Efficacy of invasive alien plants in controlling Arionidae slugs

Ziga Laznik (Laznik, Z) 1, Tanja Bohinc (Bohinc, T) 1, Kristijan Franin (Franin, K) 2, Ivana Majić (Majić, I) 3 and Stanislav Trdan (Trdan, S) 1

1University of Ljubljana, Biotechnical Faculty, Dept. Agronomy, Jamnikarjeva 101, 1000 Ljubljana, Slovenia. 2University of Zadar, Dept. Ecology, Agronomy and Aquaculture, Ulica Mihovila Pavlinovića bb, 23000 Zadar, Croatia. 3University of Osijek, Faculty of Agrobiotechnical Sciences, Section of Entomology and Nematology, Vladimira Preloga 1, 31000 Osijek, Croatia.

Abstract

Aim of study: To develop an alternative slug control method, we explored the use of plant material from seven invasive plant species against Arion slugs.

Area of study: The experiments were performed at the University of Ljubljana (Slovenia).

Material and methods: In laboratory (exp. A-C) and semi-field studies (exp. D), we investigated the contact and barrier efficacy of plant material (powder or liquid formulation) of seven invasive plant species (Japanese knotweed, bohemian knotweed, Canadian goldenrod, giant goldenrod, staghorn sumac, tree of heaven, and false indigo) against Arion slugs. In order to test a contact efficacy of the substance (exp. A), slugs were rolled in a plant material powder. In exp. B, powder made from a plant material was used as a barrier for slugs. Antifeedant effect of the slugs was tested in exp. C, where lettuce leaves were treated with a liquid formulation of a plant material. In exp. D, all above mentioned techniques were used in a semi-field trial.

Main results: The results of our studies showed that the plant material of staghorn sumac, giant goldenrod, and Japanese knotweed showed the strongest anti-feedant and barrier effects against the slugs. In the semi-field trial, only 7% of the plants treated with giant goldenrod plant material were attacked by slugs.

Research highlights: A contact efficacy of plant powders against Arion slugs was not confirmed in our investigation. Furthermore, several plant powders (goldenrods, staghorn sumac) showed good barrier efficacy. A semi-field trial showed that plant material (giant goldenrod) could represent an alternative solution in slug control.

Additional key words: Arion; plant extract; plant powder; invasive alien plants; slug control.

Citation: Laznik, Z; Bohinc, T; Franin, K; Majić, I; Trdan, S (2020). Efficacy of invasive alien plants in controlling Arionidae slugs. Spanish Journal of Agricultural Research, Volume 18, Issue 1, e1001. https://doi.org/10.5424/sjar/2020181-15542

Introduction

Slugs of the genus Arion (Gastropoda: Arionidae) have been classed as a major agricultural economic pests in Asia, Australia, Europe, and North America (Barker, 2002; Ahmadi, 2004; Douglas & Tooker, 2012; Rowson et al., 2014). They cause damage to vegetables, field crops, fruit trees, lawns, and wild plants (Peters et al., 2000; Douglas & Tooker, 2012). They may also appear as stored product pests (Henderson & Trieb- skorn, 2002). Slug feeding can severely damage the plants and thus subject them to stress (Rowson et al., 2014). Consequently, such plants are less resistant and more susceptible to diseases and are less likely to survive unfavourable weather conditions (Hammond & Byers, 2002).

The economically important agricultural pest species from the Arionidae family in Europe are Arion distinctus Mabille, A. hortensis (Férussac), and A. vulgaris (Moquin-Tandon) (Rowson et al., 2014; Laznik & Trdan, 2016). For the purpose of effective management of any agricultural pest, knowledge of its biology and
Slugs activity is correlated with different factors, such as air temperature, soil surface temperature, wind speed, humidity and soil moisture content (Young & Port, 1989; Kozlowski, 2007; Slotsbo et al., 2011). Slugs favour heavier soils, since they can survive over the summer in cracks in the soil and under clods (Barker, 2002). Terrestrial molluscs are generally susceptible to desiccation, and several studies have found habitat selection to be strongly correlated with the availability of water (Carne-Cavagnaro et al., 2006). The most obvious water regulating behaviour of slugs is their preference for moist habitats (Slotsbo et al., 2011). In contrast to snails, slugs lack the physical protection of a shell and must find other ways to reduce water loss. Thompson et al. (2005) suggested that water conductance of the skin is an important factor. However, the ability to survive drought cannot be explained only by water conductance alone but is also influenced by body size and the magnitude of water reserves. Active slugs can lose up to 60% of their initial body weight (Thompson et al., 2005). Furthermore, dehydrated slugs can rapidly recover from dehydration by absorbing water through their integument; this process is termed contact re-hydration (Prior, 1985; Thompson et al., 2005).

