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Slug damage and control of field slug (*Deroceras reticulatum* (Müller)) by carvone in stored potatoes

A. ESTER and R. TRUL[1]

Applied Research for Arable Farming and Field Production of Vegetables, P.O. Box 430, 8200 AK Lelystad, The Netherlands
[1] Christian Agricultural College, 8251 JZ Dronten, The Netherlands

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Summary

After a wet autumn and harvesting under wet conditions, slugs brought into potato stores via clods and soil adhering to tubers may cause substantial damage by feeding on the tubers.

A carvone sprout inhibitor, Talent®, applied in the potato stores at a dose of 50 ml per tonne potatoes, controlled slugs within a few days. A dose of 25 ml carvone was insufficient. Using a laboratory box test, the slug (*Deroceras reticulatum*) affected only wounded tubers and, although slime was present on the unwounded potatoes, they were not damaged by slugs.

Introduction

Potatoes are the most important crop for arable farmers in The Netherlands. Damage caused by slugs such as *Deroceras reticulatum* (Müller) can be a serious problem, particularly in stored potatoes. Slugs cause problems mainly in crops grown on clay soils (20–45% silt) (Rayner, 1975) in which they shelter in cracks and between clods. The optimum conditions for slugs occur when the potato crop canopy is closed and humidity under the foliage is high. The slugs are particularly active during wet periods in summer and autumn (Wareing & Bailey, 1989).

Under wet conditions, soil is cloddy and it is difficult to prepare a fine seedbed for planting seed potatoes. Clods remain throughout the growing period and are present at harvest. More clods will form if the potatoes are harvested under wet conditions and these provide excellent shelter for slugs. Consequently, when potatoes are harvested and stored, clods containing slugs are also brought into stores (Ester & Trul, 1997). At this time the potatoes are undamaged by slugs but damage occurs in the first few weeks of storage (Bus & Ester, 1996). The main reason for slug damage is that during harvest the tubers are slightly wounded although after a wound-healing period of some weeks a corky layer develops.

After the wet summer and autumn in 1993 slugs were found in 30–40% of the ware potato stores in the southwest of The Netherlands (Ester & Bus, 1995). Three factors accounting for the presence of slugs were identified. First, storing potatoes from different fields together increased the risk of contamination (Beer, 1989). Secondly, large stores with potatoes from different source made it easier for slugs to infect a large number of potatoes. Thirdly, the temperature within the stores fell slowly because of the large amount of potatoes, thus allowing the slugs to remain active for a longer period.

From samples of stored potatoes harvested in 1987 and 1988, Beer (1989) found that 34% of the 1987 harvest and 67% of the 1988 harvest were affected by slugs. Although most farmers store their potatoes in bulk, some are changing to storage in wooden boxes of 1–1.5 m^3 (Rastovski, 1987). Theoretically, in such a system problem batches could be isolated, but the high capacity of modern harvesting methods makes this unpractical.

Currently, slugs in stores are controlled by applying molluscicides when they and/or faeces and/or slime are detected. Unfortunately, molluscicide baits are insufficiently effective and slugs escape by moving deeper into the potato pile to reach more humid conditions.

To prevent sweetening, potatoes are stored at 7–8 °C but to avoid sprouting at this relatively high temperature sprout suppressants are applied. A new natural sprout inhibitor Talent® (active ingredient: d-carvone 95%, Luxan, Elst, The Netherlands) based on carvone has recently been introduced in The Netherlands (Diepenhorst & Hartmans, 1996) and suppresses sprout growth for up to ten months. Besides sprout suppressant activity, carvone has been found to control in vitro and in vivo growth of fungal pathogens of stored potatoes such as silver scurf, and in vitro growth of *Fusarium* spp. (Oosterhaven, 1995). Ester & Nijënstein (1995) found that wheat seeds treated with carvone were protected against damage by slugs. The compound has also been found to have an effect on slugs when used as a seed treatment of perennial ryegrass (Ester & Nijënstein, 1996).

This paper focusses on the susceptibility of potatoes to slug damage and on the efficacy of applying carvone in the first few days of storage to prevent slug damage.

Materials and methods

Laboratory experiments with slugs. Experiments were carried out with potato tubers cv. Accent, size 35–45 mm. On 5 August 1996 the potatoes were harvested by hand to ensure that they were undamaged.

In all the experiments slugs of the species *Deroceras reticulatum* weighing 400–600 mg each were used which had been collected from traps in a clover field at the Research Station, Lelystad. Slugs that appeared unhealthy were rejected. Following collection, they were kept without food for three days at 16 °C in a dark/light cycle of 10/14 h.

