these insect species is able to overwinter successfully in temperate areas (Japan, Korea and most areas of China), and colonization occurs annually following long-distance migration from overwintering areas[6]. Thus, occurrence of these two species of rice planthopper in temperate areas is highly dependent on the populations in overwintering areas.

Since 2005, outbreaks of rice planthoppers, particularly of BPH, have occurred simultaneously in many countries in Indochina and East Asia. These outbreaks were closely related to changes in insecticide resistance in the rice planthoppers. Here, we review the current status of insecticide resistance development and distribution in Asian populations of rice planthoppers.

Recent outbreaks of rice planthoppers in East Asia

Historically, severe BPH outbreaks occurred during the 1970s in many Southeast and East Asian countries[4]. At that time, WBPH was a secondary pest of rice. However, since about the mid-1980s, population densities of WBPH increased following a nationwide adoption of hybrid rice in China[18]. To control these planthoppers, neonicotinoid (mainly imidacloprid) and phenylpyrazole (mainly fipronil) insecticides have been used since the mid-1990s in many East Asian countries and Indochina. The application methodologies used for these insecticides vary among countries. In Japan, imidacloprid and fipronil are used exclusively for treating seedling boxes

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Received 6 July 2009; accepted 22 October 2009.

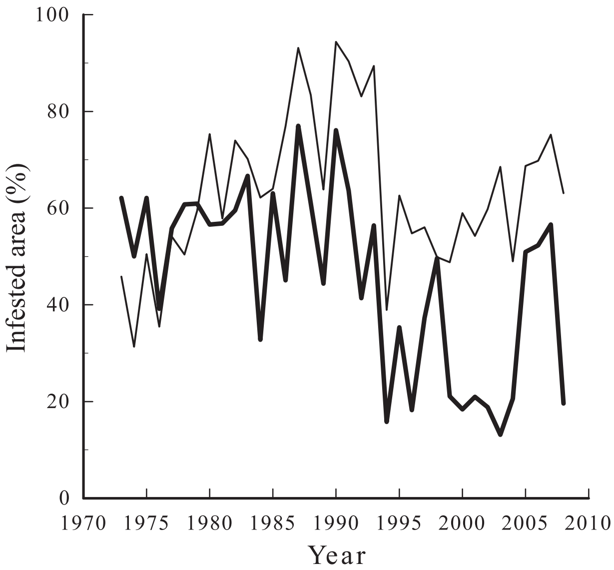

Fig. 1. The proportion (%) of areas (infested paddy fields / total paddy fields × 100) infested by *Nilaparvata lugens* (BPH) or *Sogatella furcifera* (WBPH) in Kyushu, Japan
——— :WBPH, ━━━ :BPH.

to control the rice planthoppers. In Vietnam and China, in contrast, the insecticides are usually sprayed onto rice fields. In any event, the population densities of BPH and WBPH had been relatively low since the mid-1990s when these insecticides were introduced.

Long-term fluctuations in the occurrence of rice planthoppers in Japan are shown in Fig. 1. From the mid-1990s, the areas infested by BPH and WBPH decreased dramatically and remained at this lower level (except for BPH in 1998) until 2004. In part, this might be related to the spread of seedling box treatment in Japan. However, from 2005, the infestation area of BPH showed a large increase and continued at this higher level over the next three years. Outbreaks of BPH were not limited to Japan but also occurred simultaneously in China and Vietnam from 2005. These outbreaks are the result of development of insecticide resistance to imidacloprid in BPH in East Asia as described in the next section.

Insecticide susceptibility of rice planthoppers in East and Southeast Asia

The development of resistance to imidacloprid in BPH was first observed in Thailand and has since been found in neighboring countries such as Vietnam, India and China[3]. Wang et al.[20, 21] used the rice-stem dipping method to survey susceptibility to neonicotinoids in Chinese BPH populations. However, no data are available for the LD_{50} values of Asian BPH and WBPH populations against either neonicotinoid or phenylpyrazole insecticides tested by the topical application method, which is the only method to produce data that can be compared between different years and different countries. Matsumura et al.[10] attempted to remedy this deficit by determining insecticide susceptibility using the standard topical application method[2] in BPH and WBPH populations collected from East and Southeast Asian countries. They tested four commonly used insecticides, imidacloprid, thiametoxam, fipronil, and BPMC.

