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**PROJECT REPORT No. OS54**

**SEED DRESSINGS TO CONTROL SLUG DAMAGE  
IN OILSEED RAPE**

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## **SEED DRESSINGS TO CONTROL SLUG DAMAGE IN OILSEED RAPE**

by

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## **ABSTRACT**

### **Aims**

Slugs are major pests of oilseed rape that are poorly controlled by conventional bait pellets.

The project had the overall aim of developing oilseed rape seed-treatments containing either molluscicides or feeding deterrents that will give protection against slug damage equivalent to, or better than molluscicidal pellets.

The specific objectives were:

- To determine levels of methiocarb, metaldehyde, cinnamamide and 3,5-dimethoxycinnamic acid (DMCA) that provide maximum protection to seedlings, from *Deroceras reticulatum* slugs, without causing phytotoxicity.
- To compare the efficacy of the above four compounds in terms of damage reduction and potential cost.
- To compare efficacy in laboratory bioassays of the most promising formulation identified above with conventional molluscicidal pellets.

### **Results and conclusions**

Metaldehyde and methiocarb were not phytotoxic at any doses, whereas all doses of cinnamamide and DMCA were. All compounds reduced slug damage, but metaldehyde and methiocarb consistently performed better than cinnamamide and DMCA. Metaldehyde and methiocarb seed-treatments were compared with baited pellets containing the same active ingredients at recommended field doses. The seed-dressings protected plants from damage by the grey field slug, *Deroceras reticulatum*, and the dusky slug, *Arion subfuscus*, as well as, or better than baited pellets.

### **Implications for levy payers**

This was a pilot study to identify if slug damage to oilseed rape can be controlled with seed-treatments. Seed-treatments allow better targeting of the active ingredient, reduce the amount of active ingredient applied, and avoid a separate field-pass for pesticide application. In addition, unlike slug pellets that are broadcast on the soil surface, coated seeds may be drilled below ground, making the active ingredient less available to wildlife. Thus, the cost of slug control to growers and the environment could be reduced. Both metaldehyde and methiocarb show considerable promise as a seed-treatment for controlling slug damage. We therefore recommend that metaldehyde and methiocarb should be field-tested as seed dressings to control slugs in oilseed rape.

## SUMMARY

### Introduction

Slugs are a serious pest of oilseed rape, damaging seedlings immediately after emergence, killing the plant and thus reducing plant stand. Slug pellets often fail to give adequate protection against slugs for several reasons: a) the active ingredients are known to be repellent to slugs, and slugs stop feeding prior to ingesting a lethal dose, b) the pellets break down quickly in wet weather (when slugs are most active) and become unavailable, c) pellets can become covered by soil after heavy rain as a result of rain-splash. In addition, molluscicide pellets lying on the soil surface pose a hazard to wildlife. Farming practices such as minimal cultivation and lower seed application rates are becoming more popular, in order to lower costs of establishment. However, these methods make crops vulnerable to slug damage. Therefore, greater control over slug damage, with better targeting of the active ingredients, is required.

A seed treatment of a molluscicide or repellent could be one alternative to bait pellets, and may have many economic and environmental advantages. Seed coatings allow better targeting of the active ingredient, reduces the amount of active ingredient applied, and a separate field-pass for pesticide application is avoided. In addition, unlike slug pellets that are broadcast on the soil surface, coated seeds would be drilled below ground, making the active ingredient less available to wildlife. Thus, the cost of slug control to growers and the environment could be reduced.

Previous work on seed treatments to control slug damage have focussed on protecting seeds as opposed to seedlings, with the most promising chemicals being metaldehyde, methiocarb and the non-lethal invertebrate feeding deterrents cinnamamide and 3,5-dimethoxycinnamic acid (DMCA). However, slugs do not feed on oilseed rape seeds, instead causing most damage to newly emerged seedlings. Recent work in the Netherlands has demonstrated that coating wheat seedlings with molluscicides protects not only the seed, but also the emerged seedling.

This study aimed to build on this work to develop a seed coating to protect oilseed rape seedlings from slug attack. We tested four compounds (metaldehyde, methiocarb cinnamamide and DMCA), over a range of doses, in seed coatings to control damage by the grey field slug, *Deroceras reticulatum*, and phytotoxicity to oilseed rape seedlings. The most promising compounds, at optimum doses, were then compared with conventional

molluscicidal bait pellets for ability to protect oilseed rape seedlings from grey field slugs, *D reticulatum* and dusky slugs, *Arion subfuscus*.

## **Materials and Methods**

### *Seed Treatment*

Oilseed rape seeds (cv. Pronto, a low glucosinolate variety) were coated in 20 g lots with either metaldehyde, methiocarb, cinnamamide or DMCA, mixed with a commercial seed adhesive, Sepiret. Control seeds were coated with seed adhesive only, at the same application rate as treated seeds. Seeds were mixed until an even distribution of the coloured seed adhesive was observed. Seeds were air dried overnight and stored in the dark until required.

Doses used were based on those found to be most effective in previously published studies on wheat. These were then adapted to oilseed rape (cv. Pronto), to give the same mass of active ingredient per seeds. A higher and lower dose were also tested so that final application rates were, metaldehyde - 5.8, 18 and 58g a.i./kg seed, methiocarb - 1.8, 5.8 and 18g a.i./kg seed, cinnamamide - 10, 32 and 100g a.i./kg seed, and DMCA - 11, 35 and 111g a.i./kg seed.

### *Phytotoxicity assessments*

Two methods were used to determine germination percentages: a) the International Seed Testing Association (ISTA) method, and b) a soil tray method, the same set-up used in bioassays.