The experiments were carried out in a growth chamber at a constant temperature of 16 °C and 70% humidity in January and February 1997 and the experiments were done in plastic boxes measuring 40×30×12 cm using four replicates. Boxes were filled with 750 gram hydro-kerns (Jongkind Grond B.V., Aalsmeer, The Netherlands) and 200 ml tap water was added to each box. The boxes were covered with a polyethylene gauze of 1.35×1.35 mm to prevent the slugs escaping.

In these experiments unwounded tubers, freshly wounded tubers and tubers on which an artificial wound was covered with a cork layer (wound-healed potatoes) were used. Tubers were wounded uniformly by removing 1.1 cm^2 of the potato skin tissues at one spot per tuber by using a punch apparatus. Wound-healed tubers were obtained by storing freshly wounded tubers at 14 °C and 60% humidity for two weeks, conditions which encourage a cork layer to cover the wounds (referred to as wound-healed tubers) (Wigginton, 1974; Meyers, 1987).

Freshly wounded and wound-healed tubers were placed on the hydrokern surface with the wound facing upwards. Unwounded tubers were also placed on top of the hydro kerns. After 1, 4 or 5 and 7 days the potatoes were assessed for the incidence of slug damage and also examined for slime which indicated that slugs had been present on them. Data were analysed using analysis of variance (ANOVA) in Genstat 5. Least significant differences (LSD) and F-probabilities were derived from the ANOVA means. LSDs were calculated with Student's t distribution.

Two laboratory experiments were set up. The first experiment consisted of eight boxes and in each eight tubers were placed in two rows. In four boxes only unwounded or freshly wounded tubers were used (non-preference situation). In the remaining boxes four wounded together with four unwounded tubers were used (preference situation). Five slugs were added to each box. Final assessments of affected potatoes were made after seven days.

The second experiment consisted of 12 boxes. In each of 4 boxes 3 tubers were placed, either unwounded or wound-healed tubers (non-preference situation). In eight boxes, combinations of two (six tubers and four boxes) or three (nine tubers and four boxes) types of tubers (unwounded, wounded or wound-healed) were placed (preference situation). All possible combinations were assigned to twelve boxes. Four slugs were added to each box.

Potato storage experiments. Potatoes cv. Accent grown on clay soil were used at the Research Station during the 1997/1998 storage season in long term storage experiments in several compartments designed for box storage, each with a capacity of 18 tonnes. The potatoes were stored in boxes each containing 500 kg which were stacked five boxes high with free space between them. These letterbox stores were cooled with outside air ventilation (rate approx. 100 m^3 air per 1000 kg potatoes per hour) using a system programmed to maintain a temperature of 5–7 °C. Electronic temperature sensors were installed 50 cm below the surface of the potatoes in each compartment.

Carvone (a.i.: d-carvone 95%), derived from caraway seed (*Carum carvi* L.) and registered in The Netherlands since 1994 as a sprout inhibitor for ware potatoes, was applied during storage at regular intervals using a swingfog apparatus and circulated within the store for 1 hour after each application (anon., 1996). Ventilation was then switched off for approximately 42 hours to prevent the vapour from being removed quickly, because, carvone residues accumulate in potatoes during storage but decrease quickly towards the end of the experiments following the ventilation of the stores (Hartmans et al., 1995). The stores consisted of timber walls and the potatoes were stored in wooden boxes which absorbed about 25% of the carvone applied. To account for this loss, the rate of carvone applied was 25% higher that thought necessary for slug control.

The carvone concentration in the air was determined in all storage compartments. Air samples were taken at the beginning of the experiments and on the day of the final assessments.

The experiments were carried out in nylon gauze bags (nets) of 2 mm mesh, each containing 10 unwounded as well as 10 wounded tubers and four slugs (*Deroceras reticulatum*). Each replicate comprised four nets which were buried 15 cm deep in the storage boxes (1 m^3) filled with potatoes.

For practical reasons, the different rates of carvone were used in separate experiments, each with an untreated control.

Experiment A. Six stores with 18 tonnes of potatoes were treated with carvone and six stores remained untreated. Four nets of potato tubers with four slugs per net were used per treatment using six replicates (storage compartments). At the start of the experiment 25 ml carvone t^{-1} potatoes was applied, but by the end of the experiment this had fallen to a concentration of 20 ml carvone. Store humidity was 71% and observations were carried out after three days.

Experiment B. Six stores with 18 tonnes of potatoes each were treated with carvone and six stores remained untreated. Four nets of potato tubers with four slugs per net were used per treatment and the experiment was done with six replicates. Carvone was applied to each store at a rate of 82 ml t^{-1} potatoes but after three days the concentration of carvone in the air corresponded to 27 ml carvone t^{-1}. It was concluded that approximately 50 ml of biologically active carvone was available. Store humidity was 76%. Assessment of the damage took place after five days.

