[The Great Lakes Entomologist](https://scholar.valpo.edu/tgle)

Volume 23
Number 1 - Spring 1990 *Number 1 - Spring 1990*

Article 6

April 1990

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Araya, J. E.; Foster, J. E.; Schreiber, M. M.; and Wing, R. E. 1990. "Residual Action of Slow Release Systemic Insecticides on *Rhopalosiphum Padi* (Homoptera: Aphididae) on Wheat," *The Great Lakes Entomologist*, vol 23 (1)
DOI: https://doi.org/10.22543/0090-0222.1690
Available at: https://scholar.valpo.edu/tgle/vol23/iss1/6

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RESIDUAL ACTION OF SLOW RELEASE SYSTEMIC INSECTICIDES ON *RHOPALOSIPHUM PADI* (HOMOPTERA: APHIDIDAE) ON WHEAT[1]

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ABSTRACT

Slow release formulations of acephate and carbofuran encapsulated in pearl cornstarch or corn flour granules were applied to the soil at seeding time of potted 'Caldwell' wheat in the laboratory. Dosages of these insecticides were adjusted to a standard of 10 kg/ha of a 10% granular formulation of carbofuran. The residual action of these insecticide treatments against *Rhopalosiphum padi* were compared with those obtained with that of carbofuran 15G at corresponding dosages and foliar sprays of solutions of acephate (25% EC) at 0.2% and carbofuran (4F) at 1.25%, applied 12 d after seedling emergence. The residual action of carbofuran 15G, which controlled *R. padi* since seedling emergence, lasted 28.5 d. The slow release granular formulations of carbofuran began to provide control (>50% aphid mortality) on days 13.3 and 17.9 after seeding. They controlled the insect until days 31.6 and 35.5 after seeding. The two corresponding granular formulations of acephate began to provide control on days 15.0 and 17.0 after seeding and controlled the aphids until days 31.5 and 32.8 after seeding. The foliar sprays of acephate and carbofuran provided control for 18.3 and 36.2 d from application, respectively. The slow release granular formulations provided control of *R. padi*, an important vector of barley yellow dwarf virus, during early stages of wheat development.

The bird cherry-oat aphid, *Rhopalosiphum padi* (L.), is one of the most important insect pests of wheat in the United States and throughout the world (Araya et al. 1986). This insect may damage wheat crops, both by feeding and by transmitting barley yellow dwarf virus (BYDV) (Gill 1980). The damage is particularly severe

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[1]Mention of a proprietary product does not constitute an endorsement or a recommendation for its use by the U.S. Dept. of Agriculture. Purdue University Agr. Exp. Stn. Journal Paper No. 11,626.

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Published by ValpoScholar, 1990

The Great Lakes Entomologist, Vol. 23, No. 1 [1990], Art. 6

when winter wheat seedlings are colonized by migrant alates during the fall (Endo and Brown 1963, Araya et al. 1987).

Economic infestations of cereal aphids can be controlled easily with foliage sprays of diverse insecticides. However, most insecticide sprays cause heavy mortality to the beneficial fauna (van Rensburg 1978, Hellpap 1982). When the crops are sprayed at early stages, most of the insecticide does not reach the seedlings and is lost to the environment. Soil application of systemic pesticides requires minimal energy input and quantities of formulated chemicals and produces little human and ecological exposure (Gabrielson and Getzin 1979). The release of insecticide from granular formulations varies, depending on the dosage and type of material used as a carrier. The insecticide is absorbed once the roots begin to grow, protecting the crop against insects for variable time periods depending upon the insecticide and dosage used. Early and selective protection against aphids in small grains has been obtained with granular formulations of systemic insecticides applied at seeding (De Pew 1974, Arretz and Araya 1980).

In the greenhouse, with 2 min of daily soaking, slow release tablets formulated by Oetting et al. (1984) released 87% of acephate, a broad-spectrum organophosphorous systemic insecticide of moderate persistence, in 7 d. The tablets provided efficacy and residual control of the chrysanthemum aphid, *Macrosiphoniella sanborni* (Gillete), and citrus mealybug, *Planococcus citri* (Risso), equivalent to other formulations of acephate. Acephate is relatively non-toxic to non-target species (Sanders et al. 1983, Zinkl et al. 1984), and causes minimal adverse effects on diverse insect parasitoids (Flanders et al. 1984, Hsieh and Allen 1986).