ISTA: The ISTA-method consist of 20 seeds placed in concentric circles of 10, 6 and 4, in a 145 mm petri dish on top of grade 1, qualitative, 125 mm filter paper. 5 ml of tap water was added to the petri dishes, which were then placed in the light at room temperature. The experiment had a fully randomised design, with six replicates. Germination was recorded weekly for two weeks. Seed tray method: Sixty treated seeds were sown in seed trays (220 × 165 × 57 mm) containing John Innes No. 2 potting compost.

Seeds were covered with 1 cm of air dried soil (loamy sand texture) that was moistened with 175 ml of tap water. A clear plastic propagator lid, with ventilation holes, was fitted to each seed tray and sealed at the edges. Seed trays were placed in a controlled temperature room in early experiments, and a glass house or cold frame in later experiments. All experiments had fully randomised design, each with six replicates. Numbers of seeds germinated were recorded at weekly intervals for 4 weeks.

### *Efficacy of seed treatments to control slug damage*

Comparison of four active ingredients: Seed trays were prepared, as previously described, with the seeds being protected with 1 cm of soil to ensure slugs could not come into contact with the seeds. Six replicate trays of control seeds or seeds coated with metaldehyde, methiocarb, cinnamamide or DMCA were prepared. Four field-collected adult *D. reticulatum* (mean biomass per tray = 0.7g) were added immediately after sowing. Weekly assessments, from the day of planting, of slug damage and slug mortality were recorded for 4 weeks. Slug damage to seedlings was assessed as either fatal (loss of apical meristem) or as grazing damage.

Comparison of seed treatments with slug bait pellets: For comparison of seed treatments to slug pellets the optimum doses of metaldehyde (58g a.i./kg seed) and methiocarb (18g a.i./kg seed) were tested against metaldehyde slug pellets (Metarex Green, 6%, recommended application rate 8kg/ha, De Sangosse, UK) and methiocarb slug pellets (Draza, 4%, recommended application rate 5.5kg/ha, Bayer, UK). Seeds for slug pellet treatments were coated with Sepiret seed adhesive only. Seed trays were prepared and planted as previously described. Slugs were added immediately after sowing. Slug pellets were added at the manufacturers recommended dose, according to the area of the seed tray, of 25.2mg for metaldehyde pellets and 17.6mg for methiocarb pellets, per seed tray 3 days after sowing. The experiment had a fully randomised design, with six replicates. Slug damage and slug mortality were as previously described. Two experiments were performed, one using four field collected *D. reticulatum* per tray (mean biomass = 0.7 g/tray), and another using four field collected *A. subfuscus* per tray (mean biomass = 3.3 g/tray). Slug damage and mortality was assessed as previously described.

## **Results**

### *Phytotoxicity assessments*

In the ISTA germination test the lowest dose of cinnamamide did not reduce germination, but the two higher doses and all doses of DMCA were phytotoxic. However, no metaldehyde or methiocarb treatments reduced germination compared with control seeds. As with the ISTA method, the seed tray germination method showed no evidence of phytotoxicity for any metaldehyde or methiocarb treatments. Both cinnamamide and DMCA were phytotoxic at all doses causing significant reductions in germination compared with control seeds.

### *Slug damage experiments*

All doses of metaldehyde and methiocarb seed treatments significantly reduced slug damage compared with control treatments. In treatments containing feeding deterrents, the lowest of cinnamamide and highest doses of both cinnamamide and DMCA significantly reduced slug damage compared with control treatments. But in both cases, damage was significantly greater than the two highest doses of metaldehyde and methiocarb.

### *Comparison with slug bait pellets*

*Deroceras reticulatum* - Control seed trays had significantly more plants damaged by slugs compared with all other treatments. No differences in slug damage were found between slug bait pellet and seed-treatment methods of controlling slug damage.

*Arion subfuscus* - Least slug damage was found in metaldehyde seed treatment trays, in comparison to both slug bait pellets treatments, methiocarb seed-treatments and control treatments. Methiocarb seed treatments had significantly fewer damaged plants compared with both control and metaldehyde pellet treatments.

## **Discussion and implications**

It is often found in seed treatments that phytotoxicity and efficacy are related, with higher doses offering greater protection, but often increased phytotoxicity. It is therefore necessary to obtain equilibrium where the efficacy of the chemical is balanced with its potential phytotoxicity. In our experiments, both ISTA and seed tray methods of testing germination revealed metaldehyde and methiocarb seed-treatments to have no phytotoxic effects on oilseed rape. In contrast, all tested doses of cinnamamide and DMCA were phytotoxic.

Both metaldehyde and methiocarb seed treatments offered good protection to oilseed rape seedlings at doses with no phytotoxic effects, and therefore show considerable promise as a seed treatment. Cinnamamide and DMCA offered low protection against slug damage, and were very phytotoxic to oilseed rape, and therefore show no potential as a seed dressing for oilseed rape, from our findings.

In our laboratory experiments, metaldehyde and methiocarb seed treatments protected seedlings as well as or better than bait pellets. Differences between damage caused by the two slug species were noticeable in the two experiments comparing slug bait pellets to seed treatments. *A. subfuscus* caused greater damage to seedlings in all treatments, and were less



effected by bait pellets, in comparison to *D. reticulatum*. These differences are probably a result of the greater biomass of the *A. subfuscus* slugs.

This was a pilot study to identify if slug damage to oilseed rape can be controlled with seed-treatments. Seed-treatments allow better targeting of the active ingredient, reduce the amount of active ingredient applied, and avoid a separate field-pass for pesticide application. In addition, unlike slug pellets that are broadcast on the soil surface, coated seeds could be drilled below ground, making the active ingredient less available to wildlife. Thus, the cost of slug control to growers and the environment could be reduced. Both metaldehyde and methiocarb show considerable promise as a seed-treatment for controlling slug damage from our laboratory tests. We therefore recommend that metaldehyde and methiocarb should be field-tested as seed dressings to control slugs in oilseed rape.

