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Agamermis unka (Mermithidae) Parasitism of *Nilaparvata lugens* in Rice Fields in Korea

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Abstract: The mermithid *Agamermis unka*, a parasite of the brown planthopper (BPH), was found in many rice paddies in Gyeongnam Province, Korea. Nematode parasitism of adult BPH varied from year to year, reaching as high as 50% in paddies not treated with an insecticide. Parasitism was lower in insecticide-treated paddies. Generally, mermithid parasitism was higher in BPH adults collected from the lower part (19%) compared with adults collected from the upper part (8%) of the rice plant and in brachypterous (57%) compared with macropterous forms (8%). No difference in parasitism between first (54%) and second (57%) generation was observed.
Key words: *Agamermis unka,* biological control, brown planthopper, entomogenous nematode, integrated control, mermithid, *Nilaparvata lugens,* rice pest.

The brown planthopper (BPH), *Nilaparvata lugens* (Stål), is a serious pest in many rice-growing regions of the Far East. In Korea and other temperate countries, BPH cannot survive the harsh winters; its annual influx is dependent on adult dispersal from southern China by tropical storms in June and July. Its feeding on rice plants often results in hopperburn and reduces yield (3,6), and it serves as a vector of two viral diseases, rice grassy stunt and ragged stunt (9). This pest has a high reproductive potential, high tolerance to crowding, and good adaptability to various rice cultivars (8).

In Gyeongnam Province on the southern part of the Korean peninsula, rice is especially susceptible to severe damage because of the large numbers of BPH adult immigrants early in the season and favorable environment for their establishment. Although resistant rice cultivars have lowered BPH populations, evolving biotypes break down plant resistance (5). Chemical insecticides, which are becoming ever more expensive, are the main tools used to suppress BPH populations (4), but they have disadvantages including secondary pest resurgence, insecticide resistance, pollution, and impact on nontarget organisms.

The integrated pest management tactics of host-plant resistance and biological control need to be developed and implemented in Korea. Biological control of BPH has not been studied extensively, however, and the natural enemies of BPH have received attention only recently. Natural enemies of BPH include predators, parasitoids, pathogenic micro-organisms, and nematodes. The seasonal prevalence of BPH parasitism by parasitoids in the Philippines and the application of hyphomycetous fungi for suppression of BPH in the Philippines and Korea have been studied (1,11,12). A nematode parasite, *Agamermis unka* Kaburaki and Imamura (Nemata: Mermithidae), was isolated from BPH (7) and some basic ecological observations have been made in Korea (2) and China (14,15). We are reporting 1) the effects of several insecticides used for BPH control on the distribution of nematodes in soil and prevalence of parasitism, 2) nematode parasitism according to insect wing type (i.e., brachypterous vs. macropterous) and generation, and 3) nematode occurrence throughout the rice-growing regions of Gyeongnam Province, Korea.

MATERIALS AND METHODS

Insecticides and nematode occurrence in soil: The effects of insecticides on nematode distribution in the soil were conducted in

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a rice paddy (2.7% sand, 51.5% silt, 45.8% clay; 2.4% organic matter; pH 5.8) known to be naturally infested with the mermithid at Gyeongsang National University, Gyeongnam Province. Rice (*Oryza sativa* L. cv. Chucheong) was hand transplanted on 3 June 1986 in experimental plots, 8.5 × 9.0 m. Thirty pairs of insectary-reared brachypterous BPH adults were released in each plot on 2 July, 20 pairs on 8 July, and 20 pairs on 19 July. All plots received 12 kg/ha urea on 10 June for tillering and 28 July for heading, and 12 kg/ha urea plus 4 kg/ha potassium chloride for ripening on 27 August. The fungicide edifenphos (0-ethyl-S, S-diphenyl phosphorodithioate) was applied at the rate of 0.8 kg a.i./ha on 3, 18, and 24 July and 20 August. Weeds were removed by hand on 16 August.

Two formulations of decamethrin ([S]-*a*-cyano-*m*-phenoxybenzyl [IR, 3R]-3 [2, 2-dibromovinyl]-2, 2-dimethylcyclopropane-carboxylate), which is being tested as a potential insecticide to control BHP, and buprofezin (2-tert-butylimino-3-isopropyl-5-phenylperhyxro-1,3,5-thiadiazin-4-one), and a combination of cartap (S,S′-[2-(dimethylamino) trimethylene] bis (thiocarbamate) hydrochloride), and BPMC (2-(1-methylpropyl) phenyl methylcarbamate) which are normally used to control BPH in Korea, were applied to rice. The insecticides were sprayed on the plots with a hand sprayer at 11 liters/66 m^2 on 5 August and 3 September as follows: decamethrin, 5.6% WP (wettable powder) at a rate of 1.65 kg a.i./ha, decamethrin, 3.9% FL (flowable) at a rate of 1.65 kg a.i./ha; buprofezin, 25% WP at a rate of 1.65 kg a.i./ha, or cartap, 50% SP (soluble powder) and BPMC, 50% EC (emulsifiable concentrate) at a rate of 1.65 kg a.i./ha for each insecticide. In the case of cartap and BPMC combination plot, cartap was applied on 5 August and BPMC was applied on 3 September. The control treatment was sprayed with distilled water. The experiment was a randomized block design with three replicates for each treatment. After rice harvest in October, soil samples (30 × 30 cm, to a depth of 11 cm) were removed from each plot and examined for adult mermithids by sieving (2).

Insecticides and nematode parasitism of BPH adults: Comparison of nematode parasitism in BPH adults between insecticide-treated and untreated rice paddies was conducted at the Gyeongnam Provincial Rural Development Administration. Rice was transplanted by machine in 33-m^2 experimental plots on 27 May 1986. The plots received one of three registered insecticides normally used to control BHP during the course of the growing season. Carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate) 3% G (1.2 kg a.i./ha) was applied with a granular spreader on 31 July, BPMC 2% D (0.8 kg a.i./ha) was applied on 11 August with a duster, and cartap 4% G (1.6 kg a.i./ha) was applied with a granular spreader on 20 August. Control plots were not treated. BPH populations were allowed to establish from natural migration into the rice fields. On 25 August and 5 September, 25–320 second-generation brachypterous BPH adults from each plot were collected with an aspirator and dissected to determine mermithid parasitism. A time limit of 30 minutes was used to collect BHP in each plot. The experiment was a randomized block design with three replicates per treatment.

Survey for nematode parasitism of BPH adults: Second-generation BPH adults were sampled from the same rice paddy at the Gyeongnam Provincial Rural Development Administration on the same dates in 1978, 1979, and 1986 to determine fluctuations in nematode parasitism at a single site. The rice paddy had not been treated with insecticides. In addition, adult BPH were sampled in 1980 and 1987 at irregular intervals; the overall rate of parasitism is reported for those years.

Surveys of nematode parasitism of BPH in insecticide-treated and insecticide-free rice paddies in coastal, mountain, and inland regions in Gyeongnam Province were conducted in 1986 and 1987. The insecticides (many insecticides were used including carbofuran, buprofezin, cartap;

BPMC, and others), concentrations, and times of application varied from year to year and from farm to farm. Insecticide treatments were determined by asking the farmer at the time of sampling for BPH adults.

Nematode parasitism of BPH adults by plant location, generation, or wing type: Brown plant hopper adults were collected with an aspirator from the lower and upper parts of the rice plant on 12 and 14 September and examined for nematode parasitism. They were collected from 60-cm-tall plants until 50 adults had been obtained from below the midpoint and 50 from above the midpoint on each date at the Gyeongsang National University site.

Nematode parasitism of first-generation or second-generation BPH was determined at the Gyeongnam Provincial Rural Administration site. In both years, first-generation adults (the progeny of the immigrating adults) were collected between 15 and 25 August and second-generation adults were collected between 15 and 27 September. In addition, parasitism of macropterous and brachypterous adults was determined from BPH collected throughout Gyeongnam Province.

Statistical analysis: Data for the insecticides and nematode occurrence in soil and insecticides and nematode parasitism of BPH adults were analyzed by one-way analysis of variance with Duncan's multiple-range test used to establish the significance of differences among means. Data for nematode parasitism of BPH adults by plant location, generation, or wing type were analyzed by chi-square tests.

Results and Discussion

Insecticides and nematode occurrence in soil: The occurrence of the postparasitic mermithid in the soil varied greatly, but it was not significantly affected by treatment. The untreated control had a lower mean than three of the four insecticide treatments. The mean numbers ± one standard deviation of mermithids recovered were 19 ± 9 from the control, 26 ± 10 from decamethrin WP 5.6%, 20 ± 12 from decamethrin FL 3.9%, 42 ± 24 from buprofezin WP 25%, and 10 ± 10 from cartap 50% SP + BPMc EC 50% treatments. Insecticides apparently had little or no effect on the preparasitic (infective) stage, and sufficient BPH were present in the plots to become parasitized and produce postparasites. Nematode parasitism and emergence may have occurred before insecticidal application, but the residual insecticides more probably had lost their effectiveness on the foliage and parasitized and nonparasitized BPH may have redistributed themselves throughout the plots. The emerging mermithid postparasites would then be present in the insecticide-treated plots. The possibility that the mermithids represented both old and new populations in the soil cannot be discounted. Old mermithids from the previous season could mask the new postparasite population and account for the variation observed. The possibility that the insecticidal treatments selectively killed more nonparasitized BPH than parasitized ones to account for the nonsignificant distribution of the mermithid in these plots seems unlikely.

Insecticides and nematode parasitism of BPH adults: Although nematode occurrence in soil did not appear to be affected by insecticides, parasitism of second-generation BPH was significantly lower in the insecticide-treated plots (Fig. 1). The BHP carbofuran-treated plots had a significantly lower percentage of parasitism than did the cartap-treated or BPMC-treated plots. Carbofuran and cartap were applied as granules and incorporated into the soil and may have adversely affected the preparasites directly or preparasite production by the adults, thus reducing parasitism in these plots. The compatibility, however, of the insecticides and *Agamermis* preparasites is not known. Carbofuran has nematicidal activity, and parasitism of the mosquito (*Culex quiquefasciatus* Say) by *Romanomermis culicivorax* Ross and Smith was lower in carbofuran-treated plots than in untreated ones (13).

Assuming even distribution of the mer-

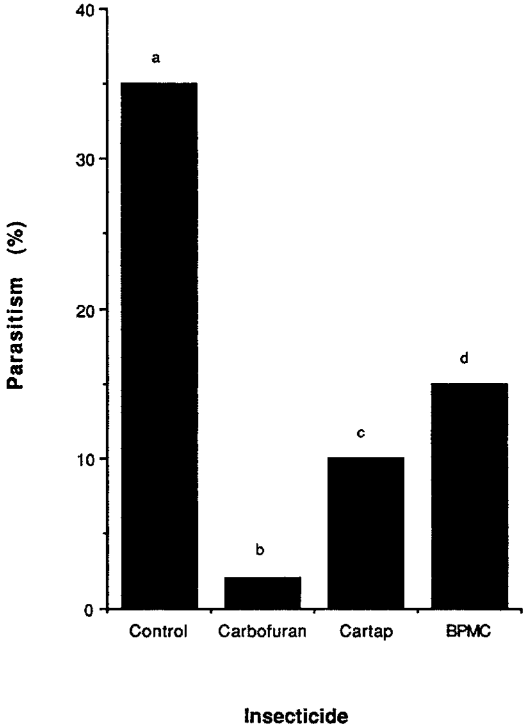

FIG. 1. Parasitism of second-generation brown planthopper adults by *Agamermis unka* following insecticide treatment. Bars with same letters are not significantly different ($P = 0.05$) according to Duncan's multiple-range test.

mithid preparasites in the plots, the number of available BPH hosts for these preparasites should have been greater in the control plots than in the insecticide-treated plots. The insecticide treatments may have reduced the BPH populations to such low levels that few suitable hosts were present in the plot at the time preparasites were most likely to infect them. Fewer BPH were collected from the insecticide-treated plots than from the control plots, and the low host density and, perhaps, nematicidal or nematostatic effects, especially by carbofuran, may account for the lower parasitism observed in the treated plots.

Survey for nematode parasitism of BPH adults: The occurrence of parasitism of BPH in an untreated rice paddy varied from 10% on 20 September 1986 to 81% on 30 August 1978 (Table 1). The prevalence of parasitism fluctuated by sample dates (and years), but the mermithid was present in the rice paddy from year to year. Overall

TABLE 1. Nematode parasitism of brown planthopper (BPH) in an insecticide-free plot at Gyeongnam Provincial Rural Development Administration site.

	BPH parasitized									
	1978		1979		1980†		1986		1987†	
Date	%	N	%	N	%	N	%	N	%	N
August										
25	41.6	24	37.2	65			25.0	20		
30	80.6	31	58.2	42			62.0	100		
September										
5	54.6	11	75.2	21			47.1	85		
10	45.4	22	72.0	84			12.5	40		
15	40.0	25	38.3	50			20.0	20		
20	60.0	5	46.1	45			10.0	10		
Mean ± SE	56.1 ± 3.7		54.5 ± 3.8		51.2 ± 2.5		29.4 ± 2.6		59.0 ± 4.9	
Total		118		307		400		275		100

† Not reported by dates because samples were taken at irregular intervals.

TABLE 2. Nematode parasitism of brown planthopper (BPH) in insecticide-treated (+) and insecticide-free (−) rice paddies in three different ecological regions in Gyeongnam Province.

Locality	Year	Insecticide treatment	BPH parasitized	
			% ± SE	N
Coastal region	1986	+	5.3 ± 0.5	2,159
	1987	+	22.2 ± 1.9	467
		−	58.8 ± 3.1	250
Inland region	1986	+	4.0 ± 0.4	2,036
	1987	+	20.8 ± 3.9	110
		−	55.7 ± 4.5	120
Mountainous region	1986	+	5.3 ± 0.9	608

parasitism was greater than 50% in all years except 1986. Pena and Shepard (10) observed 50% parasitism by an unidentified nematode (presumably *Agamermis*) in BPH during the wet season in the Philippines. Overall parasitism from a number of collection sites averaged 19% (range 0–57%).

The prevalence of nematode parasitism from various localities within Gyeongnam Province showed lower parasitism rates in 1986 than in 1987 (Table 2). In 1986, collections made only from rice paddies treated with insecticides showed low nematode parasitism varying from 4 to 5.3%. Parasitism was considerably higher for the insecticide-treated paddies in 1987 than in 1986, but the untreated paddies had more than double the parasitism of the treated ones.

A great reduction in mermithid parasitism occurred within Gyeongnam Province in 1986 (Tables 1, 2). Overall parasitism was reduced in the untreated paddies, even though on 30 August and 5 September parasitism was relatively high (Table 1). We observed no appreciable temperature change or storm that could account for such a drastic reduction in parasitism for this particular year.

Nematode parasitism of BPH adults by plant location, generation, or wing type: BPH located on the lower part of the rice stem had a significantly ($\chi^2 = 4.5$, $P < 0.05$) greater rate of parasitism than those on the upper portions of the plant. Of 100 BPH collected from each site, 19% on the lower part of the plant were parasitized compared with 8% on the upper part. The preparasitic nematodes are more likely to encounter BPH on the lower portions of the plant; therefore, the higher parasitism observed here is not surprising. However, the possibility that nematode-infected BPH either show a preference for the lower part of the rice plants or a diurnal behavior rhythm cannot be eliminated.

No significant difference in parasitism was observed between first-generation and second-generation BPH. The first generation had an average of 53.9% ± 1.8 (N = 798), whereas the second generation had an average of 57.4% ± 1.8 (N = 741). These data suggest that the preparasites are synchronized with their BPH host.

The wing type of the BPH adult appears to be a significant factor in nematode parasitism. The macropterous adult form was parasitized significantly ($\chi^2 = 776$, $P < 0.01$) less (8.3% ± 0.8, N = 1,231) than the brachypterous form (57.2 ± 1.1, N = 2,044). The reason for this difference in parasitism is probably related to nematode and insect behavior rather than a difference in host suitability. The brachypterous form usually rests near the water surface, where the nematode has a better chance to encounter it than the macropterous form which usually rests on the upper part of the plant.

The mermithid *A. unka* is firmly established in Korean rice paddies. It survives in rice paddies treated with chemical insecticides, although BPH parasitism tends to be lower than in insecticide-free paddies. Understanding the ecological and behavioral relationships between the nematode and BPH could result in the proper use of compatible insecticides or other biological control agents in providing an integrated approach to BPH management.

LITERATURE CITED

1. Aguda, R. M., M. C. Rombach, D. J. Im, and B. M. Shepard. 1987. Suppression of populations of the brown planthopper, *Nilaparvata lugens* (Stål) (Hom.; Delphacidae) in field cages by entomogenous fungi (Deuteromycotina) on rice in Korea. Journal of Applied Entomology 104:167–172.

2. Choo, H. Y., H. K. Kaya, S. M. Lee, Y. I. Lee, and D. J. Cho. 1987. Distribution of a nematode parasite of brown planthopper in the soil, with notes on bionomics. Journal Institute Agricultural Research Utilization, Gyeongsang National University 21:81–85. (In Korean.)

3. Dyck, V. A., and B. Thomas. 1979. The brown planthopper problem. Pp. 1–17 *in* Brown planthopper: Threat to rice production in Asia. International Rice Institute, Los Banos, Laguna, Philippines.

4. Heinrichs, E. A. 1979. Chemical control of the brown planthopper. Pp. 145–167 *in* Brown planthopper: Threat to rice production in Asia. International Rice Research Institute, Los Banos, Laguna, Philippines.

5. Heinrichs, E. A., G. B. Aquino, S. L. Valencia, S. de Sagun, and M. B. Arceo. 1986. Management of the brown planthopper, *Nilaparvata lugens* (Homoptera: Delphacidae), with early maturing rice cultivars. Environmental Entomology 15:93–95.

6. Hokyo, N., M. H. Lee, and J. G. Park. 1976. Some aspects of population dynamics of rice leafhoppers in Korea. Korean Journal of Plant Protection 15: 111–126.

7. Kaburaki, T., and S. Imamura. 1932. Mermithid-worm parasitic in leafhoppers, with notes on its life history and habits. Proceedings of the Imperial Academy 8:139–141.

8. Kisimoto, R. 1977. Bionomics, forecasting of outbreaks and injury caused by the rice brown planthopper. Pp. 27–41 *in* The rice brown planthopper. Food and Fertilizer Technology Center for the Asian and Pacific region, Taipei, Taiwan.

9. Ling, K. C. 1977. Transmission of rice grassy stunt by the brown planthopper. Pp. 73–83 *in* The rice brown planthopper. Food and Fertilizer Technology Center for the Asian and Pacific region, Taipei, Taiwan.

10. Pena, N. P., and B. M. Shepard. 1985. Parasitism of nematodes on three species of hopper pests of rice in Laguna, Philippines. International Rice Research Newsletter 10(1):19–20.

11. Pena, N., and M. Shepard. 1986. Seasonal incidence of parasitism of brown planthoppers, *Nilaparvata lugens* (Homoptera: Delphacidae), green leafhoppers, *Nephotettix* spp., and whitebacked planthoppers, *Sogatella furcifera* (Homoptera: Cicadellidae) in Laguna Province, Philippines. Environmental Entomology 15:263–267.

12. Rombach, M. C., R. M. Aguda, B. M. Shepard, and D. W. Roberts. 1986. Infection of rice brown planthopper, *Nilaparvata lugens* (Homoptera: Delphacidae), by field application of entomopathogenic Hyphomycetes (Deuteromycotina). Environmental Entomology 15:1070–1073.

13. Walker, T. W., C. L. Meek, V. L. Wright, and J. S. Billodeaux. 1985. Susceptibility of *Romanomermis culicivorax* (Nematoda: Mermithidae) postparasites to agrichemicals used in Louisiana rice production. Journal American Mosquito Control Association 1: 477–481.

14. Yan, S., H. Qian, K. Xia, and L. Ling. 1986. Life cycle of *Amphimermis* sp., a nematode parasite of the brown planthopper in China. Acta Phytophylacica Sinica 13:79–84. (In Chinese.)

15. Zhao, H., Z. Hu, and S. Zhang. 1987. Field occurrence of *Agamermis* sp., a nematode parasite of rice hoppers. Chinese Journal of Biological Control 3:73–77. (In Chinese.)