Kitayama and Luzes (1987) increased the residual action of granular aldicarb and carbofuran by conditioning the insecticide granules in gelatin capsules, which liberated the active ingredients slowly and continuously for more efficient and longer protection of the target plants than was obtained with traditional granular formulations. Carbofuran is a water soluble and broad-specrum carbamate systemic insecticide, acaricide and nematicide, which is used against foliage feeding insects, mites and soil pests. Carbofuran is highly toxic to non-target organisms (Stoner et al. 1982, Heiss and Meisch 1985). Because of the destruction of natural enemies, carbofuran sprays may favor resurgence of pests (Heinrichs et al. 1982). However, carbofuran granules applied by Gholson et al. (1978) on Iowa cornfields caused lower carabid beetle mortalities than did carbofuran sprays.

Recently, slow release formulations of chemically modified pearl starch have proved effective as encapsulating matrices for systemic herbicides, such as butylate (Wing et al. 1987a), and other bioactive compounds (Shasha et al. 1984, Trimnell et al. 1985). Aqueous gelatinization of pearl cornstarch at high temperatures followed by addition of active ingredients, drying and grinding, has yielded encapsulated products that release the active agent slowly. The release rate of active ingredients from a starch matrix can be controlled by regulating the degree of association of starch macromolecules in the matrix (Wing et al. 1987b). The encapsulated products are superior to non-encapsulated commercial formulations in extending residual activity (Coffman and Gentner 1980), reducing evaporative and degradative losses (Schreiber et al. 1987), leaching (Baur 1980), and dermal toxicity of the active ingredient (Riley 1983).

The objectives of our laboratory experiment were to evaluate the residual action of acephate and carbofuran encapsulated in chemically modified pearl starch or corn flour granules applied to the soil at seeding of wheat against *R. padi*. The results have been evaluated with reference to the potential control of this important insect vector of BYDV on winter wheat. Acephate and carbofuran were selected because of their water solubility, widespread use, and disappearance from the environment (Szeto et al. 1979, Gorder et al. 1982, Frank et al. 1984, Read 1986). Granular formulations were used because of their reported safety to beneficial arthropods (Gohlson et al. 1978, Heiss and Meisch 1985).

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DOI: 10.22543/0090-0222.1690

MATERIALS AND METHODS

Five seeds of 'Caldwell' wheat (35% of the wheat acreage in the eastern soft red winter wheat region of the U.S.) were seeded in 9.5 cm diameter plastic pots filled with sterile soil (1/3 sand, 1/3 peat moss, 1/3 top soil), with five replicates per treatment. The seedlings were thinned to 2 per pot soon after emergence. The pots were maintained at 18°C and 14:10 light:dark photoperiod. The insecticide treatments, formulations, and dosages used were:

- Acephate (Orthene®) in pearl starch granules (10.1% AI), applied at seeding (6.71 mg per pot).
- Acephate in corn flour granules (9.7% AI), applied at seeding (6.98 mg per pot).
- Acephate as emulsifiable concentrate (25% EC), 5.92 cc per pot (1 fl. oz. per 5 pots) of a 0.2% solution sprayed onto 1–2 leaf seedlings, 16 d after seeding (12 d after seedling emergence).
- Carbofuran (Furadan®) in pearl starch granules (8.1% AI), applied at seeding (8.36 mg per pot).
- Carbofuran in corn flour granules (8.3% AI), applied at seeding (8.16 mg per pot).
- Carbofuran as flowable material (4F), 5.92 cc per pot of a 1.25% solution sprayed onto 1–2 leaf seedlings, 16 d after seeding (12 d after seedling emergence).
- Carbofuran 15G, applied at seeding (4.52 mg per pot).
- Control without insecticide.

All granular dosages were adjusted to a standard dosage of 10 kg/ha of a 10% granular formulation of carbofuran. Foliar sprays were applied in 1.97 cc insecticide solution per pot. The dosages of the granular formulations were mixed with sterile soil. These mixtures were incorporated into the upper layer of the soil of the respective pots. The plants were watered by subirrigation, and the pots were maintained on separate flats to avoid contamination.

Starting with 2–3 leaf stage seedlings, and after the foliage spray treatments had dried on the leaves, ten aviruliferous last instar nymphs of laboratory reared *R. padi* were placed on one of the seedlings of each pot (replicate). Transparent plastic cups (4.0 cm base diameter; 2.5 cm top diameter; 2.0 cm tall), with the bottom exposed to part of a leaf on each seedling and the top covered with porous paper, were used to confine the aphids to the plants (Araya and Foster 1987).