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**Seed Dressings to Control Slug Damage in Oilseed Rape**

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## ABSTRACT

Slugs are major pests of oilseed rape that are poorly controlled by conventional bait pellets. A series of laboratory experiments investigated the potential of seed-dressings to control slug damage in this crop. Four compounds: metaldehyde, methiocarb, cinnamamide and 3,5-dimethoxycinnamic acid (DMCA) were tested at a range of doses for phytotoxicity and ability to reduce damage by *Deroceras reticulatum*. Metaldehyde and methiocarb were not phytotoxic at any doses, whereas all doses of cinnamamide and DMCA were. All compounds reduced slug damage, but metaldehyde and methiocarb consistently performed better than cinnamamide and DMCA. Metaldehyde and methiocarb seed-dressings were compared with baited pellets containing the same active ingredients at recommended field doses. The seed-dressings protected plants from damage by *Deroceras reticulatum* and *Arion subfuscus* as well as, or better than baited pellets. We therefore recommend that metaldehyde and methiocarb should be field-tested as seed dressings to control slugs in oilseed rape.

**Keywords:** Slugs, Oilseed Rape, Seed Dressing, Molluscicides, Feeding Deterrents, Laboratory Tests.

## 1 INTRODUCTION

Slugs are a serious pest of oilseed rape in the UK and other parts of Western Europe.<sup>1,2</sup> Plants are most at risk at the seedling stage when slugs feeding immediately after emergence kill plants and reduce plant stand.<sup>3</sup> Damage to oilseed rape has increased with the introduction of low glucosinolate varieties, which are more palatable to slugs.<sup>4</sup>

Current control methods rely primarily on chemical molluscicides (usually metaldehyde or carbamates) formulated into baited pellets that are broadcast either shortly before or after drilling. This form of control frequently fails to protect crops, and growers often make several molluscicide applications or even have to re-drill crops.<sup>5</sup> There are many reasons for failure of pelleted baits. Firstly, adequate water solubility of the bait in water is required for contact activity, but this conflicts with the need for persistence under damp conditions when slugs are most active.<sup>6</sup> Secondly, pelleted baits can become covered in soil during heavy rain and thus hidden from slugs. Thirdly, because active ingredients are repellent, slugs may stop feeding before ingesting a lethal dose.<sup>7</sup> There are also important environmental hazards of broadcasting slug baits on the soil surface as they are accessible to wildlife. Metaldehyde is toxic to vertebrates and poisoning of cats, dogs, sheep and poultry has been reported on several occasions.<sup>8</sup> Methiocarb has also been implicated in the poisoning of pets, livestock and vertebrate wildlife.<sup>10,11,12</sup> In addition, methiocarb can be toxic to beneficial invertebrates (e.g. carabid beetles,<sup>13</sup>) which are important predators of slugs and other pests.<sup>14,15</sup> Thus alternative methods to control slug damage that have better targeting of the active ingredients are needed.

One alternative to bait pellets is seed dressing. This has many economic and environmental advantages. Coating rape seeds with a molluscicide or repellent could protect the seed and the seedling at its most vulnerable stage, if the compound was systemic or if it could adhere to the emerging cotyledons. All plants would be equally protected and the disadvantages of pellets discussed above would not apply. The cost to the growers would be reduced, as a separate field pass for broadcasting baits would be avoided. This would also reduce the risk of wheeling damage. The amount of active ingredient may also be reduced lowering costs and environmental impact.

Seed dressing to control slug damage has not been tested on oilseed rape, but it has been shown to be effective in other crops. The more promising compounds include the molluscicides metaldehyde,<sup>16-20</sup> and methiocarb,<sup>21-24</sup> and the non-lethal vertebrate feeding deterrents cinnamamide and 3,5-dimethoxycinnamic acid (DMCA).<sup>25</sup> Most of these studies coated wheat seeds but other crops including rye grass, barley and legumes have been tested.<sup>17,18,20,21</sup> All the previous studies focused on seed dressing to control slug damage to seeds as opposed to seedlings. However, slugs do not feed on oilseed rape seeds, but do cause significant damage to newly emerged seedlings. Furthermore, studies have shown that seedlings were also protected by the molluscicides metaldehyde and methiocarb, thus demonstrating either a degree of systemic action or adherence to the cotyledon cuticle.<sup>17,20</sup> Nijenstein and Ester noticed that seedlings with seed dressing of metaldehyde or methiocarb, when damaged, were often cut but not eaten, suggesting that these active ingredients exert a repellent action towards slugs.<sup>20</sup> The main aim of a seed treatment, unlike slug bait, is to deter slugs from feeding on the crop, and not necessarily to kill the slug.

This study aimed to identify compounds that could be used as seed dressings to protect oilseed rape seedlings from slug damage. We tested four compounds (metaldehyde, methiocarb, cinnamamide and DMCA) that had shown promise in the research already described. Initially we investigated potential phytotoxicity to oilseed rape of these compounds, over a range of doses, by two methods: the official International Seed Testing Association (ISTA) method,<sup>26</sup> and a soil based method. These compounds and doses were also tested for their ability to protect oilseed rape seedlings from slug damage by *Deroceras reticulatum* (Müller). Optimum doses of the most promising compounds were then compared with conventional molluscicidal bait pellets (both metaldehyde and methiocarb based) for protecting oilseed rape seedlings. These experiments used two important species of slug pests. *D. reticulatum*, the most widespread agricultural pest, and *Arion subfuscus* (Draparnaud) a common agricultural pest in the UK.

