Japanese Society of Applied Entomology and Zoology

Appl. Ent. Zool. **16** (1) : 1—6 (1981)

Development of Carbamate Resistance in the Brown Planthopper, *Nilaparvata lugens* STÅL (Homoptera : Delphacidae)

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(Received April 26, 1980)

Insecticide susceptibility of the immigrant generation of the brown planthopper, *Nilaparvata lugens* STÅL, collected from the 6 prefectures in Kyushu in 1979 was estimated by the micro-topical application method. Comparison of the data with those obtained in 1967 revealed obvious development of carbamate resistance with an increase of LD_{50} by approximately 10 times to MTMC (3-tolyl N-methyl carbamate), carbaryl and MIPC (2-isopropylphenyl N-methyl carbamate). Still higher levels of resistance with a 10–30 times increase of LD_{50} were observed for the organophosphates tested. No significant local difference in insecticide susceptibility was found in this survey covering whole Kyushu district.

INTRODUCTION

Development of insecticide resistance in the brown planthopper, *Nilaparvata lugens* STÅL, as well as in the white-backed planthopper, *Sogatella furcifera* HORVATH, has been relatively slow compared with the closely related species of rice leaf- or planthoppers such as the green rice leafhopper, *Nephotettix cincticeps* UHLER, or the small brown planthopper, *Laodelphax striatellus* FALLÉN, in Japan (NAGATA et al., 1979). However, some of the insecticides which have been considered sufficiently effective against the brown planthopper are beginning to show poorer control in the fields.

In the Philippines, HEINRICHS et al. (1977) reported carbamate resistance. Carbofuran failed to control the brown planthopper in the IRRI fields in 1977 where carbofuran granules had been used for about 3 years. Further studies indicated a 7 fold increase in topical LD_{50} with the brown planthopper for carbofuran as compared with the greenhouse stock cultures. LIN et al. (1979) reported development of MTMC and MIPC resistance by laboratory selection of the brown planthopper and they also found local differences in insecticide susceptibility for the 2 carbamate insecticides by field survey in Taiwan.

We have conducted surveys of insecticide susceptibility on the brown planthopper since 1967. This report deals with the results of the latest survey on the immigrant brown planthopper following earlier studies conducted in 1976 (NAGATA et al., 1979) in which development of resistance for organophosphorus insecticides was already confirmed.

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MATERIALS AND METHODS

The 1978 autumn generations of the brown planthopper were collected from Nagasaki pref. (Isahaya city), Kagoshima pref. (Taniyama city), Ōita pref. (Usa city), Kochi pref. (Nangoku city) and Hiroshima pref. (Fukuyama city) between September and October.

The 1979 immigrant generations were collected from Nagasaki pref. (Isahaya city), Kagoshima pref. (Taniyama city), Ōita pref. (Usa city), Miyazaki pref. (Sadohara), Kumamoto pref. (Kumamoto city), and Fukuoka pref. (Chikugo city) between June 27th and July 5th just after the first distinct immigration wave was observed (Fig. 1). Occurrence of the brown planthopper is generally greatest in the Kyushu district followed by Shikoku and the southern half of Honshu. Each population was multiplied from more than 30 collected females on 25 g of rice seedlings (Reiho Variety) in a cubic glass vessel in a rearing room with a temperature of 25± 1°C and 16 hr of daylight according to the method of NAGATA and MASUDA (1980). The periods of laboratory rearing before testing were 11–12 generations for the 1978 autumn populations and 1–3 generations for the 1979 immigrant populations except the Miyazaki strain, which was reared for 5 generations. Adult males less than 3 days old were used for the tests unless otherwise mentioned. Duplicate groups of 15–20 males were assayed at each concentration. The planthoppers were anaesthetized with carbon dioxide and individual insects were treated topically with 0.05 μl of acetone solution of the active ingredient of the insecticides by the micro-topical application technique of FUKUDA and NAGATA (1969). The LD_{50} values and regression equations were obtained by statistical analysis according to Bliss's formula (BLISS, 1936) using a computer (Model: SHARP®, PC-5300) from the mortality data taken 24 hr after treatment at 25°C.

