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Molluscicidal seed treatment of barley, wheat and perennial ryegrass to control the field slug (*Deroceras reticulatum*)

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Abstract

The effects on the field slug (*Deroceras reticulatum* (Müller)) of treating seeds of barley, wheat and perennial ryegrass were investigated in laboratory experiments. Barley seeds were treated with metaldehyde and methiocarb, wheat seeds with metaldehyde, methiocarb, neem oil (azadirachtin) and saponins, and perennial ryegrass seeds with metaldehyde, methiocarb and thiocyclam hydrogen oxalate. These compounds were tested at several rates.

Metaldehyde was the most effective treatment in preventing slug damage to the seeds and seedlings. The level of protection against slugs at 0.8 g a.i. kg^{-1} barley and 1.6 g a.i. kg^{-1} wheat seeds was insufficient, but 1.6 g a.i. kg^{-1} (barley) and 3.2 g a.i. kg^{-1} (wheat) gave good protection for up to 10 and 6 days respectively after sowing. Metaldehyde at 160 g a.i. kg^{-1} perennial ryegrass seed also gave sufficient protection against the field slug.

Keywords: slugs, *Deroceras reticulatum*, barley, wheat, perennial ryegrass, seed treatment, metaldehyde, methiocarb, neem oil, azadirachtin, saponins, thiocyclam hydrogen oxalate, phytotoxicity, laboratory tests.

Introduction

Slugs damage cereals by hollowing out newly-sown seed and by severing the shoots of seedlings underground (Glen *et al.*, 1989). Damage continues after crop emergence, with characteristic shredding of leaves, but this damage is usually less severe than damage to seeds and seedlings. Slugs do not attack the seeds of perennial ryegrass but they do consume shoots of seedlings. Slug damage to winter cereals and ryegrass is a real problem for growers in The Netherlands, particularly in regions with heavy marine clay soils. These soils are favourable to slugs because they are very moisture retentive and their cloddy structure provides ideal hiding places (Glen *et al.*, 1993; South, 1992). Slug damage has become more serious in recent years, be-

cause populations can build up quickly where green manure crops or bulky old crop residues are used as part of a soil management programme.

To date, farmers have been able to protect their crops against slugs to a certain extent by spreading pelleted baits containing metaldehyde, methiocarb or thiodicarb, although when slug populations are high and conditions favour slug activity, pellets are unreliable and it may be necessary to re-drill winter cereals or ryegrass (Ester & Darwinkel, 1993). The pelleted baits are applied when drilling the cereal and grass seeds by mixing the bait with the seeds (cereals) and, in the case of cereals when plants emerge. Pellets are often applied in winter too, depending on slug population density and activity. In case of perennial ryegrass, when slug damage has been observed, any control application will be too late (Ester & Darwinkel, 1993).

The formulations are not always reliable because the pellets disintegrate in wet weather. Therefore there is a need for a more direct control method in the form of a seed treatment using a chemical which either poisons or repels slugs. Gould (1962) tested some copper salts and metaldehyde as seed treatments, and found that they gave only limited control and caused problems of phytotoxicity. Scott *et al.* (1977) and Symonds (1975) reported a laboratory test in which seeds treated with thioacetimidate or methiocarb at 0.2% a.i./wt of seed suppressed feeding and killed more than half the slugs. However, as far as we know, this never resulted in a commercial seed treatment, possibly because the effective pesticides were phytotoxic, or because the optimal dosages were not ascertained in the trials.

The laboratory experiments described in this paper were designed to investigate the efficacy of different molluscicides as seed treatments for barley, wheat and perennial ryegrass.

Materials and methods

Active ingredients used

Of the four chemicals tested, only methiocarb and metaldehyde are known as molluscicides (Worthing & Walker, 1987). We used a 50% liquid formulation (Mesurol FS) of methiocarb and a 80% WP dry powder formulation of metaldehyde. Thiocyclam hydrogen oxalate 50% dry powder formulation (Evisect S) (hereafter referred to as thiocyclam) is known as an insecticide, with slug repellent action (Port & Port, 1986; Ester & Nijënstein, 1995).