## **2 MATERIALS AND METHODS**

### **2.1 Slug collection and storage**

Adult *D. reticulatum* and *A. subfuscus* were field collected with traps baited with wheat. Slugs were kept at 15°C in clear plastic boxes, containing moist cotton wool until required. Slugs were fed on a mixture of 50% oat breakfast cereal (Ready Brek, Weetabix Ltd, Kettering, UK), 25% dried milk and 25% calcium carbonate, moistened with water, and were deprived of food for 4 to 7 days before the start of experiments.

### **2.2 Seed Treatment**

Oilseed rape seeds (cv. Pronto, a low glucosinolate variety) were coated in 20 – 50 g lots with either metaldehyde, methiocarb, cinnamamide or DMCA, mixed with a commercial seed adhesive, Sepiret (Agrichem, Whittlesey, UK). Control seeds had a Sepiret seed adhesive coating only, at the same application rate as treated seeds. Seeds were mixed until an even distribution of the coloured adhesive was observed. The seeds were then air-dried overnight and stored in the dark until required.

Doses tested were calculated based on the most effective doses found by Nijënstein and Ester for metaldehyde and methiocarb,<sup>20</sup> and by Watkins *et al.* for cinnamamide and DMCA.<sup>25</sup> These were then adapted to our cultivar of oilseed rape according to the thousand-grain weight, to give the same mass of active ingredient per seed. A higher and lower dose were also tested so that final application doses were: metaldehyde - 5.8, 18 and 58 g a.i./kg seed, methiocarb - 1.8, 5.8 and 18 g a.i./kg seed, cinnamamide - 10, 32 and 100 g a.i./kg seed, and DMCA - 11, 35 and 111 g a.i./kg seed.

### **2.3 Phytotoxicity assessments**

Germination percentages were determined by two methods: a) the ISTA method,<sup>26</sup> and b) a soil tray method, that was also used in bioassays.

### 2.3.1 ISTA

The ISTA-method comprised six replicates of 20 seeds placed in concentric circles of 10, 6 and 4, in a 145 mm petri dish on top of a grade 1, qualitative, 125 mm filter paper. 5 ml of tap water was added to the petri dishes, which were then placed in the light at room temperature. Germination was recorded weekly for two weeks.

### 2.3.2 Seed tray method

Seed trays (220 × 165 × 57 mm) containing John Innes No. 2 potting compost were sown with 60 treated seeds. Seeds were covered with 1 cm of air-dried soil (loamy sand texture), moistened with 175 ml of tap water. Each seed tray was fitted with a clear plastic propagator lid with ventilation holes. Propagator lids were then sealed at the edges. In early experiments seed trays were placed in a controlled temperature room, but in later experiments a glass-house or cold frame was used. All experiments had fully a randomised design, each with six replicates. The number of seeds that had emerged was recorded at weekly intervals for 4 weeks.

## 2.4 Comparison of four active ingredients in controlling slug damage

Seed trays were prepared, as above, with the seeds being covered with 1 cm of soil to ensure that slugs could not come into contact with the seeds. Six replicate trays of control seeds or seeds coated with metaldehyde, methiocarb, cinnamamide or DMCA were prepared. Four adult *D. reticulatum* (mean biomass per tray = 0.7 g, s.e. 0.007 g) were added immediately after sowing. Slugs were thus deprived of food for a further 2 to 3 days while the seeds germinated.

Slug damage and slug mortality were assessed at weekly intervals from the day of planting, for 4 weeks. Slug damage to seedlings was recorded as either fatal (loss of apical meristem) or as non-fatal grazing damage.

## 2.5 Comparison with slug bait pellets

For a comparison between seed dressings and slug pellets, the optimum doses of metaldehyde (58 g a.i./kg seed) and methiocarb (18 g a.i./kg seed) were tested against metaldehyde slug pellets (Metarex Green, 6%, recommended application rate 8 kg product ha<sup>-1</sup>, De Sangosse, UK) and methiocarb slug pellets (Draza, 4%, recommended application rate 5.5 kg product ha<sup>-1</sup>, Bayer, UK). Seeds for slug pellet treatments were treated with Sepiret seed adhesive only. Seed trays were prepared and planted as previously described. Slug pellets were added 3 days after sowing at the recommended dose, based on the area of the seed tray. 25.2 mg per tray of metaldehyde pellets and 17.6 mg per tray of for methiocarb pellets were used. The experiment had a fully randomised design, with six replicates. Slug damage and slug mortality were assessed as previously described.

Two experiments were done, one using four *D. reticulatum* per tray (mean biomass = 0.7 g, s.e. 0.005 g), a second using four *A. subfuscus* per tray (mean biomass = 3.3 g, s.e. 0.011 g).

## 2.6 Statistical analysis

Statistical analyses were performed with Genstat 5 (Numerical Algorithms Group, Oxford). All data were subject to analysis of variance (ANOVA) and when ANOVA revealed significant treatment effects or interactions, individual means were compared using the LSD test.

## 3 RESULTS

### 3.1 Phytotoxicity assessments

In the ISTA germination test, ANOVA showed significant differences ( $P<0.001$ ) between seed dressings (Fig 1). However, no metaldehyde or methiocarb doses significantly reduced germination compared with control seeds. The lowest dose of cinnamamide ( $10 \text{ g kg}^{-1}$ ) did not reduce germination, but the two higher doses and all doses of DMCA did significantly ( $P<0.001$ ) reduce germination.

In the seed tray germination method ANOVA showed significant effects of treatment ( $P<0.001$ ) and time after sowing ( $P<0.001$ ) but the two factors did not interact. Numbers of emerged seedlings significantly increased over the first three weeks of the experiment ( $P<0.05$ ) (Fig 2a). As with the ISTA method, there was no evidence of phytotoxicity for any metaldehyde or methiocarb treatments (Fig 2b). Cinnamamide was phytotoxic at all doses causing significant ( $P<0.05$  at  $10 \text{ g kg}^{-1}$ ) or significant ( $P<0.001$  at 32 and  $100 \text{ g kg}^{-1}$ ) reductions in germination (Fig 2b). DMCA significantly ( $P<0.001$ ) reduced germination at all doses (Fig 2b).

