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STATUS OF NEONICOTINOID INSECTICIDE RESISTANCE IN RICE PLANTHOPPERS - A REVIEW

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ABSTRACT

The status of neonicotinoid insecticide resistance in rice planthoppers *viz.*, brown planthopper *Nilaparvata lugens* Stal and whitebacked planthopper *Sogatella furcifera* (Horvath) in countries like China, Taiwan, Japan and Korea has been reviewed to formulate strategies for its management in India. The information on small brown planthopper *Laodelphax striatellus* Fallen has also been reviewed because of its similarity in physiology to BPH although it is not an important insect pest in India. Two methods commonly used for monitoring resistance were rice plant root dipping and topical application. Among biochemical mechanisms conferring resistance, target insensitivity as well as oxidation and degradation by mixed-function oxidases (m.f.o.) appeared to be important. The resistant strains of BPH had reduced biological fitness for developmental and reproductive characteristics.

Among different insect pests attacking rice crop, planthoppers constitute one of the most important group causing substantial losses. Rice brown planthopper, *Nilaparvata lugens* (Stal) and whitebacked planthopper, *Sogatella furcifera* (Horvath) are the most destructive pests in India and many other countries. Small brown planthopper, *Laodelphax striatellus* Fallen is important in Japan. These hoppers cause direct damage by sucking plant sap often causing "hopper burn" and also act as vectors of virus diseases.

Although some progress has been made in the field of host plant resistance and cultural management, farmers still, largely depend on the use of insecticides for obvious reasons. In early seventies and eighties organophosphates like monocrotophos and acephate, carbamates like carbaryl and BPMC and ether derivatives like ethofenprox have been extensively used in India as well as other countries. As a result, these hopper pests became resistant to these insecticides in Japan, Taiwan, China and Philippines, although the insecticide resistance has been reported to be in incipient stage in India (Sarupa *et al.*, 1998 and Padmakumari *et al.*, 2002). Since 1997, a new group of insecticides called neonicotinoids or chloronicotinyles such as imidacloprid, thiamethoxam and clothianidin have been extensively utilized for suppressing the hopper populations in China, India, Taiwan, Japan and Korea. Neonicotinoids are effective at 20-25 g a.i./ha as compared to 500-750 g a.i./ha in case of organophosphates and carbamates. This dose and economical advantage worked very well in favour of these neonicotinoids. Soon, there were signs of resistance development in hopper pests against this new group of insecticides in China, Taiwan, Japan and Korea and suspected resistance in several rice growing tracts in India {Krishnaiah, N.V. (2002) personal communication}. As this has become a big challenge for rice entomologists of India, it is apt to review the existing information on neonicotinoid insecticide resistance in planthopper pests to give insights into strategies for management of this insecticide resistance problem in rice planthoppers. Therefore, the information is reviewed pest wise and aspect wise.

(i) Rice brown planthopper, *Nilaparvata lugens* (Stal)

Methods for monitoring of resistance

Liu *et al.* (2002a) from Nanjing

Agricultural University, Nanjing, China evaluated several methods of insecticide application for monitoring imidacloprid resistance in BPH. They reported that the root dipping method was better in terms of simplicity, precision and accuracy of monitoring results as well as convenience of operation. Nagata *et al.* (2002) also used standardized topical application method for simultaneous monitoring of insecticide susceptibility of BPH and WBPH, which are long range migrating rice planthoppers. Xaofei-Ping *et al.* (2001) used topical application for determining insecticide susceptibility of BPH collected from China and Japan in 1997.

Selection for neonicotinoid resistance in *N. lugens* and cross-resistance patterns