Mortality was recorded after 48 h, removing by hand all the aphids (dead and alive) from the cups. Fresh aphids were put into the cups at 5-day intervals. A different leaf was exposed to the aphids each time. Mortality counts were started on the same day in all treatments and were continued until average mortality values were below or near 50% were obtained in all the treatments. The natural mortality in the untreated controls was corrected by use of Abbott's formula (Abbott 1925).

The results were analyzed with analysis of variance after the data were transformed by arcsin $\sqrt{\%\text{ mortality}}$ (Steel and Torrie 1960). Significantly different means ($P \leq 0.05$) were separated by Duncan's multiple range test (Duncan 1955). Percentage mortality also was analyzed using 3rd degree polynomial regressions (Arretz et al. 1980, Araya and Foster 1987). This method facilitates the estimation of the residual action of an insecticide treatment (period with $>50\%$ mortality).

RESULTS AND DISCUSSION

The percentage mortality for each insecticide treatment was larger than the percentage mortality observed on the control plants, with wide variations among treatments (Table 1). The treatment that caused the greatest aphid mortality over the longest period of time was the foliar spray of carbofuran. The wide amplitude of the significant differences in percentage mortality observed on the first dates tended to decrease after the first month of seedling emergence. After eliminating the natural

Table 1.—Mortality means (%) obtained with diverse insecticide treatments against *Rhopalosiphum padi* on 'Caldwell' wheat in the laboratory[1]

	Days after emergence / plant growth stages[1]							
Treatments	14/1	19/2	24/3	29/3-4	34/4	39/4-5	44/5	49/5-6
Acephate, pearl starch	16.0f	66.0c	100.0a	72.0b	34.0e	30.0c	28.0bc	20.0c
Acephate, corn flour	58.0c	68.0c	82.0c	56.0c	58.0bc	34.0bc	26.0bc	18.0c
Acephate, EC	100.0a	88.0b	76.0c	62.0c	48.0cd	42.0b	34.0b	26.0b
Carbofuran, pearl starch	22.0e	60.0c	74.0c	94.0a	62.0b	32.0bc	30.0b	22.0bc
Carbofuran, corn flour	34.0d	100.0a	80.0c	60.0c	44.0de	24.0c	32.0b	24.0bc
Carbofuran, F	98.0a	100.0a	100.0a	96.0a	84.0a	78.0a	84.0a	52.0a
Carbofuran, 15G	86.0b	98.0a	92.0b	72.0b	52.0cd	36.0b	28.0bc	18.0bc
Control, no insecticide	6.0g	14.0d	30.0d	14.0d	10.0f	12.0d	20.0c	16.0c

[1]Means in the same column followed with different letters are significantly different ($P \leq = .005$), according to ANOVAs and Duncan (1955) multiple range tests. Foliage sprays were applied 2 d before first mortality reading. Plant growth stages as in Feekes scale (Large 1954).

mortality (Abbott 1925), the mortalities over time were regressed (Fig. 1), for obtaining the residual insecticide periods for each treatment against *R. padi*, which are presented in Fig. 2. The equations used for the curvilinear regressions in Fig. 1 and their coefficients of correlation are presented in Table 2. For calculating the residual periods of all treatments, 3rd degree polynomial equations were selected, because of their high coefficients of correlation.

The insecticide treatment with the longest residual action against *R. padi* (36.2 d) was carbofuran sprayed onto the foliage 16 d after seedling emergence. This result was expected, given the relatively high dosage, for obtaining a maximum residual action for comparison purposes, at which carbofuran was applied. This dosage is not recommended for field applications, in order to avoid damage to beneficial insects. Foliar sprays at lower dosages of carbofuran, however, as reported on sorghum by Smith et al. (1985) have provided > 90% control of greenbug, *Schizaphis graminum* (Rodani), at rates as low as 0.28 kg AI/ha, while conserving beneficial insect populations.

All the other insecticide treatments were relatively similar in their residual action against *R. padi*. The commercial formulation (15G) of carbofuran was the only one that controlled the aphid from the emergence of the seedlings. Its residual action lasted 28.5 d from emergence.