### 3.2 Slug Damage Experiments

An ANOVA of the percentage of plants damaged by slugs revealed significant effects of both treatment ( $P<0.001$ ) and time ( $P<0.001$ ), but the two factors did not interact. There was significant ( $P<0.001$ ) increases in slug damage over the first three weeks, but not in the final week (Fig 3a). In comparison to control seeds, all metaldehyde treatments caused a significant ( $P<0.001$ ) reduction in slug damage, and methiocarb treatments significantly ( $P<0.01$  at  $1.8 \text{ g kg}^{-1}$ ;  $P<0.001$  at  $5.8$  and  $18 \text{ g kg}^{-1}$ ) reduced slug damage (Fig 3b). Cinnamamide significantly reduced slug damage at dose rates of  $10 \text{ g kg}^{-1}$  ( $P<0.01$ ) and  $100 \text{ g kg}^{-1}$  ( $P<0.05$ ), but in both cases, damage was significantly greater than the two highest doses of metaldehyde and methiocarb (Fig 3b). DMCA only significantly ( $P<0.01$ ) reduced slug damage at the highest dose ( $111 \text{ g kg}^{-1}$ ) and again damage for this treatment was significantly greater than the two highest metaldehyde and methiocarb doses (Fig 3b).

There were significant ( $P<0.001$ ) differences in slug mortality between treatments, and also over time (Fig. 3c), but the two factors did not interact. Slug mortality increased significantly every week for the four-week period ( $P<0.05$ ). All treatments except the middle dose of DMCA caused significant ( $P<0.05$ ) slug mortality compared with controls, with highest mortality being recorded in all metaldehyde treatments ( $P<0.001$ ) followed by all the methiocarb treatments (Fig. 3c).

### 3.3 Comparison with slug bait pellets

#### 3.3.1 *Deroceras reticulatum*

ANOVA of the total numbers of plants (damaged and undamaged) visible in seed trays showed that both treatment ( $P<0.01$ ) and time ( $P<0.001$ ) significantly affected plant numbers, but the two factors did not interact. Numbers of plants increased significantly between weeks 1 and 2 as more seeds germinated then remained similar until the end of the experiment (Fig 4a). Plant numbers were high for all treatments but there were significantly more plants in seed trays containing methiocarb dressed-seeds ( $P<0.001$ ) and methiocarb baited pellets ( $P<0.01$ ) than in control seed trays (Fig 4a).

ANOVA of the percentage of plants that had been fatally damaged (loss of apical meristem) showed a significant ( $P<0.001$ ) effect of treatment, but not of time, and there was no interaction. All four treatments had significantly ( $P<0.001$ ) less fatal damage than untreated seeds. Least damage occurred in trays containing metaldehyde dressed-seeds, and damage in this treatment was significantly less than with methiocarb dressed-seeds ( $P<0.05$ ), metaldehyde bait pellets ( $P<0.01$ ) and methiocarb bait pellets ( $P<0.001$ ) (Fig 4b). ANOVA of total slug damage (fatal and non-fatal grazing) showed that there were significant effects of treatment ( $P<0.001$ ), time ( $P<0.001$ ) and the two factors interacted significantly ( $P<0.01$ ) (Fig 4c). Damage levels increased significantly ( $P<0.001$ ) over the four weeks of the experiment (Fig 4c). All treatments had significantly ( $P<0.001$ ) less total damage than untreated plants (Fig 4c). Least damage occurred in trays containing metaldehyde dressed-seeds, but this was only significantly less than methiocarb dressed-seeds ( $P<0.01$ ) (Fig 4c).

Slug mortality increased significantly ( $P<0.001$ ) over the four weeks of the experiment, and treatment had a significant effect ( $P<0.001$ ), but the two factors did not interact. Slug mortality was significantly ( $P<0.001$ ) higher in all treatments than in control trays (Fig 4d). Slug mortality in trays containing methiocarb dressed-seeds, was significantly ( $P<0.001$ ) less than in all other slug control treatments, but there were no other significant differences (Fig 4d).

#### 3.3.2 *Arion subfuscus*

ANOVA of the total numbers of plants (damaged and undamaged) visible in seed trays showed that both treatment ( $P<0.001$ ) and time ( $P<0.001$ ) significantly affected plant numbers, and the two factors interacted significantly ( $P<0.05$ ) (Fig 5a). The number of plants visible in seed trays significantly ( $P<0.001$ ) decreased over the last three weeks of the experiment as seedlings were eaten by slugs (Fig 5a). Plant numbers were significantly ( $P<0.001$ ) higher in seed trays containing metaldehyde dressed-seeds in comparison to all other treatments (Fig 5a). Seed trays containing methiocarb dressed-seeds had significantly ( $P<0.001$ ) higher numbers of plants than the control seed trays and both metaldehyde and methiocarb baited pellet treatments (Fig 5a).