Neem oil, a product from the neem tree, has azadirachtin as its active ingredient. We tested a 95% formulation of neem oil. The product had previously been tested by West & Mordue (1992). The fourth chemical tested, saponin, is obtained by polishing *Chenopodium quinoa* seeds. Whereas the seeds contain 25–30% saponins, the polish contains 50% saponins. The product used in our tests was very coarsely ground, and not ready for use in routine seed treatment procedures. Saponin seems to act as a molluscicide by making plasma membranes permeable (Price *et al.*, 1987).

All experiments were carried out in a randomized block design. Statistical analysis was performed with the Genstat statistical package. Data were not transformed.

Seeds and seed treatment

All seeds were provided by Cebeco Zaden b.v.. Seed treatments were applied to 50 gram (grasses) or 500 gram (cereals) lots of seed in a plastic bag, to which the pesticide and 2–5% water were added. The bag was then shaken vigorously to ensure uniform distribution. After treatment the seeds were allowed to dry for two days in a cupboard in the laboratory, with a built in fume extractor, after which the seeds were stored at 10°C and 40%RH. The dosages used in our experiments are based on preliminary studies, which were not published.

Seed of the perennial ryegrass (*Lolium perenne*) cultivar Carat was used in the experiment. Its moisture content was 10.9%, the thousand kernel weight was 2.1 g, purity 99.9% and the germination percentage was 97%. The cereal seed used, was of spring wheat cultivar Baldus and spring barley cultivar Prisma, which have thousand kernel weights of 38 and 52 g respectively. A fungicide (Beret – active ingredient fenpiclonil – at 2 g a.i. kg^{-1} seed) and a coating agent (Nacret at 2 g a.i. kg^{-1} seed) were applied together with the molluscicides.

Experiments were first carried out on barley, using methiocarb and metaldehyde. Later, when saponin and azadirachtin became available, they were tested on wheat, together with the metiocarb and metaldehyde treatments that had proved most effective on barley.

Laboratory experiments with slugs

All experiments were conducted with field slugs (*Deroceras reticulatum* (Müller)) weighing 400–600 mg, collected from traps on a clover field at the Experimental Station in Lelystad. Unhealthy looking slugs were rejected. Following collection the slugs were deprived of food for four days at 15°C and a dark/light cycle of 10/14 hours. After this period no material from the field remains in the slug, so the faeces produced in the experiments were green. None of the pesticides used in our experiments has been authorized for seed treatment in The Netherlands. Special permission was obtained to use them in this screening programme.

Experiments were carried out in a growth chamber at a constant temperature, in earthenware pots 20 cm in diameter and 18 cm deep. Peat compost was put in the pots to a depth of 7 cm and then covered with 2 cm of silversand. The surface of the sand was 177 cm^2. The pots were covered with a polyethylene gauze of 1.35 × 1.35 mm to prevent the slugs from escaping.

In order to maintain the moisture of the silversand at field capacity, the pots were placed in plastic boxes measuring 30 × 45 × 13 cm with 2 cm tapwater. These boxes, each containing two pots, were covered with a transparent lid. This resulted in a relative humidity of 85–90% inside the boxes.

The ryegrass seeds were sown in five concentric circles of eight seeds per pot and then covered with 0.5 cm silversand. When at least 80% of the seedlings had emerged and were 7 to 10 cm tall the pots were stored at 5°C. When no more seedlings emerged (11 days after sowing) the trial started.

The ryegrass experiment was carried out in three replicates, this means three pots

of 40 seeds each, with four slugs per pot in January 1995 at 16 °C. The assessment of seedlings attacked by slugs was made one and four days after the trial started. Percentages of seedlings attacked were calculated on the basis of the maximum number of plants present when the trial started.

For the experiments with barley, 40 seeds per pot were also sown in concentric circles, and left uncovered on the sand. Four replicates (four pots per treatment) with five slugs per pot were used. During the experiments, which started in March 1995, temperatures were 14–15 °C. The slugs were added to the pots two days after sowing the seeds. The assessment of attacked seeds was made four and ten days after the trial started. The number of faeces per pot were counted after four days.