The high mortality obtained with carbofuran 15G was evident immediately after emergence; that obtained with the other granular formulations were initially low. This rules out a delayed mortality because of initially small root systems incapable of absorbing enough insecticide (Fig. 1). The delayed mortality obtained with the slow release formulations may have been due to a delay in the release of the insecticides. Under field conditions, emerging seedlings may not be attractive for migrating aphids (Klingauf 1987), and thus, the initial 10 d without significant systemic insecticide protection would not be too critical for the crop. As the seedlings become attractive for the aphids, these treatments would be effective against the insects in the field. The protection periods obtained in our study with the formulations of acephate in pearl starch or corn flour granules were 15.8 and 16.5 d, respectively. Those obtained with the corresponding granular formulations of carbofuran were of 17.6 and 18.3 d. These residual periods were relatively similar to the protection obtained with the foliage spray of acephate (18.3 d). We estimated that protection periods of 2–2.5 wk during the initial growth stages of winter wheat against *R. padi*

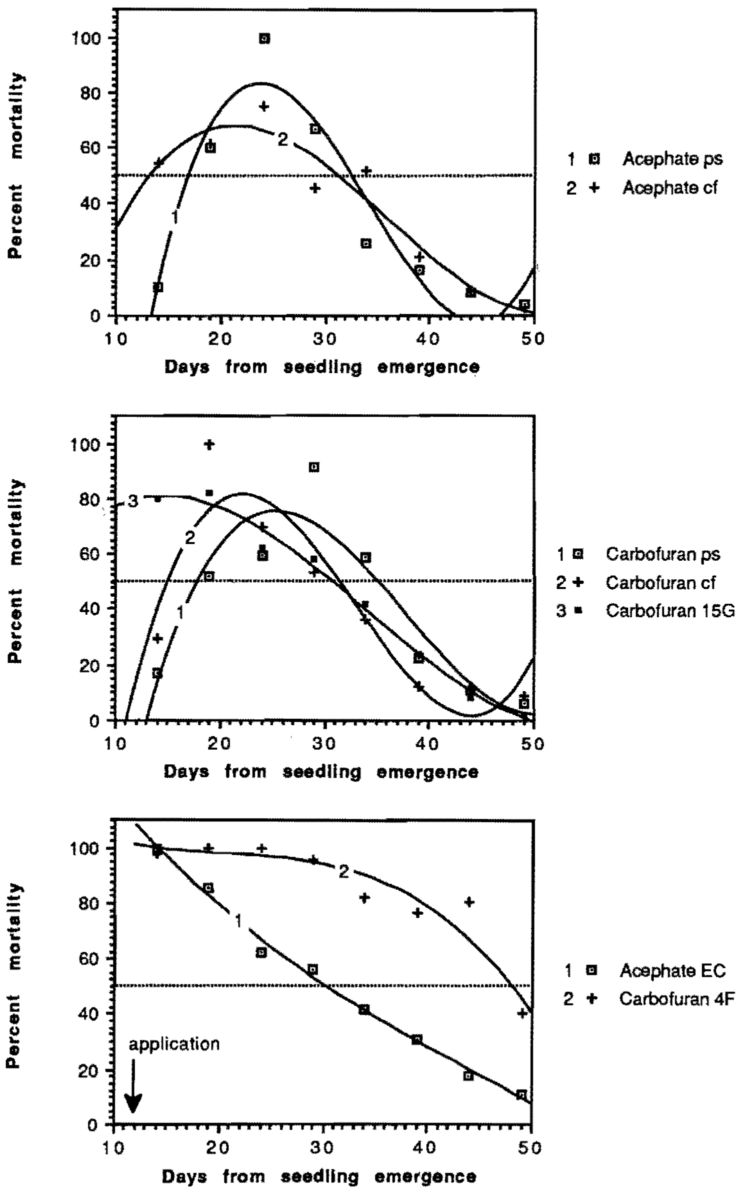

Figure 1. Curvilinear regressions (3rd degree polynomial equations) of the mortality of *Rhopalosiphum padi* over time obtained with several insecticide treatments on 'Caldwell' wheat in the laboratory.