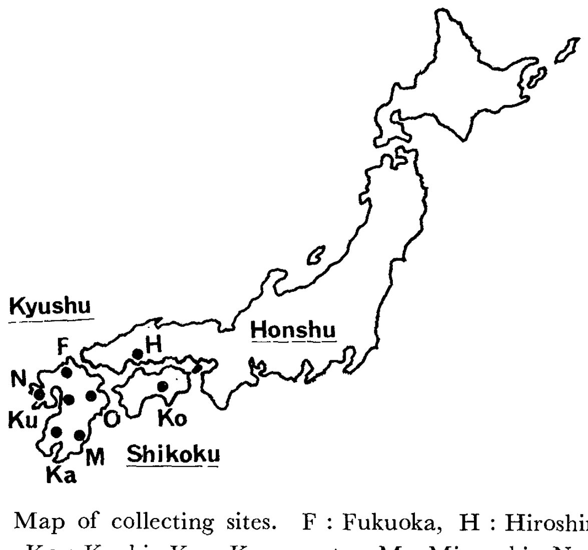

Fig. 1. Map of collecting sites. F : Fukuoka, H : Hiroshima, Ka : Kagoshima, Ko : Kochi, Ku : Kumamoto, M : Miyazaki, N : Nagasaki, O : Ōita.

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RESULTS

1978 autumn generations

As compared with the data obtained in 1967 (Fukuda and Nagata, 1969), organophosphates showed a remarkable increase in LD_{50}: malathion, 4.5–20.2 times; fenitrothion, 4.5–17.7 times; diazinon, 3.3–7.5 times, followed by the carbamates which showed 1.8–9.0 times increases in LD_{50}. The change of LD_{50} in BHC and DDT was the smallest.

In the local comparison of insecticide susceptibility, 1.5–4.5 times variance was observed in the max/min ratio of LD_{50} for the 8 insecticides tested (Table 1). Hiroshima and Ōita strains showed patterns of insecticide susceptibility somewhat different from the other 3 strains, with relatively lower susceptibility to BHC and higher susceptibility to the organophosphates and carbamates tested but this tendency was not persistent. The populations collected from both collecting sites in the following year did not retain these particular patterns of insecticide susceptibility (Table 2).

1979 immigrant generations

When compared with the data obtained in the previous year, further increase in LD_{50} was observed with organophosphates: malathion, 23.8–32.7 times; fenitrothion, 13.5–25.7 times; diazinon, 6.2–13.7 times. Even with the carbamates, LD_{50} increased 7.7–20.9 times but BHC and DDT showed no significant change in LD_{50}. The survey area was limited to the Kyushu district this year due to difficulties in collecting sufficient numbers of immigrant planthoppers with low population density in the fields. Local differences in insecticide susceptibility were very small, with a max/min LD_{50} ratio of less than 2.6 times among the 6 survey points (Table 2).

Table 1. LD_{50} Values for the 1978 Autumn Generations

Insecticides	Nagasaki	Kagoshima	Ōita	Hiroshima	Kochi	Max[c]/min	Fukuoka[d] (1967)
BHC	0.0618*/1.1[a] (1.8)[b]	0.0621*/1.9 (1.8)	0.2307*/1.0 (6.6)	0.1441*/1.7 (4.2)	0.0661*/1.8 (1.9)	3.7	0.0347*/2.7 (1.0)
DDT	0.0341*/1.1 (1.2)	0.0357*/2.1 (1.3)	0.0585*/1.4 (2.1)	0.0665*/1.2 (2.3)	0.0353*/2.4 (1.2)	1.9	0.0283*/1.8 (1.0)
Malathion	0.2404*/1.5 (19.7)	0.2468*/1.4 (20.2)	0.1041*/1.7 (8.5)	0.0550*/1.4 (4.5)	0.2048*/1.4 (16.8)	4.5	0.0122*/3.5 (1.0)
Fenitrothion	0.2386*/2.6 (17.7)	0.1738*/2.4 (12.9)	0.1060*/1.4 (7.9)	0.0608*/2.0 (4.5)	0.2105*/2.4 (15.6)	3.9	0.0135*/2.8 (1.0)
Diazinon	0.0999*/2.0 (7.5)	0.0582*/2.1 (4.3)	0.0700*/2.7 (5.2)	0.0441*/1.8 (3.3)	0.0894*/2.7 (6.7)	2.3	0.0134*/4.5 (1.0)
MTMC	0.0147/1.7 (6.1)	0.0135*/3.4 (5.6)	0.0087/1.7 (3.6)	0.0043*/2.8 (1.8)	0.0175*/1.6 (7.3)	4.1	0.0024*/5.7 (1.0)
Carbaryl	0.0111*/2.2 (7.9)	0.0124/1.2 (8.9)	0.0032*/3.2 (2.3)	0.0037 /1.5 (2.6)	0.0126*/1.6 (9.0)	3.9	0.0014*/4.2 (1.0)
MIPC	0.0110*/2.0 (6.5)	0.0098*/2.0 (5.8)	0.0077*/1.8 (4.5)	0.0071*/2.2 (4.2)	0.0137*/1.5 (8.1)	1.5	0.0017*/5.2 (1.0)

[a] LD_{50}(μg/male)/slope of regression line, * indicates that regression line fitted at Pr=0.05.