Increased mucus secretion is one of the first reactions of slugs to mechanical or chemical irritation (Barker, 2002; Schüder et al., 2003; Simms et al., 2006). The production of mucus enables the slugs to form a protective barrier preventing direct contact between the toxin and the surface of the epithelial cells. Slugs are mainly controlled with bait pellets, which usually contain either metaldehyde or iron (III) phosphate (Garthwaite & Thomas, 1996; Speiser & Kistler, 2002). The major concern related to slug control is that the chemical compounds are also toxic to non-target organisms and pets (Castle et al., 2017). Due to the physico-chemical properties of metaldehyde, it is highly mobile in soil, and hence once applied, it can run off under wet conditions into field drains, gullies and surface waters (Castle et al., 2017). Furthermore, farmers and growers often experience difficulty controlling slugs with bait pellets containing molluscicides. Hata et al. (1997) reported that in wet conditions, the efficacy of these baits can be very low. Slugs can be difficult to kill by contact molluscicides because they are covered by a layer of slime that prevents chemicals from coming in contact with skin, and at the same time, slime may serve to dilute the toxin (Barker, 2002; Speiser & Kistler, 2002; Gonzáles-Cruz & San Martín, 2013). In addition to environmental problems, human health problems also arise from agricultural pesticide usage (Nicolopoulou-Stamati et al., 2016). Many farmers are searching for new alternatives to curb pesticide usage to address the many concerns.

The development of alternative slugs control methods compatible with integrated pest management (IPM) strategies used to control other pests would help satisfy increasing market demands and environmental safety issues. In the early 1990s, a biocontrol method for slugs based on the parasitic nematode Phasmarhabditis hermaphrodita was developed (Wilson et al., 1993). The biocontrol method with parasitic nematodes proved to be a promising alternative to chemical molluscicides (Iglesias et al., 2003). Many countries have strict regulations for using biopesticides that allow only indigenous species to be used (Laznik & Trdan, 2016). Such regulations have slowed the uptake of use of P. hermaphrodita in several countries. Physical barriers, such as continuous lines of sawdust or ash, provide a dry surface which slugs avoid (Barker, 2002; Laznik & Trdan, 2016); however, the effectiveness of these barriers is reduced once they become wet. Copper barriers present an effective mechanical and physicochemical barrier for slugs (Schüder et al., 2003; Laznik et al., 2011). As shown in previous studies, mollusks take up copper through ingestion (Berger & Dallinger, 1989), and directly through the foot, at least in the form of copper compounds (Ryder & Bowen, 1977), causing internal damage and irritation (Schüder et al., 2003).

Due to the negative environmental impacts of pesticides, their non-target effect and increasingly stringent environmental policies, researchers are searching for new, more environmentally acceptable methods of plant protection against pests. One of these measures is the study of plant extracts in the control of economically important harmful organisms (Pavela et al., 2008). To develop an alternative slug control method, we explored the use of plant material from seven invasive plant species: knotweeds (Fallopia japonica [Houtt.] Ronse Decr., F. × bohemica [Chrtk & Chrtková] Bailey), goldenrods (Solidago canadensis L., S. gigantea Aiton), staghorn sumac (Rhus typhina L.), tree of heaven (Ailanthus altissima [Mill.] Swingle), and false indigo (Amorpha fruticosa L.). It was a selection of plants that are widespread in urban areas and whose control is practically impossible in practice. The main idea was to use these plants in order to see if they have any potential in plant protection programmes (Laznik et al., 2018). The aims of our laboratory and semi-field
studies were to test (1) the contact control efficacy of an individual use of the selected substances, (2) the barrier effect of the tested substances, and (3) the effect on the slug eating ability.

Material and methods

Slugs

The experiments were performed at the Laboratory of Entomology and the laboratory field of the Biotechnical Faculty (Dept. of Agronomy, University of Ljubljana, Slovenia). Arion slugs (mainly representatives of A. vulgaris and A. rufus) were collected at the laboratory field of the Biotechnical Faculty in Ljubljana (46°04'N, 14°31'E, 299 m a.s.l.) during May and August 2018. Slugs were identified to species level with the use of identification charts (Rowson et al., 2014). The slugs collected were of various lengths and ages, as we wanted to analyse a comprehensive sample of outdoor slug behaviours (Laznik et al., 2011; Laznik & Trdan, 2016). The slugs were starved for 48 hrs prior to the experiment (Schüder et al., 2003).