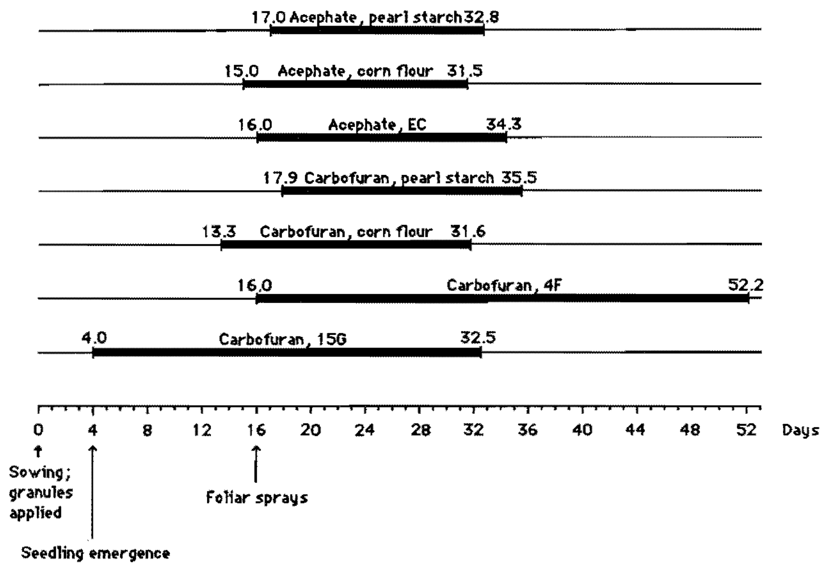

Figure 2. Days of residual action (mortality > 50%) against *Rhopalosiphum padi* obtained with several insecticide treatments on 'Caldwell' wheat in the laboratory.

Table 2.—Polynomial equations, with their coefficients of correlation, used for the curvilinear regressions in Figure 1, of the mortality obtained with diverse insecticide treatments against *Rhopalosiphum padi* on 'Caldwell' wheat in the laboratory.[1]

Treatments	3rd degree polynomial equations ($Y = A + BX + CX^2 + DX^3$)	R^2
Acephate pearl starch	$y = -497.8282 + 59.4279x - 1.9146x^2 + 0.0186x^3$	0.96
Acephate corn flour	$y = -87.7015 + 16.9244x - 0.5621x^2 - 0.0052x^3$	0.96
Acephate EC	$y = 108.5286 - 4.1021x + 0.06x^2 - 0.0005695x^3$	1.00
Carbofuran pearl starch	$y = -323.1319 + 37.6706x - 1.1164x^2 + 0.0099x^3$	0.93
Carbofuran corn flour	$y = -330.7736 + 44.6279x - 1.5120x^2 + 0.0152x^3$	0.93
Carbofuran F	$y = 100.9640 - 0.6950x + 0.0528x^2 - 0.00200x^3$	0.94
Carbofuran 10G	$y = 37.1004 + 6.5736x - 0.2858x^2 + 0.00280x^3$	0.99

[1]Foliage sprays applied 2 d before first mortality reading. Original data transformed (Abbott 1925) for eliminating natural mortality of control treatment without insecticides. y = % mortality; x = days from seedling emergence.

could be very important, particularly in relation with the greatest susceptibility of the seedlings to infection with BYDV (Endo and Brown 1963, Araya et al. 1987).

Our study showed results comparable to those reported in the literature for diverse aphid species. For example, seed treatments with carbofuran at equivalent dosages provided up to 29 d of residual action against *R. padi* (Araya and Foster 1987). Also, in-furrow, planting-time treatments of carbofuran, terbufos, bendiocarb or acephate and seed treatments of carbofuran by Mize et al. (1980) con-

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trolled greenbug on seedling sorghum for up to 30 d after planting. In a comparative test in a glasshouse, granular carbofuran, granular aldicarb and acephate water-soluble powder as post transplant applications were compared by Eulitz (1985) for control of *Myzus persicae* (Sulzer) on tobacco. Carbofuran, aldicarb, and acephate controlled aphids for 36, 25, and 12 d, respectively. In greenhouse studies, Eulitz (1984) controlled *M. persicae* for 29–31 d on two soils with acephate 5%G at 3.75 g product/potted tobacco plant (equivalent to a high dosage of 7.5 kg acephate/ha). Sprays of acephate 75% SP at 1 kg product/500 l/ha controlled the aphids for 13–18 d. Infestations of grain sorghum by *R. maidis* (Fitch) were significantly reduced by van Rensburg et al. (1978) and van Rensburg and Malan (1983) with granular carbofuran to the soil.

Overall, insecticide treatments of acephate and carbofuran encapsulated in cornstarch granular formulations applied at seeding time began to provide control of *R. padi* on wheat about 2 wk after seeding. The residual action of these treatments lasted for about 2.5 wk, demonstrating the potential value of systemic insecticides encapsulated in cornstarch granules for controlling selectively *R. padi* and other insect vectors of barley yellow dwarf virus in the field, particularly at early stages of wheat development. Further laboratory and field studies with various dosages of systemic insecticides encapsulated in granules of the cornstarch materials used in this study against cereal aphids are necessary. The rate of insecticide release from the encapsulated materials has to be considered when preparing granular formulations.

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https://scholar.valpo.edu/tgle/vol23/iss1/6
DOI: 10.22543/0090-0222.1690

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