From 1992 to 2003, the topical LD_{50} values of imidacloprid for BPH were in the range 0.09-2 μg/g in Vietnam, China and Japan[1, 7, 8, 12, 13, 15]. However, the East Asian (Japan, China and Taiwan) and Vietnam BPH populations collected in 2006 had remarkably higher LD_{50} values than those before 2003 (Fig. 2). In contrast, the BPH populations collected in the Philippines in 2006 had similar LD_{50} values for imidacloprid to those of East Asian populations before 2003 (Fig. 2). These results suggest that insecticide resistance against imidacloprid developed in East Asia and Indochina but not in the Philippines.

In contrast to BPH, all the WBPH populations had small LD_{50} values for imidacloprid and no apparent differences were present in the Asian WBPH populations sampled in 2006 (Fig. 3). Thus, the LD_{50} values in 2006 were similar to those in Japanese and Chinese populations collected in 1992-2001[8, 15]. These results suggest that no resistance to imidacloprid has developed in WBPH in Asia.

The East Asian and Vietnam BPH populations had significantly larger LD_{50} values for thiamethoxam compared to the Philippines populations (Fig. 2). The LD_{50} values of imidacloprid and thiamethoxam show a significant positive correlation (see Fig. 2 of Matsumura et al.[10]), suggesting that there is cross-resistance for the two neonicotinoids. However, other neonicotinoids, such as dinotefuran, do not show a similar relationship with imidacloprid resistance in BPH (Matsumura, M. et al., unpublished).

Almost all the Asian WBPH populations collected in 2006 had extremely large LD_{50} values for fipronil (Fig. 3). Although no topical LD_{50} values for fipronil in field WBPH populations are available prior to 2006, the available data suggest that insecticide resistance in WBPH populations to fipronil is widely present in East and Southeast Asian countries. However, all the Asian BPH populations had much smaller LD_{50} values for fipronil (Fig. 2), suggesting that no resistance to fipronil has developed in any Asian population of this species.