Experiment C. Three stores with 18 tonnes potatoes each were treated with carvone and three stores had remained untreated. For each treatment four nets containing potato tubers with five slugs per net were buried 15 cm deep in boxes (1 m^3) filled with potato tubers. This experiment was done with three replicates. At the start of the experiment 109 ml carvone t^{-1} was applied but after five days the concentration of carvone in the air corresponded to 37 ml carvone t^{-1}. It was concluded that approximately 75 ml biologically active carvone was available. Store humidity was 73%. Assessment took place after five days.

Results

Laboratory experiment 1. In both the non-preference and preference situations, slugs did not affect unwounded tubers after one and four days, and only a few tubers after seven days (Table 1). Wounded tubers were significantly affected but always only at the wounded sites. Compared with wounded tubers, the unwounded potato tubers had a significantly lower percentage of potatoes covered with slime after one and four days. After seven days, the difference in slime coverage was no longer significant.

Laboratory experiment 2. In the non-preference situation, unwounded potatoes were unaffected by slugs after 24 hours (Table 2) and although slime was found on more than 50% of the tubers after five days, no unwounded tubers were attacked by slugs even after seven days. By contrast, slugs attacked more than half the wounded tubers

Table 1. Percentage potato tubers affected by the field slug after 1, 4 and 7 days. Laboratory experiment 1.

Treatment	1		4		7	
	Affected	Slime	Affected	Slime	Affected	Slime
Non-preference						
Unwounded	0	13	0	66	3	69
Wounded	28	38	57	88	72	94
Preference						
Unwounded	0	25[a]	0	81[a]	0	91[a]
Wounded	19		81		94	
LSD (α=0.05)	11.7	17.7	37.4	14.9	21.3	n.s.
F-prob.	<.001	0.004	0.002	0.028	<.001	n.s.

[a] Total of the unwounded and wounded damaged potatoes.

Table 2. Percentage potatoes affected by slugs after 1, 5 and 7 days. Laboratory experiment 2.

Treatment	1		5		7	
	Affected	Slime	Affected	Slime	Affected	Slime
Non-preference						
Unwounded	0	0	0	58	0	75
Wounded	58	58	100	100	100	100
Wound-healed	17	33	25	92	33	100
Preference						
Unwounded	0	17	0	50	0	75
Wound-healed	8	33	8	83	50	92
Wounded	33	58	83	92	92	92
Wound-healed	0	8	8	75	17	100
Unwounded	0	8	0	58	0	58
Wounded	58	58	83	100	92	100
Wound-healed	0	25	0	75	8	92
LSD (α=0.05)	25.6	22.2	20.2	24.9	19.0	23.7
F-prob.	<.001	<.001	<.001	0.010	<.001	<.001

within 24 hours and all after five days. Wounded tubers that had been held in wound healing conditions were also attacked by slugs but to a much lesser extent than the freshly wounded tubers. When given a choice (preference situation), slugs showed a preference for freshly wounded tubers compared with wound-healed tubers. The percentages of tubers with slime showed similar trends.

Potato storage experiments. After three days, a higher percentage of slugs were killed in stores treated with carvone compared with untreated stores (Table 3). Unwounded potatoes in both untreated and in carvone-treated stores were free from slug damage. Wounded potatoes (freshly wounded) in untreated stores were significantly more affected than those in the carvone treated stores. Wounded and unwounded potatoes from untreated stores showed a significantly higher percentage of potatoes with slime in comparison with potatoes from carvone-treated stores.

After five days 99% of the slugs in experiment B in the treated stores were dead compared with 17% for the untreated stores (Table 4). Unwounded potatoes were not affected by slugs. Wounded potatoes in carvone-treated stores had a significantly lower percentage of affected potatoes than those in untreated stores. In carvone-treated stores, 25% of the unwounded and 35% of the wounded potatoes showed slime coverage, compared with 47 and 56% in untreated stores. This difference was not statistically significant. Wounded potatoes in the untreated stores were affected at the site of the artificial wound.

Table 3. The percentage of unwounded and freshly wounded potatoes affected by slugs, the percentage of potatoes covered with slime and the percentage of slugs killed after treating the potatoes with 25 ml carvone t^{-1}. 3 days after treatment. Experiment A.

Treatment	Dosage	Slugs Killed	Affected		Slime	
			Unwounded	Wounded	Unwounded	Wounded
Untreated	0	6 a	0	29 a	50 a	65 a
Carvone	25	71 b	0	7 b	19 b	29 b
F-prob.		0.030		0.028	0.012	0.025

Table 4. The percentage of freshly wounded and unwounded potatoes affected by slugs, the percentage of potatoes covered with slime and the percentage slugs killed after treating the potatoes with 50 ml carvone t^{-1}. 5 days after treatment. Experiment B.

Treatment	Dosage	Slugs Killed	Affected		Slime	
			Unwounded	Wounded	Unwounded	Wounded
Untreated	0	17 a	0	18 a	47 a	56 a
Carvone	50	99 b	0	1 b	25 a	35 a
F-prob.		<.001		<.001	n.s.	n.s.