ANOVA of the percentage of plants that had been fatally damaged (loss of apical meristem) showed significant ( $P<0.001$ ) effects of treatment and time, but there was no interaction between the two factors (Fig



5b). The percentage of plants fatally damaged, averaged over all treatments, significantly increased from weeks 2 to 3 ( $P<0.001$ ) and from weeks 3 to 4 ( $P<0.01$ ). Seed trays containing metaldehyde dressed-seeds had significantly ( $P<0.001$ ) lower fatal damage than all other treatments (Fig 5b). Fatal damage to seedlings in seed trays containing methiocarb dressed-seeds was significantly lower than in control ( $P<0.001$ ) treatments, and in both metaldehyde ( $P<0.01$ ) and methiocarb ( $P<0.05$ ) baited pellet treatments (Fig 5b). In seed trays containing baited pellets, only methiocarb pellets had significantly ( $P<0.01$ ) lower fatal damage to seedlings in comparison to the control (Fig 5b). ANOVA of total slug damage (fatal and non-fatal grazing) showed significant effects of treatment ( $P<0.001$ ), time ( $P<0.001$ ) and that the two factors interacted significantly ( $P<0.001$ ) (Fig 5c). Damage levels increased significantly ( $P<0.001$ ) over the first three weeks of the experiment then remained similar until the end of the experiment (Fig 5c). Seed trays containing metaldehyde dressed-seeds again had significantly ( $P<0.001$ ) less damage than all other treatments (Fig 5c). Total damage in seed trays containing methiocarb dressed seeds was significantly less than control treatments ( $P<0.01$ ) and metaldehyde baited pellet treatments ( $P<0.05$ ) (Fig 5c). Again, in seed trays containing baited pellets, only methiocarb pellets had significantly ( $P<0.05$ ) lower fatal damage to seedlings in comparison to the control (Fig 5c).

Mortality of *A. subfuscus* increased significantly ( $P<0.001$ ) during the course of the experiment. Treatment had a significant ( $P<0.001$ ) effect on slug mortality, but this did not interact with the effect of time. Slug mortality was significantly ( $P<0.05$ ) greater than control treatments in all treatments except the methiocarb dressed-seeds (Fig 5d). Mortality of slugs in trays with methiocarb bait pellets was significantly ( $P<0.01$ ) less than in trays with methiocarb dressed-seeds and metaldehyde bait pellets (Fig 5d).

## 4 DISCUSSION

Whenever seeds are treated with agrochemicals, it is necessary to balance efficacy of the chemical with potential phytotoxicity. In our experiments, both ISTA and seed tray methods of testing germination revealed metaldehyde and methiocarb seed-dressings to have no phytotoxic effects on oilseed rape. These results are in agreement with previous work for metaldehyde,<sup>16,17,18,20</sup> and methiocarb.<sup>17,18,20,24</sup> Conversely, all tested doses of cinnamamide and DMCA were phytotoxic. Watkins *et al.*,<sup>25</sup> tested a single dose of cinnamamide and DMCA for phytotoxicity to wheat seeds, and found no toxicity for cinnamamide and slight, but significant phytotoxicity for DMCA. In our work, these doses and doses a third lower, showed substantial phytotoxicity to oilseed rape seeds. This probably reflects differences in physiology of the two plants, and perhaps differences in experimental conditions. In general, phytotoxicity was greater in seed tray germination tests than in the ISTA method, with the exception of the two highest doses of cinnamamide, for which phytotoxicity was much greater in the ISTA method. The reasons for this are not known.

It is encouraging that both metaldehyde and methiocarb greatly reduced slug damage at doses that showed no detectable phytotoxicity. This is the first report of oilseed rape seedlings being protected from slug damage with seed-dressings. Previous studies had concentrated on protecting seeds prior to germination. However, our results agree with general findings of other workers, in that both metaldehyde

and methiocarb have considerable potential as seed-dressings.<sup>16-20</sup> Our results for cinnamamide and DMCA are less encouraging. In addition to the phytotoxicity discussed above, the protection offered against slugs by these compounds was low. Therefore, we do not feel cinnamamide or DMCA warrant further investigations as seed treatments for oilseed rape. These findings are in contrast to those of Watkins *et al.*<sup>25</sup> who concluded that cinnamamide has “considerable potential to protect a whole range of agricultural and horticultural plants from slug damage”. Differences in crop plants and methodology may in part explain this discrepancy. However, even in the work of Watkins *et al.*,<sup>25</sup> damage to cinnamamide dressed-wheat seeds in no-choice experiments (similar to those described above) was great with approximately 90 % of seeds being damaged within one week.

When compared with conventional slug pellets, our seed treatments protected plants, as well as, or better than baited pellets. This is in agreement with the work of Ester *et al.*,<sup>19</sup> and Scott,<sup>23</sup> who found similar results in field experiments with winter wheat. *A. subfuscus* caused much more damage to seedlings in our experiments than *D. reticulatum*. More importantly *A. subfuscus* caused much more fatal than non-fatal damage to seedlings, whereas for *D. reticulatum* the converse was true. In addition, the effects of the various slug control treatments were not consistent between the two slugs. Both bait pellet treatments caused greater mortality in *D. reticulatum* than *A. subfuscus*. Both this effect and the greater plant damage caused by *A. subfuscus* were probably a result of the much greater biomass of this species. Whereas methiocarb and metaldehyde bait pellets were equally effective against *D. reticulatum*, the methiocarb pellets caused higher mortality of *A. subfuscus* than did the metaldehyde pellets. Previous work has also suggested that methiocarb is more effective than metaldehyde at controlling *Arion* spp.<sup>27,28</sup>

Metaldehyde and methiocarb are both toxic and repellent to slugs. It is not easy to determine the extent to which repellence is influencing plant damage for seed-dressings in our experiments, because both metaldehyde and methiocarb seed dressings caused high mortality. However, in the experiment with *A. subfuscus*, mortality caused by metaldehyde seed dressings was the same as that caused by methiocarb pellets, but damage was much less in the metaldehyde treated seeds, suggesting a repellent action.

We believe that seed dressing could lower the amount of molluscicide a.i. applied in the field compared with bait pellets. The reduction would be dependent on dose and seed sowing rate. Our optimal doses of metaldehyde (58 g kg<sup>-1</sup>) and methiocarb (18 g kg<sup>-1</sup>) represent reductions of 21% and 45% compared with metarex and draza pellets respectively, if plants were sown at typical field rates of 100 m<sup>-2</sup>. However, with improved canopy management techniques, many growers are now switching to a lower sowing rate of 60 seeds m<sup>-2</sup> representing reductions of 53% for metaldehyde and 77% for methiocarb.