The wheat experiment was carried out at a temperature of 17 °C in June 1995. The assessment of attacked seeds was made two and six days after the trial started. The number of faeces per pot was counted after six days. Other details are as described for barley.

Germination

The pots were placed in a greenhouse with 12 hours light and a temperature of 15/25 °C. Germination percentages of perennial ryegrass were established by counting the seedlings that had emerged before the slugs were added.

Results

Barley experiment

Efficacy of molluscicides

When seeds are not protected, slugs hollow out the seeds completely. A growing point 0.5 cm long is often present, but because no roots are left the plants die.

On days four and ten it was found that all seed treatments containing metaldehyde and methiocarb had effectively protected the seeds and seedlings of barley against slug damage (Table 1). However, on day four methiocarb and the lowest rate of metaldehyde, were found to be slightly less effective than higher rates of metaldehyde. By day ten methiocarb no longer protected the seedlings. In the case of metaldehyde, only the lowest rate of 0.8 g a.i. kg^{-1} did not give full protection by day ten.

The number of faeces produced correlated very well with the percentage of seeds attacked.

Germination

Seeds in this experiment with slugs showed excellent germination without any phytotoxicity resulting from the two molluscicides tested, metaldehyde and methiocarb (Table 1).

Table 1. Percentage of barley seeds attacked by the field slug; the percentage of non germinated seed and the average number of faeces per pot after four days.

Molluscicide	g a.i. kg^{-1} seed	Seeds attacked (%) after ... days four	Seeds attacked (%) after ... days ten	Faeces (no.)	Non germinated seeds
Untreated	–	99	98	24	1
Metaldehyde	0.8	17	54	1	0
Metaldehyde	1.6	5	18	0	4
Metaldehyde	2.4	3	8	0	1
Metaldehyde	3.2	2	8	0	1
Metaldehyde	4.0	1	7	1	1
Metaldehyde	4.8	0	6	0	3
Metaldehyde	6.4	0	12	0	2
Metaldehyde	8.0	3	13	0	4
Methiocarb	1.0	20	94	21	1
LSD ($\alpha = 0.05$)		8	17.3	8	2.5
F-prob.		<.001	<.001	<.001	0.008

Wheat experiment

Efficacy of pesticides

As with barley, metaldehyde was very effective. Until day four methiocarb and all rates of metaldehyde protected wheat seeds and seedlings (Table 2). Saponin at the highest rate slightly reduced damage by slugs on day two, but had no effect by day six. Azadirachtin was not effective at all, either on day two or on day six.

On day six methiocarb still protected wheat against slug damage. On day six met-

Table 2. Percentage of wheat seeds attacked by the field slug and the average number of faeces per pot after six days.

Pesticide	g a.i. kg^{-1} seed	Seeds attacked (%) after .. days two	Seeds attacked (%) after .. days six	Faeces (no.)
Untreated	–	54	100	97
Metaldehyde	1.6	10	83	95
Metaldehyde	3.2	3	29	14
Metaldehyde	4.8	2	28	10
Metaldehyde	6.4	1	12	3
Methiocarb	1.0	10	10	21
Azadirachtin	3.8	54	100	110
Azadirachtin	19.0	41	99	91
Saponin	2.0	50	100	111
Saponin	10.0	28	99	104
LSD ($\alpha = 0.05$)		14	9	37
F-prob.		<.001	<.001	<.001

Table 3. Control of field slug in perennial ryegrass. Percentage of plants attacked after one and six days; germination percentage 12 days after drilling.

Pesticide	g a.i. kg^{-1} seed	Percentage attacked after ... days		Germination
		one	six	
Untreated	–	92	99	93
Metaldehyde	160	22	24	92
Metaldehyde	240	34	36	100
Metaldehyde	320	30	33	100
Methiocarb	100	82	96	88
Methiocarb	150	82	84	84
Methiocarb	200	81	87	92
Thiocyclam	75	87	97	68
Thiocyclam	100	67	69	49
Thiocyclam	125	72	92	38
LSD ($\alpha = 0.05$)		34	26	17
F-prob.		0.001	<.001	<.001

aldehyde showed a dose-response effect (Table 2), and only metaldehyde at 6.4. g a.i. kg^{-1} acted at the same level as at day two. Rates of 3.2 and 4.8 g a.i. kg^{-1} still reduced the attacks by slugs considerably, but 1.6 g a.i. kg^{-1} gave insufficient protection.