In experiment C, carvone killed almost all the slugs whereas those in the untreated stores survived (Table 5). Unwounded potatoes were free from slug damage, while wounded potatoes treated with carvone had a significantly lower percentage of affected potatoes in comparison with untreated potato tubers. Although 42% of wounded tubers in untreated stores were damaged by slugs after three days, this percentage would be likely to increase during further storage as almost all slugs were alive at this time. Of the carvone-treated potatoes, 51% were covered with slime compared with the average of 79% (unwounded and wounded tubers) in the untreated potatoes stores; these differences were not statistically significant.

In three days, the carvone concentration, obtained by air sampling, in the store atmosphere fell from 109 ml to 37 ml t^{-1} potatoes, indicating that about 70 ml carvone is biologically active and available for the potato tubers and slugs (experiment C).

Table 5. The percentage of freshly wounded and unwounded potatoes affected by slugs, the percentage of potatoes covered with slime and the percentage slugs killed after treating the potatoes with 75 ml carvone t^{-1}. 3 days after treatment C.

Treatment	Dosage	Slugs Killed	Affected		Slime	
			Unwounded	Wounded	Unwounded	Wounded
Untreated	0	1	0	42 a	71 a	87 a
Carvone	75	99	0	5 b	50 a	51 a
F-prob.				0.011	n.s.	n.s.

Discussion

Wounded potatoes. Laboratory experiments 1 and 2 showed that unwounded tubers were not damaged by slugs of the species *Deroceras reticulatum*. On the contrary, at least 72% of freshly wounded tubers were affected after seven days. Such tubers were affected only at wounds made by removing 1.1 cm^2 of the skin. Unwounded tubers were at least 69% covered with slime. This suggests that slugs moved over the unwounded potatoes, seeking tuber parts without peel. Pinder (1974) found that the slug *Arion hortensis* was of greater importance than *D. reticulatum* in causing primary tuber damage in the field and it therefore appears that *D. reticulatum* is responsible for much of the secondary damage. Our results also show that *D. reticulatum* is more likely to cause secondary damage rather than primary damage. Airey (1987) reported a laboratory study in which some slug species did not attack potato tubers. It was suggested that tuber skin may contain feeding deterrents and this could explain the reluctance of slugs to feed when damaged areas on tubers are not available. Johnston & Pearce (1994) also mentioned that *D. reticulatum* attacked potato tubers as secondary feeders when other organisms such as wireworms had already broken through the skin.

Wound-healed potatoes were significantly less attacked in comparison with wounded potatoes in the non-preference situation. This indicates that the corklayer that had developed over the wound is not an barrier for slugs. The percentage of tubers covered with slime in potatoes with healed wounds was also significantly lower compared with freshly wounded potatoes.

In the preference situation, fewer potatoes with healed wounds were attacked by slugs than those in the non-preference situation, although differences were not significant. After seven days almost all the wounded tubers and those with healed wounds show slime on their skin.

Efficacy of carvone. Treating potato stores with carvone at 25 ml t^{-1} potatoes resulted in 71% slug mortality after three days, whereas doses of 50 and 75 ml per tonne potatoes resulted in nearly 100%. By comparison, at least 83% of the slugs in the untreated stores were alive.

Tubers that had been wounded by removing 1.1 cm^2 of the skin were significantly more affected by slugs in the untreated stores than in the carvone-treated stores and all these potatoes were attacked at the wounds.

After applying carvone at 50 and 75 ml per tonne, the slugs did not die immediately. This can be inferred by the 25 and 35% respectively of tubers with slug slime, indicating that the tubers were visited before slug death. Possibly carvone penetrated slowly into the slugs. From the carvone rates at the beginning of the experiments and residues after three days it is clear that biologically active material was available to potatoes and that the potatoes had absorbed 56 ml and 72 ml per tonne. Slugs also absorbed carvone and those on potatoes in the untreated stores were significantly more active than those in carvone-treated stores, as shown by the incidence of tubers with slime. The reason for 17% slug mortality in untreated stores (Table 4) is unexplained.

Use of slug-resistant cultivars of potato may also be considered a solution to prevent slug damage. Winfield et al. (1967) and Pinder (1974) found differences between cultivars in susceptibility to tuber damage by slugs; cv. Pentland Falcon was less susceptible and cv. Maris Piper very susceptible. Such differences in the susceptibility to tuber damage may similarly be linked to differences in susceptibility to foliage damage (Hunter et al., 1968).

The main recommendation is to prevent any mechanically damage to potato tubers during harvesting. If slugs or faeces or slime are observed on the potatoes in storage, Talent™, a.i. carvone at a rate of 50 ml t^{-1} potatoes should be applied directly after storing the potatoes because slug damage will increase if treatment is delayed.

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