Our laboratory results need some caution in interpretation, as plant and slug densities were not representative of those found in the field, both being higher. While these numbers of slugs per unit area (110 m<sup>-2</sup>) are found in arable fields, the biomass we used would be unrealistically high, as only adult slugs were included. Furthermore, the number of plants per unit area was much higher than the conventional 100 plants m<sup>-2</sup>. Thus, for our seed treatments, the amount of active ingredient per unit area within the boxes would be very much greater than in the field. However, the amount of active ingredient per plant would be identical to

field conditions, and thus we would expect protection per plant to be similar, if repellence is an important factor.

**We conclude that both metaldehyde and methiocarb show potential as seed-dressings to protect oilseed rape from slug damage and therefore should be field-tested.**

## ACKNOWLEDGEMENTS

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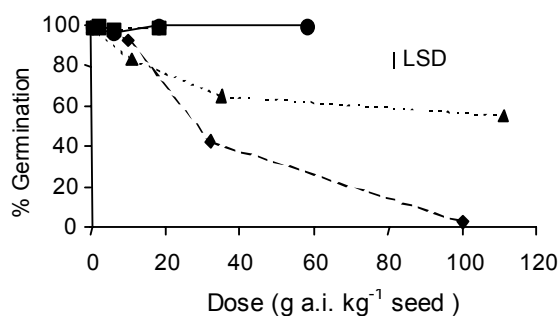
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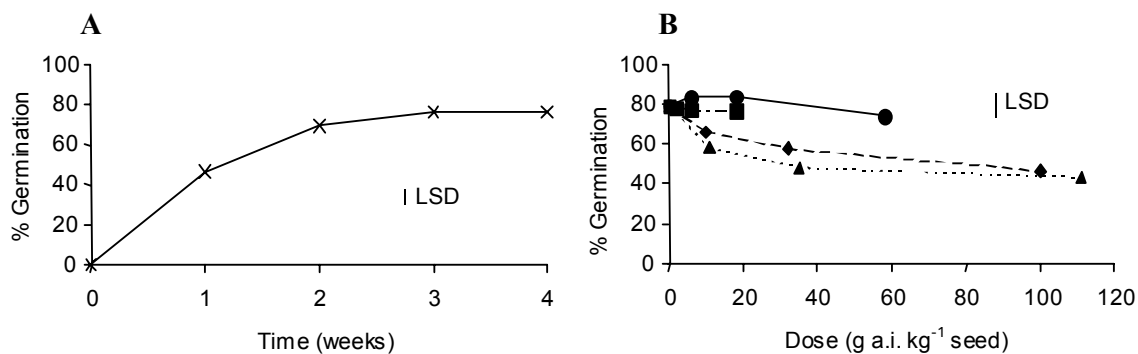
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## FIGURES

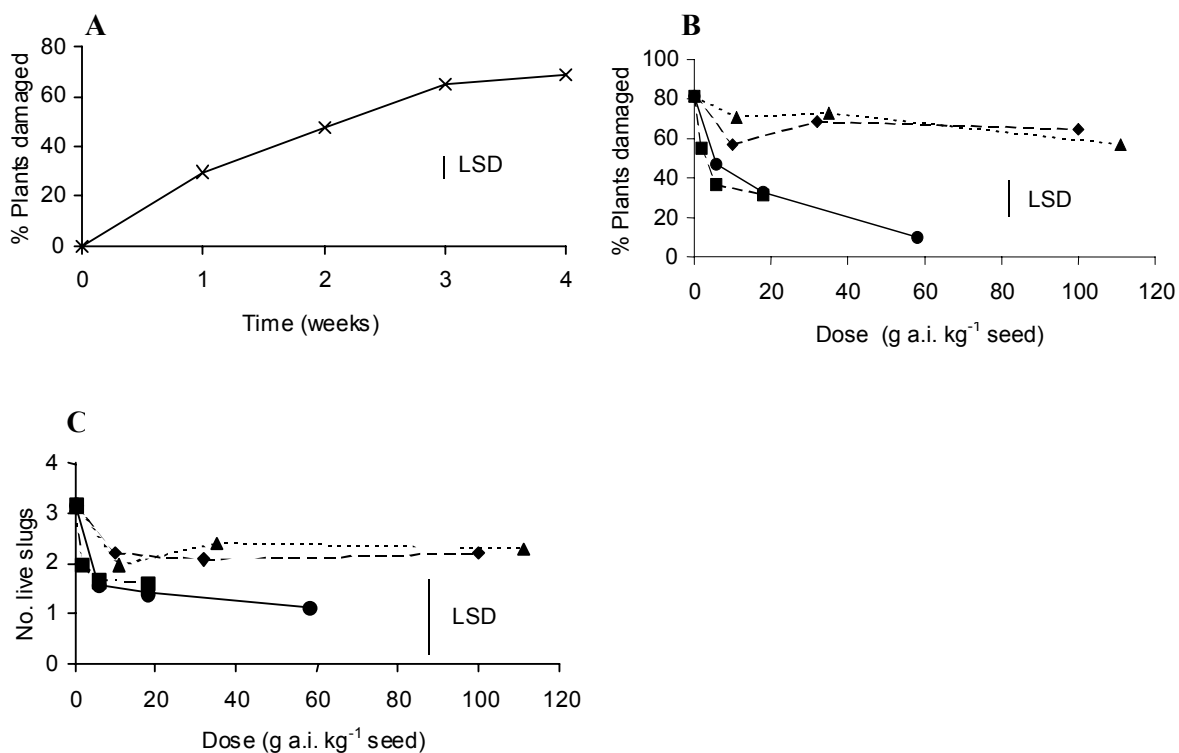
**Figure 1.** Mean percentage germination of oilseed rape seeds after two weeks in the ISTA germination test for seeds dressed with metaldehyde (●), methiocarb (■), cinnamamide (◆) or DMCA (▲) versus the dose of the seed-dressing. (LSD = Least Significant Difference,  $P = 0.05$ , 65 *df*).