The LD_{50} values for BPMC were larger in several

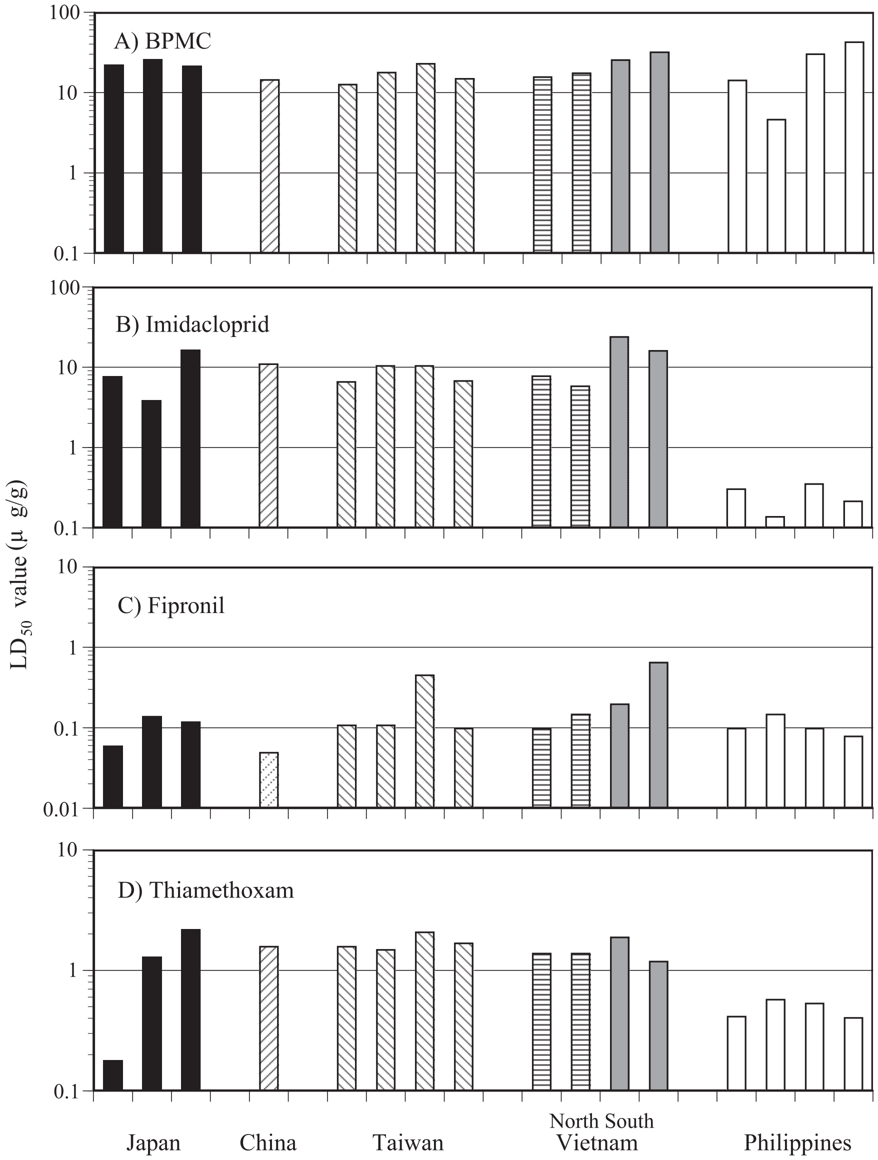

Fig. 2. The LD$_{50}$ values of *Nilaparvata lugens* (BPH) strains collected in East and Southeast Asia in 2006[10]

Vietnam and Philippine BPH populations than elsewhere, but there were no significant differences among countries (Fig. 2). Likewise, there were no significant differences in LD$_{50}$ values for BPMC between East Asian and Southeast Asian WBPH populations (Fig. 3). In 2006, the LD$_{50}$ values of BPH and WBPH populations for BPMC were similar to those in Japan, China and Vietnam between 1992 and 2001[1, 8, 13, 15].

In conclusion, species-specific changes in insecticide susceptibility have been identified in Asian rice planthoppers, specifically for imidaclopirid in BPH populations and fipronil for WBPH populations. Resistance in BPH to imidacloprid developed in East Asia and Indochina, but not in the Philippines. In contrast, resistance in WBPH to fipronil developed widely across East and South East Asia.

Possible reasons for species-specific development of insecticide resistance

Imidacloprid is commonly used to control BPH in the later stages of rice crop growth in Vietnam and China; in northern Vietnam, application of the insecticide to winter-spring rice occurs in May to early June (Fig. 4). In contrast, fipronil is commonly used to control the rice leaffolder (RLF), *Cnaphalocrocis medinalis*

