Effects of Insecticides on the Entomopathogenic Nematode *Steinernema carpocapsae* WEISER¹

Li ZHANG, Toshio SHONO, Satoshi YAMANAKA²
and Hiroshi TANABE²

*Laboratory of Applied Zoology, Institute of Agriculture and Forestry,
University of Tsukuba, Tsukuba, Ibaraki 305, Japan*

² *SDS Biotech K. K. Tsukuba Technology Center,
Midorigahara, Tsukuba, Ibaraki 300–26, Japan*

(Received 28 March, 1994; Accepted 27 May, 1994)

The toxic effects of 14 organophosphates (OP's), 7 carbamates, 4 synthetic pyrethroids, cartap and imidacloprid on the entomopathogenic nematode *Steinernema carpocapsae* WEISER were tested by checking the mortality of infective juveniles (IJs) in insecticide solutions. Cartap and two OP's (profenofos and pyraclofos) were the most toxic to the IJs: 83.4% mortality for cartap and 57.1 and 47.8% for profenofos and pyraclofos, respectively, in solutions of 100 µg/ml after 48 h exposure. Seven OP's (diazinon, dichlorvos, fenthion, malathion, trichlorfon, propetamphos and prothiofos) showed weak toxicity at 100 µg/ml. Other chemicals tested showed no toxicity to the IJs at 100 µg/ml. The IJs were incubated in insecticide solutions (100 µg/ml) for 24 h and then used to treat newly-molted last instar *Spodoptera litura* larvae. OP's (except acephate, malathion and temephos), 1 carbamate (methomyl), 2 pyrethroids (permethrin and ethofenprox) and cartap apparently inhibited infectivities of IJs to these larvae. However, when insecticides were washed off the body surface of IJs, only cartap (≥10 µg/ml) and profenofos (100 µg/ml) left a detrimental effect on the IJ infectivity.

Key words: *Steinernema carpocapsae*, entomopathogenic nematode, infective juvenile, biological control agents, insecticides

INTRODUCTION

Entomopathogenic nematodes in the families Steinernematidae and Heterorhabditidae possess potential as biological control agents of insect pests (KAYA et al., 1993). Infective juveniles (IJs) of *Steinernema carpocapsae* are highly infectious to various species of insects, especially to lepidopterous insects (KONDO, 1987; KONDO and ISHIBASHI, 1989; POINAR, 1990). Chemical insecticides, however, are still predominantly used to control insect pests. Combinations of entomopathogenic nematodes with chemical pesticides may increase the overall efficacy against insect pests, since positive results have shown that *S. carpocapsae* is compatible with many pesticides (HARA and KAYA, 1983 a; ROVESTI and DESEÖ, 1990; ZIMMERMAN and CRANSHAW, 1990). In practical application, insecticides that enhance nictating behavior of IJs or, at least,

¹ This work was supported in part by a Grant-in-Aid for Developmental Scientific Research from the Ministry of Education, Science and Culture of Japan. Grant No. 02506001.

have no effect on this behavior may be used with nematodes (ISHIBASHI, 1993; ISHIBASHI and CHOI, 1991; ISHIBASHI and KONDO, 1990; ISHIBASHI and TAKII, 1993). However, previous studies have shown that certain organophosphates (OP's) and carbamates have adverse effects to *S. carpocapsae* (PRAKASA RAO et al., 1975; KAMIONEK, 1979; HARA and KAYA, 1982, 1983 b), and these insecticides may preclude its further use. This study was thus focused on the effects of insecticides on IJs of *S. carpocapsae* to determine possible combinations of insecticides and the nematode.

MATERIALS AND METHODS

Chemicals. The technical grade chemicals representing the following classes of insecticides generously provided by companies were tested; purity of the chemical and company name are shown in brackets: (1) organophosphates (OP's)—acephate (97.4%, Takeda Chemical Industries), chlorpyrifos (97%, DowElanco Japan), diazinon (96.6%, Nippon Kayaku), dichlorvos (98.5%, Nippon Soda), fenitrothion (96.5%, Sumitomo Chemical), fenthion (96.3%, Nihon Bayer Agrochem), malathion (95.6%, Sumitomo Chemical), temephos (95%, Cyanamid Japan), trichlorfon (99%, Nihon Bayer Agrochem), profenofos (95%, Ciba Geigy, Japan), propetamphos (91%, Sankyo), prothiofos (89%, Nihon Bayer Agrochem), pyraclofos (94.1%, Takeda Chemical Industries), sulprofos (91%, Nihon Bayer Agrochem); (2) carbamates—carbosulfan (90.3%, Nissan Chemical Industries), fenobucarb (97.8%, Sumitomo Chemical), methomyl (99.17%, DuPont, Japan), metolcarb (96.6%, Sumitomo Chemical), oxamyl (99.2%, DuPont, Japan), propoxur (98.2%, Nihon Bayer Agrochem), xylylcarb (98.1%, Sumitomo Chemical); (3) synthetic pyrethroids—fenvalerate (94.9%, Sumitomo Chemical), permethrin (91.2%, Sumitomo Chemical), cypermethrin (94.5%, Sumitomo Chemical), ethofenprox (89%, Mitsui-Toatsu Chemicals); (4) cartap (98.5%, Takeda Chemical Industries); (5) nicotinoid—imidacloprid (90%, Nihon Bayer Agrochem). Each chemical was diluted in reagent grade ethanol except cartap and imidacloprid which were diluted in distilled water. Stock solutions of these chemicals were freshly prepared for each test.

Nematode and insect. The infective juveniles (IJs) of *S. carpocapsae* WEISER (All strain) were provided by Biosys Co. (Palo Alto, CA, U.S.A.). Distilled water was used to make a nematode suspension shortly before the experiment. The common cutworm, *Spodoptera litura*, used in this study was an insecticide susceptible strain offered by Sumitomo Chemical Co., Takarazuka, Japan and reared in this laboratory on an artificial diet. Newly-molted last-instars of the insects were used for the experiment.

Bioassay of mortality. Two milliliters of nematode suspension (about 150 IJs per ml) was put into a 4 ml screw vial to which 0.02 ml insecticide solution was then added. Dilutions of the insecticides were made to final concentrations of 1, 10 and 100 µg/ml in the vial. The vials were sealed with caps to prevent vaporization of the solution. Tests of each concentration were replicated three times. Two sets of all treatments were established to observe nematode mortality at 24 and 48 h respectively. Distilled water and solvent treatments (1%, v/v) served as controls. All treatments were maintained at 22°C, and mortality was recorded by observing whether or not the nematodes were moving or inactive in an "S" or straight posture in a PETERS' one-ml counting slide under a stereomicroscope immediately after violent agitation of the vial.

Bioassay of infectivity, development and reproduction without washing. Each insecticide

was tested at 100 $\mu\text{g}/\text{ml}$ (10 $\mu\text{g}/\text{ml}$ for pyraclofos) by adding 0.05 ml of insecticide solution into a 7 ml screw vial which contained 5 ml nematode suspension (180–200 IJs per ml). After 24 h exposure to chemicals, the mixture was agitated, and a 0.4-ml aliquot was then taken out and dropped onto a 5.5-cm-d filter paper placed in a plastic cup (bottom diameter 6.0 cm). A newly-molted last instar *S. litura* was put into each cup and covered. All tests were conducted at 22°C and the mortality of insects was observed at 24, 48 and 72 h after treatment. Six days after exposure to the nematodes, each dead larva was dissected and examined for development of nematode. Nematode infectivity was assessed by the percentage of insects harboring nematodes in their bodies. Ten larvae were used for each treatment and control.

Bioassay with washing off of insecticides. After 24 h incubation at 22°C, 5 ml of nematode-insecticide suspension (250–300 IJs per ml) was diluted with distilled water to 25 ml to remove the chemical substance from the nematode body surface. After centrifugation (2,000 rpm, 2 min) three times, nematodes were collected and subjected to the bioassay described above. Each test was replicated three times with 10 insects per replication. Mortality of insects and the nematode infectivity were checked as above.

Statistical analysis. Percentages of nematode mortality were arcsine transformed to ensure normality and subjected to analysis of variance. Data were corrected for control mortality with ABBOTT's formula. Treatment means were compared by *t*-test ($p < 0.05$).

RESULTS

None of the insecticides tested had any effect on *S. carpocapsae* at 1 $\mu\text{g}/\text{ml}$ (Table 1). None of the pyrethroids, carbamates or imidacloprid had any effect even at 100 $\mu\text{g}/\text{ml}$ after 48 h of treatment. Nine OP's showed various degrees of toxicity to the nematode at 100 $\mu\text{g}/\text{ml}$ in 48 h while the other 5 (acephate, chlorpyrifos, fenitrothion, temephos and sulprofos) had a nontoxic effect. The most toxic OP's were profenofos and pyraclofos, which killed about 50% of the nematode at 100 $\mu\text{g}/\text{ml}$ in 48 h while dichlorvos, trichlorfon and prothiofos brought about 20% nematode mortality. Cartap was the most toxic of all the tested insecticides and caused as high as 83.4% mortality (48 h; 100 $\mu\text{g}/\text{ml}$).

The results of insect mortality by treatment with nematode-insecticide mixture are summarized in Table 2. Mortalities and infectivities of controls were 80–100% and nematodes developed and reproduced juveniles (Js) in insect cadavers. Most of the OP's caused low infectivity of the nematode whereas the carbamates (except methomyl) did not affect its infectivity. Pyrethroid insecticides other than cypermethrin inhibited infectivity of nematodes. Cartap completely stopped nematode infectivity, while imidacloprid had no any adverse effect to nematodes at 100 $\mu\text{g}/\text{ml}$.

Acephate, malathion, temephos, fenobucarb, metolcarb, propoxur, xylylcarb, carbosulfan, oxamyl, cypermethrin and imidacloprid had no or little effect on the nematode because both insect mortalities and nematode infectivities were high, and nematodes developed in the insect cadaver (Table 2). On the contrary, fenthion, propetamphos, profenofos, prothiofos, pyraclofos (10 $\mu\text{g}/\text{ml}$), sulprofos, methomyl, permethrin and cartap were toxic to the nematode but nontoxic to the insect because both insect mortality and nematode infectivity were very low.

Table 1. Toxicity of insecticides to infective juveniles of *S. carpocapsae*

Insecticide	Exposure (h)	Mortality (%) $\pm$ SD ^a		
		1 μ g/ml	10 μ g/ml	100 μ g/ml
Organophosphate				
Acephate	48	NS	NS	NS
Chlorpyrifos	48	NS	NS	NS
Diazinon	48	NS	NS	13.6 $\pm$ 4.3
Dichlorvos	48	NS	10.3 $\pm$ 3.6	23.6 $\pm$ 4.7
Fenitrothion	48	NS	NS	NS
Fenthion	48	NS	11.3 $\pm$ 6.7	13.7 $\pm$ 3.7
Malathion	24	NS	NS	9.6 $\pm$ 3.2
	48	NS	13.4 $\pm$ 3.3	11.8 $\pm$ 3.4
Temephos	48	NS	7.4 $\pm$ 1.8	NS
Trichlorfon	24	NS	NS	9.0 $\pm$ 2.5
	48	NS	11.1 $\pm$ 0.6	16.5 $\pm$ 3.9
Profenofos	24	NS	NS	7.6 $\pm$ 2.5
	48	NS	33.1 $\pm$ 10.8	57.1 $\pm$ 3.7
Propetamphos	48	NS	NS	11.5 $\pm$ 3.1
Prothiofos	48	NS	30.4 $\pm$ 9.2	18.3 $\pm$ 5.5
Pyraclofos	24	NS	12.7 $\pm$ 2.6	48.0 $\pm$ 4.3
	48	NS	24.8 $\pm$ 5.8	47.8 $\pm$ 5.9
Sulprofos	48	NS	NS	NS
Carbamate				
Carbosulfan	48	NS	NS	NS
Fenobucarb	48	NS	NS	NS
Methomyl	48	NS	NS	NS
Metolcarb	48	NS	NS	NS
Oxamyl	48	NS	NS	NS
Propoxur	48	NS	NS	NS
Xylylcarb	48	NS	NS	NS
Pyrethroid				
Cypermethrin	48	NS	NS	NS
Ethofenprox	48	NS	NS	NS
Fenvalerate	48	NS	NS	NS
Permethrin	48	NS	NS	NS
Cartap	48	NS	20.6 $\pm$ 5.1	83.4 $\pm$ 8.2
Imidacloprid	48	NS	NS	NS

^a Mortality of IJs was recorded by observing the nematode in a PETERS' one-ml counting slide under a stereomicroscope immediately after violently shaking the vial, and percentage of mortality was corrected with ABBOTT's formula. Where data are given, mortality was significantly different than the concurrently run distilled water control at 5% level by *t*-test. NS: nonsignificant mortality compared with the controls. Values at 24 h are not given if there was no any significant mortality.

Table 2. Mortality of *S. litura* larvae treated with mixtures of *S. carpocapsae* IJs and insecticides

Insecticide (100 µg/ml)	Mortality (%)			Infected larvae (%)	Symptom of intoxication	Nematodes in insect
	24 h	48 h	72 h			
Experiment 1						
Acephate	0	50	80	80		adult & J
Chlorpyrifos	0	10	40	10	+	adult only
Diazinon	0	0	30	10	+	adult only
Dichlorvos	0	10	60	0	+	
Fenthion	0	0	0	0		
Malathion	0	40	80	80		adult & J
Temephos	0	40	80	70		adult & J
Trichlorfon	0	0	30	0	+	
Profenofos	0	0	20	0	+	
Propetamphos	0	0	20	0	+	
Prothiofos	0	0	20	0	+	
Pyraclofos ^a	0	0	0	0		
Sulprofos	0	0	10	0	+	
Control (SC) ^b	0	80	80	80		adult & J
Experiment 2						
Carbosulfan	0	40	80	80		adult & J
Fenobucarb	0	90	100	90		adult & J
Methomyl	0	0	0	0		
Metolcarb	0	70	100	100		adult & J
Propoxur	0	70	80	80		adult & J
Xylcarb	0	50	80	60		adult & J
Cypermethrin	0	100	100	100		adult & J
Ethofenprox	0	70	100	10	+	adult only
Fenvalerate	0	100	100	50	+	adult & J
Permethrin	0	0	0	0	+	
Cartap	0	0	0	0		
Control (SC)	0	60	80	80		adult & J
Control (DW)	0	60	90	90		adult & J
Experiment 3						
Fenitrothion	3.3	80	93.3	46.7		adult & J
Oxamyl	0	86.7	93.3	86.7		adult & J
Imidacloprid	0	96.7	100	100		adult & J
Control (SC)	0	100	100	96.7		adult & J

^a Concentration of pyraclofos was 10 µg/ml.^b SC, solvent control (1% v/v); DW, distilled water.

+, intoxication of insects caused by insecticides; J, juvenile.

There were discrepancies between insect mortality and nematode infectivity in the treatments of chlorpyrifos, diazinon, dichlorvos, fenitrothion, trichlorfon, fenvalerate, and ethofenprox. The insect mortality was higher than the nematode infectivity in these treatments, and it was difficult to determine whether the insects were killed by the insecticide or the nematode, or both of them.

Table 3. Mortality of *S. litura* larvae treated with *S. carpocapsae* IJs after removal of insecticides from IJs body surface

Insecticide	Conc. ($\mu\text{g/ml}$)	Mean mortality ^a (%)			Infected larvae ^a (%)
		24 h	48 h	72 h	
Experiment 1					
Acephate	100	0	73.3	93.3	96.7
Chlorpyrifos	100	0	73.3	90	90
Diazinon	100	0	73.3	76.7	83.3
Dichlorvos	100	0	90	93.3	93.3
Fenthion	100	0	36.7	56.7	66.7
Malathion	100	0	100	100	100
Temephos	100	3.3	93.3	100	100
Trichlorfon	100	0	93.3	96.7	93.3
Profenofos	10	0	80	80	76.7
Propetamphos	10	0	86.7	93.3	96.7
Prothiofos	10	0	76.7	93.3	100
Pyraclofos	10	0	36.7	60	60
Sulprofos	10	0	70	83.3	83.3
Control (SC) ^b		0	90	96.7	96.7
Experiment 2					
Carbosulfan	100	0	90	93.3	93.3
Fenobucarb	100	0	93.3	100	100
Methomyl	100	0	63.3	80	76.7
Metolcarb	100	0	70	90	83.3
Propoxur	100	0	80	83.3	86.7
Xylylcarb	100	0	80	100	96.7
Cypermethrin	100	0	86.7	100	100
Ethofenprox	100	0	96.7	96.7	93.3
Fenvalerate	100	0	83.3	90	90
Permethrin	100	0	90	100	100
Cartap	10	0	10	13.3	3.3
Control (SC)		0	83.3	90	90
Control (DW)		0	90	96.7	96.7
Experiment 3					
Fenitrothion	100	0	90	100	90
Oxamyl	100	0	100	100	100
Imidacloprid	100	0	100	100	93.3
Control (SC)		0	96.7	96.7	100
Profenofos	100	0	3.3	13.3	10
Propetamphos	100	0	66.7	100	100
Prothiofos	100	0	86.7	100	100
Sulprofos	100	0	83.3	93.3	93.3
Control (SC)		3.3	93.3	100	100

^a Combined data of three replicates with 10 insects per replicate.^b SC, solvent control (1% v/v); DW, distilled water.

Table 4. Mortality of *S. litura* larvae treated with *S. carpocapsae* IJs and cartap solution

Conc. ($\mu\text{g/ml}$)	Mean mortality ^a (%)			Infected larvae ^a (%)
	24 h	48 h	72 h	
No washing				
1	3.3	66.7	76.7	63.3
10	3.3	6.7	13.3	0
100	0	3.3	3.3	0
Control (DW) ^b	3.3	93.3	93.3	86.7
Washing				
1	6.7	80	93.3	93.3
10	0	16.7	20	13.3
100	0	0	3.3	0
Control (DW)	3.3	93.3	100	100

^a Combined data of three replicates with 10 insects per replicate.^b DW, distilled water.

To eliminate the toxic effect of insecticides to the cutworm, we washed nematodes with water after 24 h treatment. Washing the insecticides from the body-surface of the nematodes resulted in high insect mortality as well as increased nematode penetration in most treatments (Table 3). Development and reproduction of the nematode were observed in all treatments. Only cartap (10 $\mu\text{g/ml}$) and profenofos (100 $\mu\text{g/ml}$) had strong adverse effect on the nematode, so that mortality of *S. litura* larvae was low as was nematode infectivity. Treatments of fenthion (100 $\mu\text{g/ml}$) and pyraclofos (10 $\mu\text{g/ml}$) brought ca. 60% insect mortality and 60–70% nematode infectivity while profenofos (10 $\mu\text{g/ml}$) and methomyl (100 $\mu\text{g/ml}$) had slight effects which led to insect mortality and nematode infectivity of ca. 80%.

To see the effect of insecticide, we treated the nematode with the most toxic insecticide cartap, at 1, 10, 100 $\mu\text{g/ml}$ and examined the nematode infectivity (Table 4). Cartap was obviously detrimental to the nematode at 10 and 100 $\mu\text{g/ml}$ even after the chemical was removed from the body surface of IJs. It also inhibited the nematode infectivity to some extent at 1 $\mu\text{g/ml}$ without washing.

DISCUSSION

S. carpocapsae is compatible with most of the carbamates tested and with imidacloprid at 100 $\mu\text{g/ml}$ but incompatible with most OP's and some pyrethroids. It is worth noting that profenofos, propetamphos, prothiofos, pyraclofos and sulprofos which have an asymmetric phosphorus atom in their chemical structure are toxic to *S. carpocapsae* (Tables 1, 2). Cartap is very toxic to this nematode even at low concentration. In fact, the present experiments showed that *S. carpocapsae* IJ can tolerate many insecticides at certain concentrations for a given period, and that it can regain its infectivity after the chemical is removed from its body surface, even though the effect on it by the chemical may be an adverse one (Tables 2, 3). Thus the nematode can be of practical use when the use pattern of these insecticides is altered, such as by considering the residual effects of insecticides and the buffering action of the soil (FEDORKO et al.,

1977 a, b), or by spacing the applications of nematodes and insecticides apart to allow time for insecticide degradation (HARA and KAYA, 1983 a, b).

Many insecticides caused intoxication of insect larvae when the later were treated with the nematode-insecticide mixture (shown by “+” in Table 2). Nematode infectivities were very low in these treatments (except fenvalerate), no nematode or only adult nematodes were found in the host insect. These insecticides might have been detrimental to the infective behavior of nematodes. ISHIBASHI (1993) and ISHIBASHI et al. (1994) suggested that acephate, permethrin, and oxamyl can be combined with *S. carpocapsae*. According to ISHIBASHI and TAKII (1993), insecticides such as acephate or permethrin, which keep nematodes nictating for a longer period, should be suitable for soil application, while oxamyl-type insecticide would be preferable for foliar application, because oxamyl (50–100 µg/ml) very quickly enhances the nictation behavior but precipitously reduces the behavior rate thereafter. Our experiments with permethrin did not achieve results coinciding with those of ISHIBASHI (1993), though after removal of the chemical from the body surface, nematodes had high infectivity. Our investigations with acephate and oxamyl largely support the results of ISHIBASHI et al. (1994).

The bioassay system in our experiments encountered some difficulties for the nematode mortality test because many unaffected IJs tended to remain in a quiescent, J-shaped posture (ROVESTI and DESEÖ, 1990). Malathion had no effect on nematode infectivity, development or reproduction (Table 2) though it had direct adverse effect to IJs at 10 and 100 µg/ml in 48 h (Table 1). On the contrary, although sulprofos and methomyl were nontoxic to *S. carpocapsae* IJs, both chemicals affected the infectivity and development of the nematode, and to some extent the resumption of normal undulatory locomotion after they were removed. In the present experiments, we aimed at insecticides compatible with the entomopathogenic nematode, *S. carpocapsae*, for use in integrated pest management, since it is our belief that chemical insecticides could compensate for the limited effectiveness of nematodes. Our results show that, this nematode is compatible with imidacloprid which is highly effective against sucking insects hardly being controlled by steinernematid nematodes. *S. carpocapsae* has been purported to be an ambushing search strategist (CAMPBELL and GAUGLER, 1993; ISHIBASHI, 1993) and the majority of the population after emergence from the host is immobile, staggering their period of infectivity for maintenance of the species (KAYA and GAUGLER, 1993). The relatively poor field efficacy of nematodes released in inundating numbers could be attributable to a high proportion of these inactive nematodes. Accordingly, it is desirable that chemical insecticides and nematodes be used in combination if we can find insecticides that activate or stimulate nematodes to enhance their infection of insect pests without affecting the nematode detrimentally. An improved bioassay system is required in further studies.

ACKNOWLEDGEMENTS

We are deeply indebted to Prof. N. ISHIBASHI, Laboratory of Nematology and Soil Biology, Department of Applied Biological Sciences, Saga University, for his critical reading the manuscript, and to Assoc. Prof. H. HONDA, Laboratory of Applied Zoology, Institute of Agriculture and Forestry, University of Tsukuba, for his kindly reading an earlier draft and making valuable suggestions.

REFERENCES

- CAMPBELL, J.F. and R. GAUGLER (1993) Nictation behaviour and its ecological implications in the host search strategies of entomopathogenic nematodes (Heterorhabditidae and Steinernematidae). *Behaviour* **126**: 155–169.
- FEDORKO, A., M. KAMIONEK, J. KOZLOWSKA and E. MIANOWSKA (1977 a) 8. The effects of some insecticides on nematodes of different ecological groups. *Pol. Ecol. Stud.* **3**: 79–88.
- FEDORKO, A., M. KAMIONEK, J. KOZLOWSKA and E. MIANOWSKA (1977 b) 9. The effect of vydate-oxamyl on nematodes of different ecological groups. *Pol. Ecol. Stud.* **3**: 89–93.
- HARA, A.H. and H.K. KAYA (1982) Effects of selected insecticides and nematicides on the *in vitro* development of the entomogenous nematode *Neoaplectana carpocapsae*. *J. Nematol.* **14**: 486–491.
- HARA, A.H. and H.K. KAYA (1983 a) Development of the entomogenous nematode, *Neoaplectana carpocapsae* (Rhabditida: Steinernematidae), in insecticide-killed Beet Armyworm (Lepidoptera: Noctuidae). *J. Econ. Entomol.* **76**: 423–426.
- HARA, A.H. and H.K. KAYA (1983 b) Toxicity of selected organophosphate and carbamate pesticides to infective juveniles of the entomogenous nematode *Neoaplectana carpocapsae* (Rhabditida: Steinernematidae). *Environ. Entomol.* **12**: 496–501.
- ISHIBASHI, N. (1993) Integrated control of insect pests by *Steinernema carpocapsae*. In *Nematodes and the Biological Control of Insect Pests* (R.A. BEDDING, R.J. AKHURST and H.K. KAYA, eds.). CSIRO, Victoria, Australia, pp. 105–113.
- ISHIBASHI, N. and D.R. CHOI (1991) Biological control of soil pests by mixed application of entomopathogenic and fungivorous nematodes. *J. Nematol.* **23**: 175–181.
- ISHIBASHI, N. and E. KONDO (1990) Behavior of infective juveniles. In *Entomopathogenic Nematodes in Biological Control* (R. GAUGLER and H.K. KAYA, eds.). CRC Press, Inc., Boca Raton, pp. 139–150.
- ISHIBASHI, N. and S. TAKII (1993) Effects of insecticides on movement, nictation, and infectivity of *Steinernema carpocapsae*. *J. Nematol.* **25**: 204–213.
- ISHIBASHI, N., S. TAKII and E. KONDO (1994) Infectivity of nictating juveniles of *Steinernema carpocapsae* (Rhabditida: Steinernematidae). *Jpn. J. Nematol.* **24**: 20–29.
- KAMIONEK, M. (1979) The influence of pesticides on the mortality and effectiveness of *Neoaplectana carpocapsae* WEISER. In *Proceedings of the International Colloquium on Invertebrate Pathology and 11th Annual Meeting Society for Invertebrate Pathology* (J. WEISER, ed.). Prague, Czechoslovakia, pp. 87–88.
- KAYA, H.K., R.A. BEDDING and R.J. AKHURST (1993) An overview of insect-parasitic and entomopathogenic nematodes. In *Nematodes and the Biological Control of Insect Pests* (R.A. BEDDING, R.J. AKHURST and H.K. KAYA, eds.). CSIRO, Victoria, Australia, pp. 1–10.
- KAYA, H.K. and R. GAUGLER (1993) Entomopathogenic nematodes. *Ann. Rev. Entomol.* **38**: 181–206.
- KONDO, E. (1987) Size-related susceptibility of *Spodoptera litura* (Lepidoptera: Noctuidae) larvae to entomogenous nematode, *Steinernema feltiae* (DD-136). *Appl. Entomol. Zool.* **22**: 560–569.
- KONDO, E. and N. ISHIBASHI (1989) Non-oral infection of *Steinernema feltiae* (DD-136) to the common cutworm, *Spodoptera litura* (Lepidoptera: Noctuidae). *Appl. Entomol. Zool.* **24**: 85–95.
- POINAR, G.O., Jr. (1990) Biology and taxonomy of Steinernematidae and Heterorhabditidae. In *Entomopathogenic Nematodes in Biological Control* (R. GAUGLER and H.K. KAYA, eds.). CRC Press, Inc., Boca Raton, pp. 23–61.
- PRAKASA RAO, P.S., P.K. DAS and G. PADHI (1975) Note on compatibility of DD-136 (*Neoaplectana dutkyi*), an insect parasitic nematode with some insecticides and fertilisers. *Indian J. Agric. Sci.* **45**: 275–277.
- ROVESTI, L. and K.V. DSEÖ (1990) Compatibility of chemical pesticides with the entomopathogenic nematodes, *Steinernema carpocapsae* WEISER and *S. feltiae* FILIPJEV (Nematoda: Steinernematidae). *Nematologica* **36**: 237–245.
- ZIMMERMAN, R.J. and W.S. CRANSHAW (1990) Compatibility of three entomogenous nematodes (Rhabditida) in aqueous solutions of pesticides used in turfgrass maintenance. *J. Econ. Entomol.* **83**: 97–100.