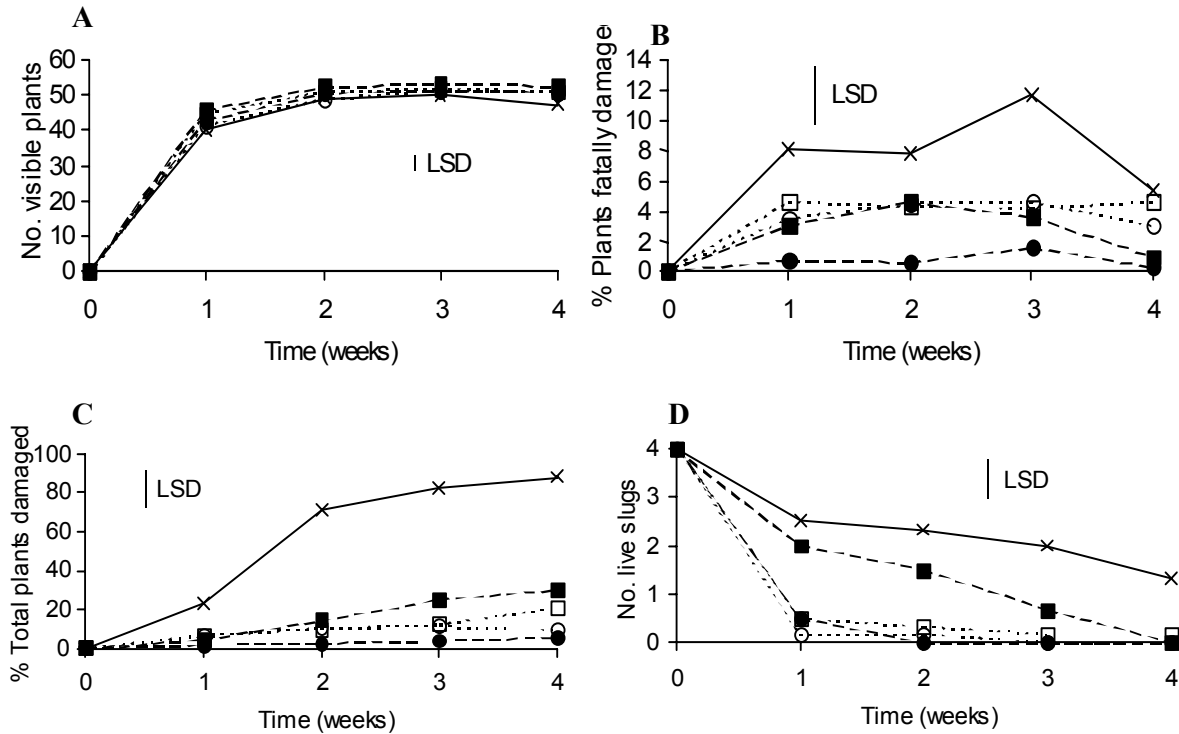
**Figure 2.** Mean percentage germination of oilseed rape seeds in the seed tray germination experiment. (A) Mean germination of all treatments versus time (×). (B) Mean germination for seeds treated with metaldehyde (●), methiocarb (■), cinnamamide (◆) or DMCA (▲) versus the dose of the seed-dressing. (LSD = Least Significant Difference,  $P = 0.05$ , 260 *df*).



**Figure 3.** Influence of four active ingredients applied to oilseed rape seeds on plant damage and mortality of *Deroceras reticulatum* slugs. (A) mean percentage damage to seedlings of all treatments versus time (×). (B) mean percentage damage of seedlings and, (C) mean percentage mortality of *D. reticulatum*, in trays containing seeds treated with metaldehyde (●), methiocarb (■), cinnamamide (◆) or DMCA (▲) versus the dose of the seed-dressing. (LSD = Least Significant Difference,  $P = 0.05$ , 260 df).



**Figure 4.** Comparison of efficacy of seed treatments and baited pellets containing either metaldehyde or methiocarb on slug damage to oilseed rape seedlings, and slug mortality. (A) number of seedlings visible in seed trays, (B) mean percentage of fatal damage to seedlings, (C) mean percentage of total damage to seedlings, and (D) mean percentage of slug mortality, in trays containing *D. reticulatum* slugs and treatments of either: control ( × ), metaldehyde seed-dressing ( ● ), metaldehyde bait pellets ( ○ ), methiocarb seed-dressing ( ■ ) and methiocarb bait pellets ( □ ), versus time. (LSD = Least Significant Difference,  $P = 0.05$ , 100 *df*).



**Figure 5.** Comparison of efficacy of seed treatments and baited pellets containing either metaldehyde or methiocarb on slug damage to oilseed rape seedlings, and slug mortality. (A) number of seedlings visible in seed trays, (B) mean percentage of fatal damage to seedlings, (C) mean percentage of total damage to seedlings, and (D) mean percentage of slug mortality, in trays containing *A. subfuscus* slugs and treatments of either: control ( × ), metaldehyde seed-dressing ( ● ), metaldehyde bait pellets ( ○ ), methiocarb seed-dressing ( ■ ) and methiocarb bait pellets ( □ ), versus time. (LSD = Least Significant Difference,  $P = 0.05$ , 100 *df*).