Liu *et al.* (2003b) from Nanjing, China, collected the field population of BPH and selected for imidacloprid resistance in the laboratory. The resistance increased by 11.35 times in 25 generations in the field collected population and the resistance ratio reached 72.83 compared with a laboratory susceptible strain. The selected resistant strain showed cross resistance to all the acetylcholine receptor targeting insecticides like monosultap (1.44 fold), acetamiprid (1.61 fold) and imidacloprid homologues JS599 (2.46 fold) and JS598 (3.17 fold). But there was no cross resistance to other groups of insecticides. They demonstrated that Triphenyl phosphate (TPP) and Diethyl maleate (DEM) had no synergism with imidacloprid. However, PBO displayed significant synergism in some different strains and the synergism increased with resistance (S strain 1.2 fold; field population 1.43 fold; R strain 2.93 fold). PBO synergism to cross resistant insecticides was also found in the resistant strain (monosultap 1.25 fold; acetamiprid 1.39 fold; JS598 1.94 fold; JS599 2.02 fold). It was concluded that esterase and glutathione S-transferase play little role in imidacloprid detoxification. The increase of P450-monoxygenases detoxification is an important mechanism for imidacloprid resistance and target insensitivity may also exist in *N. lugens*. Liu *et al.* (2002b) in their studies on development of methamidophos resistance in BPH observed that R-strain of the pest selected for methamidophos resistance, displayed 43.74 fold resistance to methamidophos and also had cross resistance to malathion, diazinon, isoprocarb (MIPC), fenubucarb (BPMC) and ethofenprox but no cross resistance to fenvalerate and imidacloprid. Synergistic bioassay showed that TPP (triphenyl phosphate) significantly synergised methamidophos (synergistic ratio (SR) 4.52) and moderately synergised malathion (SR 2.76), diazinon (SR 2.07), fenubucarb (SR 2.17) and isoprocarb (SR 1.64). Piperonyl butoxide (PBO) partially synergised methamidophos (SR 2.24), malathion (SR 1.86) and ethofenprox (SR 1.73). Biochemical assay showed that esterase activity in the R-strain was 7.93 times than that in S-strain, in which the changed activity of MFO was 1.98 and for glutathione transferase it was 1.44. TPP could significantly inhibit esterase activity (Per cent Inhibition : 69.04) in the R-strain while, the PI for MFO s was 29.30 by PBO. Thus, esterase played an important role in biochemical mechanism of methamidophos resistance and to a lesser extent, cross resistance to malathion, diazinon, fenobucarb and isoprocarb. MFO might play some role in resistance to methamidophos and cross resistance to malathion and ethofenprox. Krishnaiah *et al.* (2002) in their green house studies on resistance development to monocrotophos and a neem formulation (NG-4 with 300 ppm azadirachtin) in green house strain of BPH (*N. lugens*) exposed the insect to LD_{50} - LD_{80} levels of these materials for 26 generations. Mono strain of BPH developed cross resistance to NG-4; ethofenprox and imidacloprid but remained susceptible to BPMC and cartap, while NG-4 strains of BPH continued to be susceptible to monocrotophos, ethofenprox, BPMC, cartap and imidacloprid.

Monitoring for neonicotinoid resistance in BPH

Liu *et al.* (2002a) from Nanjing, China determined the base line susceptibility of females, males and different nymphal instars of BPH to imidacloprid by using root dipping method. The results of the neonicotinoid resistance monitoring in *N. lugens* in three areas in China *viz.*, Guilin, Anquing and Dongtai showed that these populations had developed low level of resistance to imidacloprid in all three areas. However, the resistance of the hopper in Anquing and Dongtai was a little higher than the level in Guilin populations. Xaofei-Ping *et al.* (2001) determined the insecticide susceptibility of BPH collected from China and Japan in 1997 by topical application. The insecticide susceptibility of BPH was not much different among the populations from Nagasaki (South West Japan), Hangzhou (Zhejiang, China) and Jhinghong (Yunnan, China). LD_{50} of BPH was 0.027-0.062 µg/g for nitenpyram, 0.083-0.14 mg/g for imidacloprid, 0.58-0.88 µg/g for silafluofen, and 0.78-1.2 µg/g for ethofenprox in contrast to 67-130 µg/g for malathion, 51-93 µg/g for fenitrothian and 57-94 µg/g for DDT. The LD_{50} s for chloronicotinyl and pyrethroids were much smaller than those of organophosphates and organochlorines. LD_{50} of monocrotophos was 1/23-1/3 times as large as that of other organophosphates. It was also observed that organophosphate and carbamate susceptibilities were not different between BPH population collected in 1992 and 1997. Nagata *et al.* (2002) monitored insecticide susceptibility of BPH simultaneously in Japan, China (3 locations) and Malaysia by standardized topical application method for 10 insecticides in 2000. The LD_{50} for BPH population from Japan BPH coincided with those for two Chinese populations, but one of the populations from China gave remarkably larger LD_{50} for imidacloprid.

Biological fitness of imidacloprid resistant strain of BPH

Liu *et al.* (2003a) studied the effect of imidacloprid resistance on the fitness of BPH in terms of developmental and reproductive characteristics by constructing and comparing the life tables of the two resistant strains (R_1, R_2) with those of the susceptible strain. The results showed that both R_1 and R_2 strains had developmental disadvantages, including a lower larval survival rate from neonate to 2nd instar, a lower adult emergence rate and shorter female life span. The reproductive disadvantages included lower copulation rate, fecundity and hatchability. In addition, the R_2 strain had prolonged egg duration and a lower larval survival rate from the 3rd to 5th instar. The fastigium of R_2 was lower than that of S and F_2. The fitness of the two resistant strains was determined by comparing the population number tendency index (I) with the susceptible strain as standard. The relative fitness value for R_1 strain was calculated to be 0.609 and the R_2 strain was only 0.245.