Experimental design

Plant material was collected in the area of the municipality of Ljubljana (Slovenia). For the purpose of the experiments, we used aerial parts of the plants (leaves, flowers). Plant samples were air-dried. They were tied together and hung to expose the plant to air at ambient temperature for 7-10 days until dry. This drying method does not force dried plant materials using high temperature, meaning heat-labile compounds are preserved (Azwanida, 2015). An electric blender was used to reduce the particle size of the samples to increase the surface contact between the samples and extraction solvents (Azwanida, 2015).

To obtain a liquid formulation, we used a maceration technique (Azwanida, 2015). Maceration involved soaking the plant material (previously prepared powder) in tap water. For the purpose of the experiment, we used two concentrations, 2.5 and 10% w/v (2.5 or 10 g of dry powder was added into 100 mL of tap water). We soaked the plant material for 24 hrs. After this period, the mixture was pressed manually through medical gauze (type 12/8, produced by the company Tosama d.d., Vir pri Domžalah).

The experiment involved the following substances: [1,2] knotweeds (Fallopia japonica, F. x bohemica), [3,4] goldenrods (Solidago canadensis, S. gigantea), [5] staghorn sumac (Rhus typhina), [6] tree of heaven (Ailanthus altissima), and [7] false indigo (Amorpha fruticosa). The substances were studied individually. Each treatment was repeated ten times. The control sample [8] was a slug sprinkled with water. All laboratory experiments were carried out in a growth chamber (type: RK-900 CH, produced by the company Kambič laboratorijska oprema d.o.o., Semič, Slovenia) at 20 °C, 12/12 h photoperiod, and 75% relative air humidity.

The study of the contact efficacy of the substances (experiment A)

The experiment, which lasted 48 hrs, included 80 slugs (8 different treatments which were repeated 10 times). The experiment was carried out in plastic petri dishes (150 × 20 mm). Moistened tampons (35 × 11 mm) and fresh leaves of lettuce (Lactuca sativa L.) were placed in plastic petri dishes. Before starting the experiment, the slugs were weighed. The slugs were then rolled in individual substances (dry powder of tested plant material). In control treatment slugs were only sprinkled with water. In the 48 hrs experiment, we checked the survival of slugs once a day, weighed them again, replaced the lettuce leaf (the source of food), added additional moisture to the tampon, and rolled them again in the substances studied (or sprinkled with water in control). The slugs that died during the experiment were not replaced with live slugs (Laznik et al., 2011). The aims of experiment A were (i) to test the contact control efficacy of the tested substances and (ii) to test the effect of the substances on slug eating ability.

The substances studied as barriers for slugs (experiment B)

The experiment lasted 48 hrs and involved 80 slugs (8 different treatments, which were repeated 10 times). The experiment was carried out in glass insectaria (width-length-depth 500-350-400 mm). Moistened tampons were placed in glass insectaria with fresh leaves of lettuce. Before starting the experiment, the slugs were weighed. We sprinkled the barrier (40 g of a substance) 3 cm wide and 2 cm thick around the lettuce leaf. In control treatment only lettuce was given to slugs without any barrier. In the two-day experiment, we checked daily whether the slugs had crossed the barrier, whether they had eaten lettuce leaves, how much they weighed, replaced the leaves of lettuce (the source of food), added additional moisture to the tampons and repaired barriers if they were damaged. The slugs that died during the experiment were not replaced.
with live slugs (Laznik et al., 2011). The aims of experiment B were (i) to test the barrier effect of tested substances and (ii) to test the effect of the substances on slug eating ability.

The studied substances in liquid formulation (experiment C)

The experiment, which lasted 48 hrs, included 160 slugs (8 different treatments that were repeated 10 times at 2 different concentrations). The experiment was carried out in plastic petri dishes (150 × 20 mm). Moistened tampons (35 × 11 mm) and fresh leaves of lettuce were placed in plastic petri dishes. The slugs were weighed before starting the experiment. We prepared 2.5% and 10% (w/v) concentration of selected plant material (Azwanida, 2015). A lettuce leaf (the source of food) was soaked into the liquid formulation. In the experiment, we checked the survival of slugs once a day, weighed them again, replaced the lettuce leaf (the source of food and soaked it again in liquid formulation) and added additional moisture to the tampon. The slugs that died during the experiment were not replaced with live slugs (Laznik et al., 2011). The aims of experiment C were (i) to test the contact control efficacy of the substances tested and (ii) to test the effect of the substances on slug eating ability.