Again, the number of faeces produced correlated very well with the percentage of seeds attacked.

Perrenial ryegrass experiment

Efficacy of pesticides

After just one day metaldehyde was the only chemical that was able to protect ryegrass seedlings (Table 3). The level of protection did not fall between day one and day six. Methiocarb and thiocyclam were not effective at all.

Germination

None of the treatments containing metaldehyde and methiocarb appeared to be phytotoxic. All rates of thiocyclam were very phytotoxic (Table 3).

Discussion

Of the active ingredients we tested, metaldehyde was the most effective for all three crops. This compound is toxic to slugs when ingested and absorbed by the foot of the mollusc. It increases the secretion of slime, causing immobilization and eventual death by dehydration (Cremlyn, 1991). In our experiments with barley and wheat seeds treated with metaldehyde, slugs crawled over the treated seeds and probably took up the metaldehyde through their feet.

Gould (1962) used metaldehyde at a rate of approximately 10 g a.i. kg^{-1}, and found this rate to be very effective against slugs for up to ten days, in boxes and in the field. Charlton (1978) treated *Trifolium* and *Lotus* with methiocarb, and also found good protection against slugs. Scott *et al.* (1977, 1984) found that methiocarb exerted some control, but metaldehyde was completely ineffective in their experiments. However, our experiments show that the rates at which metadehyde was used should have been a little higher.

Metaldehyde on barley was effective at 1.6 g a.i. kg^{-1}, but was less effective on wheat, even at 3.2 g kg^{-1}. This may be due to differences in systemicity, but also to different conditions during the experiments (e.g. temperature, degree of starvation of slugs), or to differences in palatability between barley and wheat.

Products from the neem tree, like azadirachtin are very effective in controlling insect pests (Ruskin, 1992). West & Mordue(1992) tested azadirachtin as a seedling treatment on barley plants using solutions of 25–500 mg L^{-1} applied to leaves or to the base of the stem at soil level. They did not find any significant effect against four kinds of slugs. This is in accordance with our results.

Saponin, a botanical pesticide from *Chenopodium*, is one of the new natural molluscicides. Its efficacy in controlling water snails had previously been investigated by Hostettmann *et al.* (1982). When used to treat wheat seeds we found a slight dose-response effect after 48 hours, but after six days the saponin appeared to be ineffective. Gaffner *et al.* (1985) reported molluscicidal activity of a saponin against snails, applied at a rate of 1.5 mg L^{-1} in water. The different methods of application may account for the efficacy differing between their experiment and ours. Hostettmann *et al.* (1982) found differences in molluscicidal activity between monodesmosidic triterpenoid saponins which acted very strongly, and bidesmosidic saponins and aglycones, which were completely inactive. It is possible that our sample contained inactive saponins of this type.

The saponin powder formulation we used was too coarse for seed dressing, and resulted in an uneven seed-to-seed distribution. A more finely ground formulation might enhance the efficacy of saponin.

Covering the perennial ryegrass with 0.5 cm sand meant that the slugs were not in direct contact with the treated seeds; nevertheless the slugs also produced much slime and were immobilized, and some died. In this particular crop the metaldehyde reached the soil water and was transported to the sand surface and came into contact with the foot of the slug. It is also possible that the metaldehyde was taken up by the seedlings and slugs came in contact with it via the plants. This phenomenon of exuding much slime was observed at all rates of metaldehyde, but for barley and wheat seeds treated at the lowest rate, less slime was assessed.

In some cases perennial ryegrass plants from seeds treated with metaldehyde were attacked. They were cut off just above the coleoptilum of the seedling, but not eaten. However, untreated plants were attacked and eaten fully. From this we infer that the coleoptilum of the plant contained a higher dose of metaldehyde than the cutted leaves.

Ryegrass requires a rate that is 50–100 times higher than that is required by cereals. This may in part be due to differences in seed mass, or to differences in systemicity or method of sowing.

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