(ii) Neonicotinoid resistance in Whitebacked Planthopper (WBPH), *Sogatella furcifera* (Horvath)

Xaofei Ping *et al.* (2001) determined the insecticide susceptibility of WBPH collected from China and Japan in 1997 by topical application. The insecticide susceptibility of WBPH was not much different among the populations from Nagasaki (South West Japan), Hangzhou (Zhejiang, China) and Jinghong (Yunnan, China). The LD_{50} s for WBPH were 0.047-0.062 mg/g for nitenpyram, 0.067-0.18 µg/g for imidacloprid, 0.72-1.5 µg/g for silafluofen and 0.89-1.6 µg/g for ethofenprox, in contrast to 96-130 µg/g for malathion, 100 µg/g for fenithrothion, and 22-51 mg/g for DDT. Thus the LD_{50} s of chloronicotinyl and pyrethroids were much smaller than those of the organophosphates and organochlorines. The LD_{50} of monocrotophos was 1/17-1/3 as large as that of the other organophosphates. The LD_{50} s of isoprocarb and propoxur for WBPH populations collected in 1997 were 5 times as large as in 1989. Nagata *et al.* (2002) from Ibaraki University, Ibaraki Japan simultaneously monitored the insecticide susceptibility of the long range migrating rice planthoppers like WBPH in Japan, China (3 locations) and Malaysia by standardized topical application method on 10 insecticides in 2000. The LD_{50} of Japanese WBPH during 2000 coincided with those for the two Chinese populations, but one of the Chinese populations gave remarkably larger LD_{50} for imidacloprid. The Malaysian population of WBPH gave LD_{50} almost equal to those of the Japanese WBPH during 2000.

Neonicotinoid resistance in smaller brown planthopper *Laodelphax striatellus* Fallen (SBPH)

The smaller brown planthopper, *Laodelphax striatellus* Fallen (Homoptera: Delphacidae) is one of the most important insect pests infesting rice plants in Japan and transmitting the stripe virus. However, fortunately this hopper pest was not reported from any part of Indian subcontinent including Bangladesh and Pakistan except a stray observation at Punjab Agricultural University, Ludhiana during 1980. Since this pest also belongs to the same Delphacidae family to which BPH and WBPH belong, the information on the development of neonicotinoid resistance in SBPH and the possible mechanisms can give us insights in tackling neonicotinoid resistance in BPH and WBPH in India.

Sone *et al.* (1995) from Yuki, Japan reared strains of *L. strietellus* in the laboratory for many generations with the selection pressure from 500 ppm malathion and 500 ppm propoxur sprayed weekly (designated as N-strain) or without this selection pressure (S-strain) and nine field strains collected from various places in Japan in 1991-92 were treated with propoxur, disulfoton, ethofenprox and imidacloprid and LD_{50} s were calculated. In general, strains from the North Japan had greater susceptibility to the insecticides than those from South of Japan. Most of the field strains were resistant to disulfoton and propoxur but susceptible to ethofenprox and imidacloprid. The N-strain showed slight cross resistance to imidacloprid (resistance ratio of 18) but 100% mortality was achieved at concentrations less than those generally used in the field. Sone *et al.* (1997) in their further studies elucidated the underlying mechanisms responsible for low susceptibility of N-strain to imidacloprid compared to S-strain including cuticular penetration and possible metabolic detoxification systems under the influence of synergists. When radio labeled imidacloprid (20 dpm/insect) was applied to 100 insects of each strain, 20% of imidacloprid penetrated into the body one hour after treatment. The amount then increased with the passage of time, but no difference in penetration rate was found between the strains.

Endo *et al.* (2002) from Ibaraki, Japan examined the insecticide susceptibility of *L. strietellus* collected from East Asia in 1992-1994 by topical application method. The LD_{50} values of organophosphorus insecticides for the Northern Vietnam populations (HAI, HAN, VIN) and the JIN population (Yunan province, China) were lower than those of the FU (Zhejiang Province, China) IB (Central Japan) and KU (South western Japan) populations. The LD_{50} values of organophosphorus and carbamate insecticides for the northern Vietnam populations were almost the same as that for Fukuoka (Western Japan) population examined in 1967. The LD_{50} values of organophosphorus insecticides did not differ among the FU (Zhejiang Province, China), IB (Central Japan) and KU (South Western Japan) populations. The LD_{50} values of carbamates for the KU population were the largest and those for northern Vietnam populations were the smallest. The carbamate susceptibility of acetylcholinesterase in the KU population was lower than that in the HAI population. Therefore, it was concluded that the insensitivity of acetylcholinesterase for carbamate was one of the carbamate resistant factors in the KU population. LD_{50} values of ethofenprox, fenvalerate and imidacloprid showed no differences among all the populations tested. This showed that there was no cross resistance to ether derivatives (ethofenprox), synthetic pyrethroids (fenvalerate) and neonicotinoids (imidacloprid) in these carbamate resistant KU population of *L. striatellus*.

CONCLUSIONS AND FUTURE THRUST

1. In view of high degree of effectiveness of neonicotinoids and lower cost involved per unit area, these insecticides are likely to be overused and abused by rice farmers in BPH endemic areas. This will further hasten the process of resistance development.
2. The information available on the practical methods for detecting and monitoring neonicotinoid resistance in rice planthoppers is inadequate and a lot of research efforts need to go into this aspect.
3. The biochemical mechanisms involved and cross resistance patterns are very poorly understood and hence emphasis should also be laid on this aspect of neonicotinoid resistance.
4. The meager evidence indicates mainly the role of m.f.o. in degrading neonicotinoids in resistant strains of planthoppers. As m.f.o. are general degrading enzymes for all xenobiotics, it is likely that there will be cross resistance to other groups of insecticides in neonicotinoid resistant populations of planthoppers. Hence, this aspect also needs emphasis as a future thrust area of research.

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