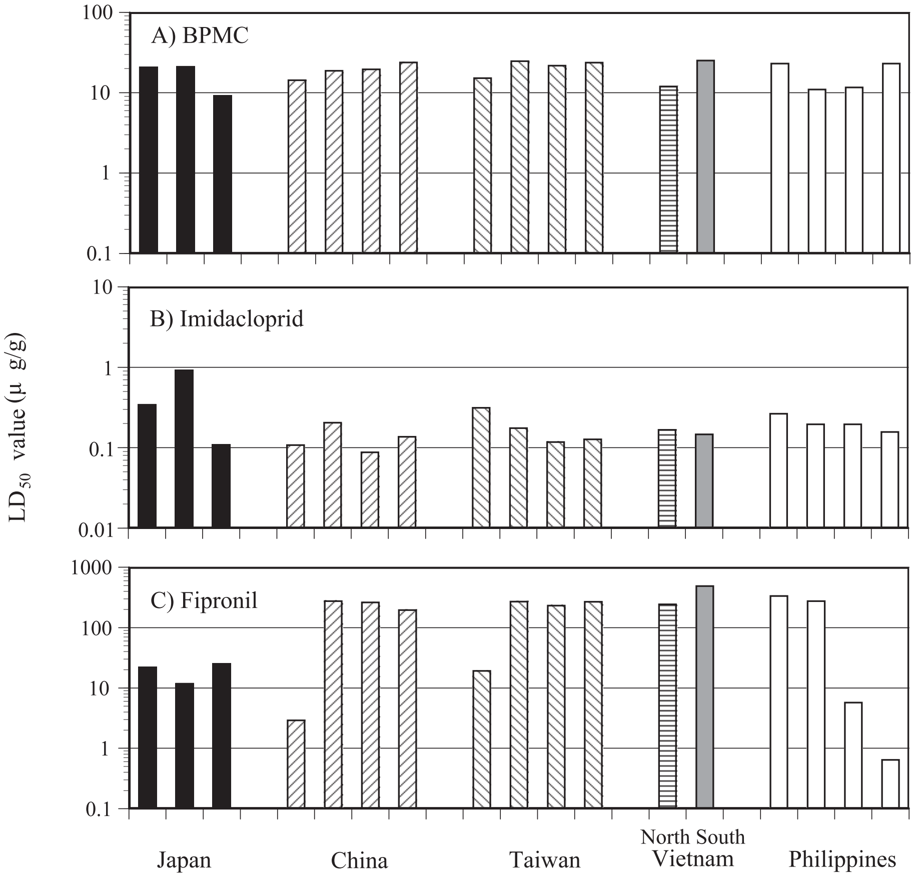

Fig. 3. The LD_{50} values of *Sogatella furcifera* (WBPH) strains collected in East and Southeast Asia in 2006[10]

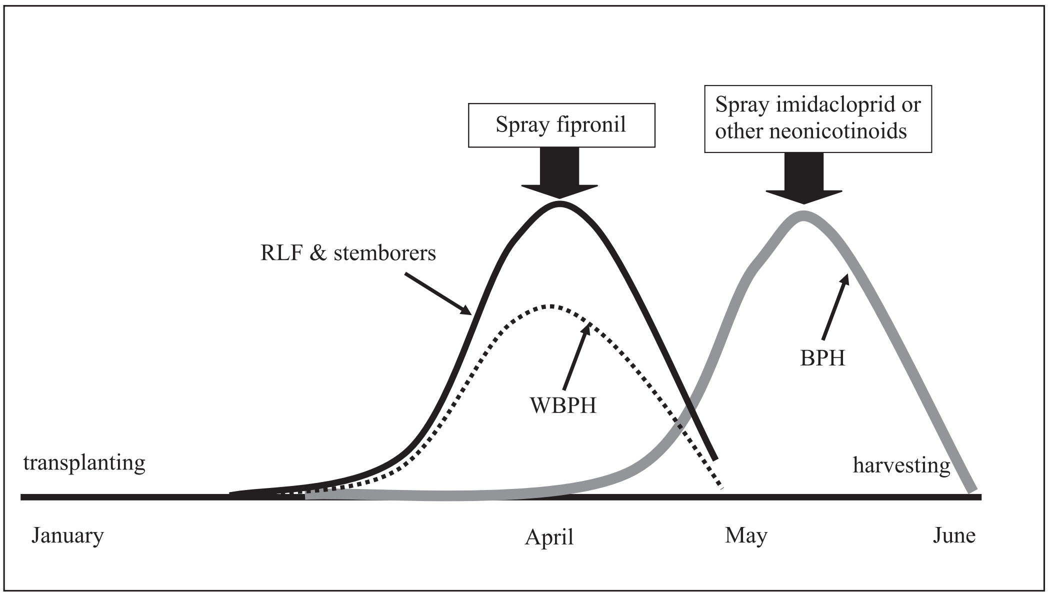

Fig. 4. Cropping patterns and timing of insecticide splaying in winter-spring season rice in northern Vietnam
WBPH: *Sogatella furcifera*, BPH: *Nilaparvata lugens*, RLF: *Cnaphalocrocis medinalis*.

(Guenée), and the rice stem borers at early stages of rice growth in Vietnam and China; in northern Vietnam, application occurs around early April on winter-spring rice (Fig. 4). Early season spraying of fipronil may be more effective on WBPH than on BPH because populations of WBPH increase earlier than those of BPH during the rice growing season (Fig. 4). This may explain why resistance to fipronil has developed only in WBPH.

Resistance of BPH to imidacloprid did not develop in the Philippines (Fig. 2). The likely reason for this is that BPH outbreaks have not occurred recently and imidacloprid has not been used commonly in the Philippines. In contrast, fipronil has been widely used to control rice stem borers in the Philippines. Population density of WBPH has been increasing recently in the Philippines because cropping areas grown with WBPH-susceptible hybrid rice varieties have been increasing. For this reason, the susceptibility of WBPH to fipronil in the Philippines is as low as in East Asia and Vietnam (Fig. 3).

Species-specific resistance to different insecticides might also have developed due to differences in the mode of action of the two insecticides. Liu et al.[7] found that a nicotinic acetylcholine receptor (nAChR) mutation confers target-site resistance to imidacloprid in BPH. However, this target-site resistance in BPH has only been identified in laboratory populations and has never been found in a field strain. Further studies on the mechanism of resistance to imidacloprid in BPH have been conducted[9, 22]. Although the target site of fipronil, GABA receptors, is different from that of imidacloprid (see review of Raymond-Delpech et al.[16]), no detailed information is available for the mechanism of resistance to fipronil in WBPH. Further comparative studies on the mode of action of neonicotinoid and phenylpyrazole insecticides in BPH and WBPH are needed to elucidate the species-specific development of resistance to neonicotinoid and phenylpyrazole insecticides.

In the Mekong Delta of southern Vietnam, outbreaks of two BPH-transmitted viral diseases, rice ragged stunt virus (RRSV) and rice glassy stunt virus (RGSV), have occurred since 2005, resulting in the heavy use of insecticides to control BPH. In 2006, the LD_{50} values of two southern Vietnam BPH populations tended to be larger than those in the two northern Vietnam populations for BPMC, imidacloprid and fipronil (Fig. 2). The LD_{50} values in southern Vietnam BPH populations in 2007 and 2008 have also shown evidence of increase compared to those in 2006 (Matsumura, M. et al., unpublished). Continued monitoring of the status of susceptibility of BPH to these insecticides in southern Vietnam and neighboring countries, such as Cambodia and Thailand, is clearly warranted.

Concluding remarks

In addition to the two rice planthoppers, outbreaks of the small brown planthopper (SBPH), *Laodelphax striatellus* (Fallén), and rice striped virus (RSV) have occurred in China since the early 2000s[19]. The outbreaks of SBPH and RSV also occurred in Japan in 2008[11, 14]. It was found that these outbreaks occurred as a result of the migration of the Chinese SBPH population, which has different insecticide resistance characteristics to those of the Japanese population[14]. Thus, it will also be important to monitor insecticide resistance of SBPH in East Asian countries.

Development of an effective management system for Asian rice planthoppers will require the establishment of an international information exchange network because of the high mobility of the insects between countries. To establish this network, IRRI (International Rice Research Institute) held a workshop-training course on toxicology and insecticide resistance monitoring in 2009[5]. The blog “Ricehoppers” was also initiated from 2009 to provide a platform for knowledge sharing on issues and for developing sustainable ways to manage rice planthopper problems[17]. This sharing of information and knowledge will be essential for the successful monitoring of insecticide resistance and management of Asian rice planthoppers.

Acknowledgments

This work was supported in part by a Grant-in-Aid for Scientific Research (B) (No. 21380039) to the corresponding author from the Japan Society for the Promotion of Science.

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