The studied substances in the semi-field trial (experiment D)

The preparation of the field began in autumn 2017, when stable manure (30 t ha⁻¹) was spread and then the field was ploughed. In spring, the field received the mineral fertilizer NPK (15:15:15). The wooden boxes (frame size: 1 m × 1 m × 0.5 m) with net covers (doors) were made by a local carpenter. In experiment lettuce variety ‘Isabel’ was used. We dug the box frame into the soil (at least 10 cm to prevent slugs from escaping from the boxes). Lettuce seedlings were transplanted into the experimental field (inside the wooden boxes). We achieved a density of 5 lettuce plants m⁻². The lettuce was not treated with other plant protection products. In a semi-field trial, only Solidago gigantea plant material was used (in previous laboratory trials, this compound showed the most promising results). Five treatments were used: [1] liquid formulation (lettuce seedlings were sprinkled with selected plant maceration in 10% concentration, [2] barrier (we constructed the barrier around the lettuce seedlings), [3] combination of the barrier and liquid formulation (the seedlings were sprinkled with selected plant maceration in 10% concentration + we constructed the barrier around the lettuce seedlings), [4] positive control (lettuce without slugs), and [5] negative control (lettuce with slugs only). Each treatment was repeated 5 times (25 boxes were used). In every box (except treatment 4), 5 slugs (Arion vulgaris) were added. In all the experiments, 100 slugs were used. We placed a tile in 1 corner of the box. This place was called the hiding area for the slugs during the experiment. Boxes were randomly distributed in the experimental field. The experiment lasted 72 hrs. On day 3, we cut all the lettuce and measured different parameters (total weight of the lettuce, weight of the slug damaged leaves, the weight of undamaged leaves, and the weight of leaves that showed phytotoxicity).

Statistical analysis

The typical behavioural responses of the slugs during the experiment were classified in terms of six events, as described in Table 1. The numbers used to index the events were used to quantify the analysis. To perform the data analysis, these index values were used as the values of the response variable “event”. For instance, if the slug died in experiment A, the value of the event was 2 (see Table 1).

Two-way analysis of variance (ANOVA) was carried out to evaluate the differences in the response of the Arion slugs to different treatments (experiments A-C). Before analysis, each variable was tested for homogeneity of variance. Duncan’s multiple range test (α= 0.05) was used to analyse the differences between individual treatment means (Hoshmand, 2006).

A multifactor ANOVA was conducted (semi-field trial, experiment D) to determine the differences in mortality rates (%) between the slugs in different treatments. Prior to the analysis, all the data were corrected for the mortality rate of the control group using Abbott’s correction. Student’s multiple range

Table 1. Definitions of behavioural events occurring during the experiments.

| Index | Event                          |
|-------|--------------------------------|
| 1     | Slug survived the experiment   |
| 2     | Slug died during the experiment|
| 3     | Slug fed on lettuce            |
| 4     | Slug did not feed on lettuce   |
| 5     | Slug crossed the barrier       |
| 6     | Slug did not cross the barrier  |
Efficacy of invasive alien plants in controlling Arionidae slugs

The feeding inhibitor effect on the slugs after 24 and 48 hrs is presented in Fig. 1A. Results of our study showed that 40% of the slugs treated with the powder of *S. canadensis* did not feed on the lettuce after 24 hrs. The feeding inhibitor effect was also confirmed after 24 hrs in treatments with *A. fruticosa*, *R. typhina*, and *S. gigantea* (30%, 20%, 10% of the slugs tested did not eat the lettuce, respectively). In all other treatments, the feeding inhibitor effect was not confirmed. After 48 hrs, 30% of the slugs treated with the powder of *R. typhina* did not feed on the lettuce. The feeding inhibitor effect was also confirmed after 48 hrs in treatments with *F. japonica* (20% of the slugs did not eat the lettuce), *S. canadensis* (20% of the slugs tested did not eat the lettuce), *A. altissima* (20% of the slugs tested did not eat the lettuce) and *S. gigantea* (10% of the slugs did not eat the lettuce). In all other treatments, the feeding inhibitor effect was not confirmed (see Fig. 1A).

Slug mortality after 24 and 48 hrs is presented in Fig. 1B. Results of our study showed that 20% of the slugs treated with powder of *S. canadensis* died after 24 hrs. Slug mortality was confirmed after 24 hrs in *R. typhina* (10%). In all the other treatments, slug mortality was not confirmed (see Fig. 1B). The results of our study showed that 30% of the slugs treated with the powder of *R. typhina* died after 48 hrs. