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Studies on the Insecticidal Properties of Benfuracarb against the Brown Rice Planthopper, *Nilaparvata lugens* (STÅL) (Hemiptera: Delphacidae)

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The insecticidal properties of the carbamate insecticide benfuracarb against the brown rice planthopper, *Nilaparvata lugens*, were investigated by different methods of its application, i.e., topical, foliage, plant-base drench or granular application, Parafilm test method, and root dipping method. Benfuracarb, a sulfenylated derivative of carbofuran, exhibited relatively poor insecticidal activity against the brown rice planthopper by topical or foliage treatment, representing contact action. On the other hand, the insecticidal activity of benfuracarb was higher, and comparable to its parent methylcarbamate insecticide, carbofuran, when applied by Parafilm test method, allowing the planthoppers to ingest the insecticide solution through a stretched membrane, i.e., representing direct oral toxicity. Soil treatment with benfuracarb in an aqueous solution, or in granular formulation, applied at the base of a potted rice plant, was at least as, or possibly more, effective than carbofuran because of the oral toxicity and/or systemic activity. It was determined that, on a weight basis, benfuracarb was one-eighth as effective as carbofuran under topical application, but was almost equal to it using Parafilm test method. When plant-base drench application was used, benfuracarb was as effective as carbofuran, and with granular application it was slightly superior to it. Because of its higher molecular weight, as compared to carbofuran (1.8 times greater), benfuracarb is considered to be more effective than carbofuran for soil application.

Key words: benfuracarb, insecticidal properties, brown rice planthopper, systemic activity, oral toxicity

INTRODUCTION

Benfuracarb (Oncol®, ethyl *N*-[2,3-dihydro-2,2-dimethylbenzofuran-7-yloxycarbonyl(methyl)aminothio]-*N*-isopropyl-β-alaninate, in Fig. 1) is a systemic carbamate insecticide marketed by the Otsuka Chemical Company. It is a new sulfenylated derivative of carbofuran (2,3-dihydro-2,2-dimethylbenzofuran-7-yl methylcarbamate) with outstanding insecticidal activity against a number of economically important pest insects, but with improved mammalian safety.

Previous papers from our laboratories (GOTO et al., 1983; TAKAGI, 1989) described the excellent insecticidal action of benfuracarb for a wide range of insects infesting

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rice, maize, sugar beet, vegetable and other major food crops. The reports also mentioned the preliminary work on insecticidal properties of benfuracarb against rice-paddy pests, including the brown rice planthopper. In continuing studies on the insecticidal properties of benfuracarb, we have investigated its insecticidal action against brown rice planthopper by different application methods, i.e., topical, foliage, plant-base drench or granular applications, Parafilm test method, and root dipping method. The results indicate that the insecticidal activity against brown rice planthopper depends greatly on differences in the application method and on the mode of intake of the active ingredient into the insects. This paper describes these interesting insecticidal properties of the benfuracarb against the brown rice planthopper.

MATERIALS AND METHODS

Insects. The brown rice planthopper, *Nilaparvata lugens*, used in this study was received from the Kagawa Agricultural Experimental Station in 1981. This strain of the planthopper was collected at Takamatsu, Kagawa Pref. in 1980. Brown rice planthoppers were reared on rice seedlings, renewed weekly, at 25±1°C, 16L–8D. Macropterous female adults, 3–5 days after emergence were used throughout the experiment.

Chemicals. Benfuracarb, technical grade (93%), was synthesized in our research center, and 5% granules (G) were formulated from the technical material. Carbofuran (95%) was prepared by extracting the active ingredient from commercially available 5% granules. Propoxur (2-isopropoxyphenyl *N*-methylcarbamate, 99%), BPMC (2-*sec*-butylphenyl *N*-methylcarbamate, 99%), isoprocarb (*O*-cumenyl *N*-methylcarbamate, 99%), diazinon (*O,O*-diethyl *O*-2-isopropyl-6-methylpyrimidin-4-yl phosphorothioate, 99%) and fenitrothion (*O,O*-dimethyl *O*-(3-methyl-4-nitrophenyl)phosphorothioate, 99%) were purchased from Wako Pure Chemical Industries, Ltd., Osaka, Japan. Diazinon 5G and ethylthiometon 5G were purchased from a commercial source.

Determination of insecticidal activity by topical application. An aliquot (0.25 μl) of an acetone solution of each compound was topically applied with an Arnold Hand Microapplicator to the dorsal abdomen of each of ten female adults planthoppers (3–5 d after emergence). The treated planthoppers were placed into a plastic cup (8 (φ)×4 cm) with two rice seedlings (about 15 cm height) whose root portion was wrapped with waters-absorbing cotton. Mortality was determined after 24 h. Data are the means of six replications.

Determination of insecticidal activity by foliage treatment of plants in pots. Ten milliliters of a 5% acetone solution containing each test compound at pre-determined concentration were sprayed with a spray gun (Piece bon PB-408, Olympos Co., Ltd.) onto

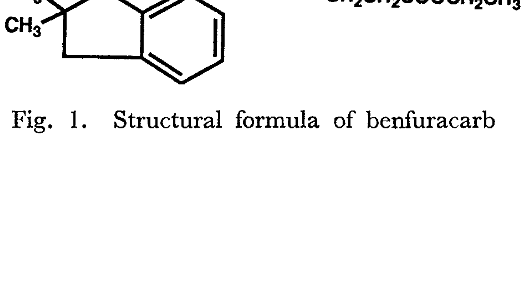

Fig. 1. Structural formula of benfuracarb

25-d-old rice seedlings (five plants per pot, about 14–15 cm ht., 2.5 leaf stage) contained in 12 cm (ϕ) pots. To prevent the absorption of the insecticide through the roots, the soil in the pots was covered with paper-towel material. Each potted plant was then covered with a stainless-steel mesh cage (12 (ϕ) $\times$ 30 cm) and ten female planthoppers were introduced into it. The pots with cages were kept in a greenhouse (25$\pm$1°C, 16L–8D) during the test. Mortality was determined 48 h after the release of the insects. Data are the means of three replications.

Determination of insecticidal activity by Parafilm test method. Five female brown rice planthoppers, anesthetized with carbon dioxide, were placed in a Petri dish (5 cm ϕ), which was then covered with stretched Parafilm M (American National Can TM). On the film, 0.5 ml of each of several 5% sugar solutions containing different concentrations of the insecticide were dropped onto the film, and then a second piece of Parafilm was stretched over the first, completely enclosing the solution between the two Parafilm membranes. The insects were allowed to ingest the insecticide-containing sugar solution through the stretched Parafilm membrane. The Petri dishes were kept at 25$\pm$1°C, 16L–8D for 48 h. Mortality was determined after 24 and 48 h with six replications.

Determination of insecticidal activity by root dipping method. The insecticidal effectiveness of each chemical which was absorbed into the rice plant through its root was determined as follows: An aqueous solution (7.5 ml each) of each test chemical was added into a glass sample container (2.2 (ϕ) $\times$ 4.0 cm) into which two rice seedlings (about 15 cm ht., 2.5 leaf stage) had been placed. A glass tube (2.2 (ϕ) $\times$ 16 cm) was placed on the top of the sample container making the total length of the glass cylinder 20 cm, and the rice plants were attached to the inner wall of the cylinder by wrapping the stem of the plant by absorbent cotton. In this case, only the root portion of the rice plant was allowed to dip into the aqueous solution. The joint between the glass container and the tube was secured with tape. After the release of five planthoppers into the cylinder, its top was covered with cheese cloth. The cylinders were held at 25$\pm$1°C, 16L–8D for 48 h and mortality was determined in four replications.

Determination of insecticidal activity by plant-base drench application. Ten milliliters of diluted solution of each insecticide was used to drench the soil around the 25-d-old rice seedlings (five plants per pot, about 15 cm height with 2.5 leaves) in 9 cm (ϕ) pots. To avoid the contact action of the insecticide on the soil, the soil surface was covered by absorbent cotton. Each plant and pot was then covered with a stainless-steel mesh cage (9 (ϕ) $\times$ 30 cm) and was kept in a greenhouse (25$\pm$1°C, 16L–8D) during the test period. Ten brown rice planthoppers were released into the cage 1, 5 and 14 d after the treatment, and 24 h mortality was determined in six replications.

Determination of insecticidal action by granular application on potted rice plant. Granular formulations of each type of insecticide (60–120 g/box) were applied to the rice seedlings (at 2.5 leaves stage) in a nursery box (30 cm $\times$ 60 cm), followed by watering to allow the insecticide to be uniformly distributed on the surface of the soil. After 1 h, five of the rice seedlings with their insecticide-treated soil were transferred into a Wagner pot (20 (ϕ) $\times$ 30 cm ht.) which was kept in a greenhouse at 15–32°C. The pot was covered with a stainless-steel mesh cage (20 (ϕ) $\times$ 60 cm ht.) 22 d after the transplanting, and ten planthoppers were released into the cage. Mortality was determined 24 h after the release of planthoppers with six replications.

RESULTS

1. Insecticidal activity of benfuracarb by contact action

The topical LD_{50} values of benfuracarb along with other insecticides against the brown rice planthopper are given in Table 1. The LD_{50} of benfuracarb was 8.5 μg/g and was one-eighth as active as the parent methylcarbamate, carbofuran (1.1 μg/g). When the LD_{50} value was compared with other methylcarbamate insecticides, benfuracarb was seen to be twice as active as BPMC, the same as isoprocarb, and half as effective as propoxur. These results indicate relatively poor insecticidal activity of benfuracarb by direct contact action against the brown rice planthopper.

The insecticidal action of benfuracarb by foliage treatment was also relatively poor. Table 2 summarizes the insecticidal activity of benfuracarb and related carbamates when applied to the foliage of rice seedlings. In that case, insecticidal activity is considered to occur primarily by contact action, even though some oral toxicity by sucking may take place also. The mortality of the planthopper from benfuracarb spraying at concentrations of 500, 250 and 125 ppm was 67, 37 and 17%, respectively, being significantly less active than carbofuran, but superior to BPMC.

Table 1. Insecticidal activity of benfuracarb and other insecticides against brown rice planthopper by topical application

Insecticide	LD_{50}[a] (μg/g insect)
Benfuracarb	8.52 (6.82–10.7)
Carbofuran	1.12 (0.93–1.34)
Propoxur	4.33 (3.33–5.63)
BPMC	15.9 (11.78–21.5)
Isoprocarb	9.72 (7.48–12.7)
Diazinon	49.7 (35.5–69.6)

[a] Figures in parentheses indicate 95% confidence limits.

Table 2. Insecticidal activity of benfuracarb and other insecticides against brown rice planthopper by foliage application

Insecticide	Concentration (ppm)	Mortality (%)
Benfuracarb	500	67
	250	37
	125	17
Carbofuran	500	100
	250	90
	125	73
BPMC	500	27
	250	17
	125	10
Untreated	—	0

Table 3. LC_{50} values (ppm) of benfuracarb and carbofuran against brown rice planthopper determined by Parafilm test method

Insecticide	LC_{50} (ppm)[a]	
	24 h	48 h
Benfuracarb	41.3 (34.0–57.8)	38.4 (27.6–53.4)
Carbofuran	39.4 (30.3–51.2)	29.1 (22.4–40.7)

[a] Figures in parentheses indicate 95% confidence limits.

Table 4. Insecticidal activity of benfuracarb and carbofuran against brown rice planthopper determined by root dipping method

Insecticide	Concentration (ppm)	Mortality (%)
Benfuracarb	50	40
	25	20
	12.5	0
Carbofuran	50	85
	25	70
	12.5	50
Untreated	—	5

2. *Oral toxicity of benfuracarb*

Oral toxicity of benfuracarb against the brown rice planthopper was determined by three different methods, i.e., Parafilm test method, root dipping method, and plant-base drench application.

Table 3 shows LC_{50} values of benfuracarb and carbofuran against the brown rice planthopper by Parafilm test method. The LC_{50} of benfuracarb at 24 and 48 h was 41 and 38 ppm, respectively, being equal to that of the carbofuran at 24 h (39 ppm), and slightly less active at 48 h (29 ppm). The results indicate that, unlike topical or foliage application, insecticidal activity of benfuracarb is comparable to that of carbofuran by Parafilm test method.

Table 4 summarizes the insecticidal activity of benfuracarb and carbofuran against the brown rice planthoppers that were fed rice seedlings treated with an aqueous solution of each insecticide applied by the root dipping method. The results showed that benfuracarb is 2 to 3.5 times less active than carbofuran applied by this method, although the difference in the activity between benfuracarb and carbofuran is significantly smaller than in the case of topical application.

In contrast with the unexpectedly poor insecticidal efficiency of the root dipping method, benfuracarb applied by drenching the soil with an aqueous solution of each insecticide around the foot of potted rice plants was observed to be highly effective. Table 5 gives mortalities of the brown rice planthopper treated with benfuracarb and other insecticides by soil-drench method. Application of 10 ml of 25 to 100 ppm of benfuracarb solution was highly effective against the brown rice planthopper, being equal in action to carbofuran during the entire test period (1 to 14 d after the application), and more active than propoxur at the same dosage during later test periods (5 and 14 d). Thus, benfuracarb proved to possess excellent insecticidal activity with systemic action against brown rice planthopper when its aqueous solution was applied to the soil under the host plants.

Table 5. Mortality of brown rice planthopper 24 h after release onto rice plants in pots 1, 5 and 14 days after treatment with benfuracarb and other insecticides by plant-base drench application

Insecticide	Dose[a] (ppm)	Mortality (%)		
		1 d	5 d	14 d
Benfuracarb	100	97	100	100
	50	87	97	93
	25	73	87	77
Carbofuran	100	100	100	100
	50	93	97	93
	25	87	93	77
Propoxur	100	100	100	93
	50	100	93	57
	25	83	73	27
Untreated	—	0	0	0

[a] Aqueous solution (10 ml each) of each insecticide was used to drench the soil around rice seedlings in 9 cm (ϕ) pots.

Table 6. Mortality of brown rice planthopper released on potted rice plants 22 days after granular application (nursery box treatment) of benfuracarb and other insecticides

Insecticide	Dose (g/box)	Mortality[a] (%)
Benfuracarb (5G)	80	96.7 (92.1–100)
	60	93.3 (87.0–99.7)
Carbofuran (5G)	80	86.7 (78.1–95.3)
Ethylthiometon (5G)	120	73.3 (62.1–84.5)
	80	83.3 (73.9–92.8)
	60	40.0 (27.6–52.4)
Diazinon (5G)	120	3.33 (0–7.88)

[a] Twenty four hours after release of the insect.
Figures in parentheses indicate 95% confidence limits.

3. Efficacy of benfuracarb by granular application

In order to investigate the insecticidal activity of benfuracarb by practical application, efficacy testing was conducted using granular formulation. Table 6 summarizes the mortality of the brown rice planthopper released onto potted rice plants 22 d after application of granular benfuracarb and other insecticides. Benfuracarb 5% granules (5G) was very effective, with 97 and 93% mortalities being obtained at dosages of 80 and 60 g/box, respectively. The effectiveness of benfuracarb 5G was equal, or even slightly superior to that of carbofuran 5G on a weight basis, and substantially greater than ethylthiometone 5G and diazinon 5G. These results indicate that benfuracarb with granular formulation exhibits excellent systemic activity against the brown rice planthopper.

DISCUSSION

Benfuracarb is a procarbamate insecticide (Umetsu, 1992) and therefore is considered to be an intrinsically inactive compound, but is altered either biologically or chemically to an intrinsically active substance, i.e., carbofuran or its related compounds (Usui and Umetsu, 1986). In fact, using whole-body preparations of the brown rice planthopper, benfuracarb proved to be a poor anticholinesterase (1/12th of carbofuran, Goto et al., 1983) which is responsible for the toxic action of the carbamate insecticides.

In order to evaluate the usefulness of benfuracarb as a rice paddy field insecticide, its insecticidal properties against the brown rice planthopper, one of the most important rice pests in Japan, were investigated by different application methods. Topical and foliage applications are useful in evaluating the contact action of benfuracarb. Parafilm test method, root dipping method, and plant-base drench application were adopted to evaluate the oral toxicity and/or systemic activity. Testing by granular application was conducted to assess the overall activity of benfuracarb.

The current study clearly indicated that the oral toxicity of benfuracarb, as measured by Parafilm test method, plant-base drench or granular application, was higher than the contact activity determined by topical or foliage application methods. Benfuracarb was particularly effective against brown rice planthopper via the leaves of rice plants when it was applied to the soil around the base of the plant. It is interesting to note that benfuracarb was, on a weight basis, one-eighth as effective as its parent methylcarbamate insecticide, carbofuran by topical application, but was almost equal to it using Parafilm test method. When plant-base drench application was used, benfuracarb was as effective as carbofuran, and with granular application it was slightly superior to it. Because of its higher molecular weight (1.8 times that of carbofuran), benfuracarb is considered to be more effective than carbofuran for soil application. Recent report from our laboratory (OSAKI et al., 1992) exposed the factor responsible for the higher insecticidal efficacy of benfuracarb when applied to the soil. The study on the mechanism involved in the enhanced efficacy of benfuracarb as compared with carbofuran indicates that the active ingredient(s) in the benfuracarb-treated soil either had low mobility, or was immobile, and, therefore, would be retained for longer periods. These soil properties of benfuracarb, combined with its excellent systemic activity (UMETSU et al., 1985), probably result in a higher ratio of absorption by the crop of the active ingredient from the benfuracarb-treated soil.

Brown rice planthopper migrating form Southeast Asia is one of the difficult pests to control owing to its very high multiplication ability. Because of its excellent insecticidal activity as proved by the current study using the nursery box treatment, the benfuracarb is a promising agent for the control, or suppression, of the brown rice planthopper at an early stage of infestation of rice plants in paddy fields. Further studies are currently in progress.

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