[b] Times increase of LD_{50} as compared with 1967 data.

[c] Max/min ratio indicates ratio of maximum LD_{50}/minimum LD_{50} for the local comparisons.

[d] Data quoted from Fukuda and Nagata (1969).

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Table 2. LD_{50} VALUES FOR 1979's IMMIGRANT GENERATION

Insecticides	Nagasaki	Kagoshima	Ōita	Fukuoka
BHC	0.0539*/1.6[a] (1.6)[b]	0.0855*/1.3 (2.5)	0.0937*/1.3 (2.7)	0.0654 /1.2 (1.9)
DDT	0.0375*/1.7 (1.1)	0.0736*/1.5 (2.6)	0.0375*/1.3 (1.3)	0.0386*/2.4 (1.4)
Malathion	0.3986*/1.2 (32.7)	0.3634*/2.4 (29.8)	0.3441*/1.6 (28.2)	0.3086*/1.6 (25.3)
Fenitrothion	0.3465*/2.2 (25.7)	0.2460*/2.2 (18.2)	0.3093*/2.6 (22.9)	0.3321 /1.5 (24.6)
Diazinon	0.1787*/2.5 (13.3)	0.1833*/1.7 (13.7)	0.1191*/1.8 (8.9)	0.0991*/1.8 (7.4)
MTMC	0.0232*/4.3 (9.7)	0.0277*/4.6 (11.5)	0.0275*/3.1 (11.5)	0.0195*/3.1 (8.1)
Carbaryl	0.0293 /1.5 (20.9)	0.0163*/2.0 (11.6)	0.0173 /1.7 (12.4)	0.0112*/1.2 (8.0)
MIPC	0.0267*/2.8 (15.7)	0.0239*/2.5 (14.1)	0.0155*/1.4 (9.1)	0.0131*/1.9 (7.7)

Insecticides	Kumamoto	Miyazaki	Max/min[c]	Hiroshima[d]
BHC	0.0697*/1.6 (2.0)	0.0416 /1.7 (1.2)	2.2	0.0951*/2.0 (2.7)
DDT	0.0594*/2.2 (2.1)	0.0294*/2.5 (1.0)	1.9	0.0427*/1.4 (1.5)
Malathion	0.2902*/1.6 (23.8)	0.3381*/2.2 (27.7)	1.4	0.4204*/2.7 (34.5)
Fenitrothion	0.3237 /2.3 (24.0)	0.1820 /2.3 (13.5)	1.9	0.3428 /3.9 (25.4)
Diazinon	0.1493*/3.0 (11.1)	0.0826 /4.0 (6.2)	2.2	0.0734*/4.2 (5.5)
MTMC	0.0218*/2.5 (9.1)	0.0203 /2.9 (8·5)	2.6	0.0098*/5.1 (4.1)
Carbaryl	0.0134*/1.8 (9.6)	0.0111*/3.4 (7.9)	1.4	0.0075*/2.9 (5.4)
MIPC	0.0209*/1.9 (12.3)	0.0140*/3.3 (8.2)	2.1	0.0078 /3.0 (4.6)

[a,b,c] See footnote in Table 1.
[d] Autumn generation collected in October 1979 in the same field as in 1978. This strain was not included for calculating the max/min ratio.

DISCUSSION

1. *Development of insecticide resistance*

The LD_{50} values of the 1978 autumn generations from Nagasaki and Kagoshima were significantly higher than those values obtained at the same places in 1976 (NAGATA et al., 1979) though the former values were determined with males which are generally more susceptible than females and were subjected to unusually a longer period of laboratory rearing. These results suggested further development of insecticide resistance after 1976 as clearly confirmed by examining the 1979 immigrant generation. The overall decrease in the coefficient of regression equations observed in 1978 and 1979 also indicates changes in the genetic nature of the immigrant planthoppers with regard to insecticide susceptibility.

In 1976, NAGATA et al. (1979) already observed the development of organo-

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phosphate resistance but reserved conclusions on carbamate resistance because the increase in LD_{50} for the carbamates was less than 3 times at that time. However, the 7.7–20.9 times increase in LD_{50} observed with the 1979 immigrants evidently indicates the development of carbamate resistance. The rate of development of resistance to organophosphates and carbamates in the last 3 years (1976–1979) seemed even faster than in the preceding 9 years (1967–1976) (Fig. 2). The brown planthopper is considered to migrate from foreign breeding sources every year and not to be able to overwinter in Japan (Kisimoto, 1971). It is highly probable that the decrease in insecticide susceptibility in the immigrant brown planthopper is due to the effects of a possible increase of insecticide use in the areas of origin. In the southern part of the Chinese mainland, one of the most probable sources of migration, the occurrence of the brown planthopper was reported to have increased leading to severe dam-

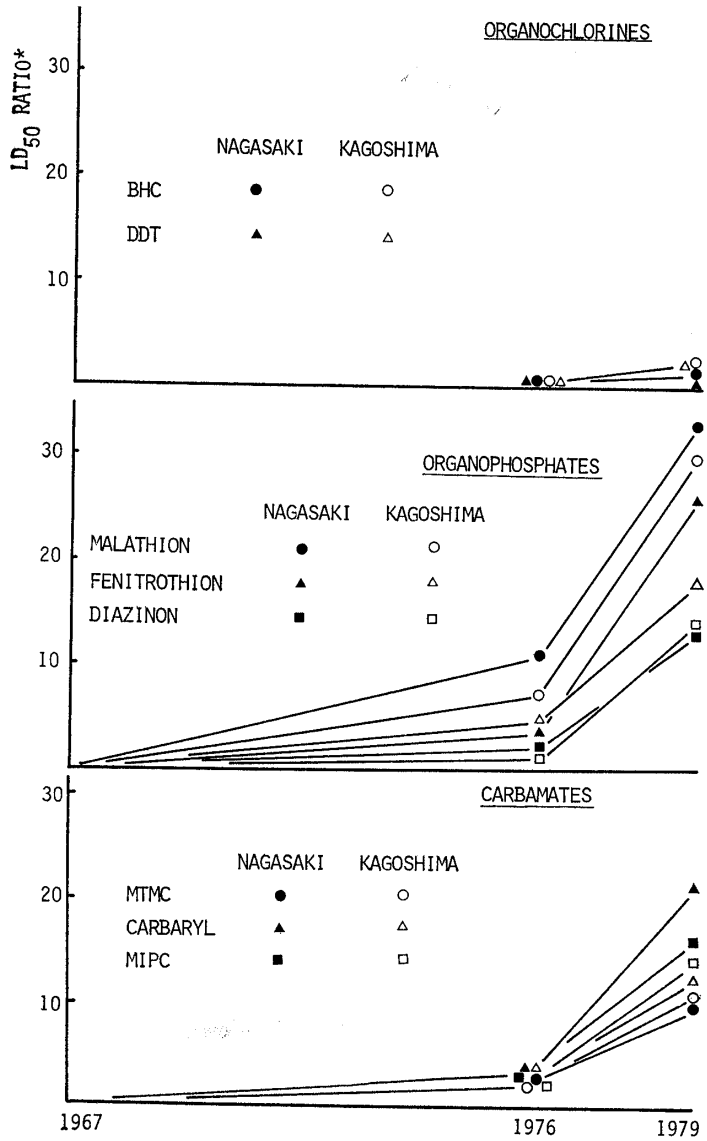

Fig. 2. Developing rate of insecticide resistance for the brown planthopper.
* LD_{50} ratio : times of increase of LD_{50} with 1967's data as baseline.

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age every year since 1973 (Crop Pest Prognostic Station, Zhao-Ching district, 1977).

2. *Local differences in insecticide susceptibility*

In the case of overwintering insect species, selection pressure by insecticide in each areas will usually show remarkable regional variance in insecticide susceptibility corresponding to the amount of insecticides used. Hence, small local differences in insecticide susceptibility despite different usage of insecticides can be regarded as a characteristic feature of migrating insects. It is reasonable for the brown planthopper to show little local difference with regard to insecticide susceptibility assuming that they cannot overwinter in Japan and are renewed by migrants every year. The LD_{50} values obtained at the period of migration in 1979 showed less than 2.6 times of variance among the 6 collection sites in the Kyushu area. These results are in good agreement with previous reports (NAGATA and MORIYA, 1974; NAGATA et al.,1979) and confirmed them by sampling so many locations covering the east coast of Kyushu for the first time in this survey.

In the survey of the 1978 autumn generations, considerable local differences were observed but the variance was not particular to any specific area as shown by the tests in the following year. However, it is possible that migration occurs as a succession of several migration waves of the brown planthopper with different levels of insecticide susceptibility derived from different migration sources and local differences in insecticide susceptibility appear depending on the migration wave which dominated in the respective areas. Further study is needed on this area.

ACKNOWLEDGEMENTS

We express sincere thanks to the staff of the prefectural experiment stations who cooperated in the collection of migrants of the brown planthopper, which is laborious due to their low density in the fields. Thanks are also due to Mr. T. WADA of Kyushu National Agricultural Experiment Station for his kind advice on computer programming.

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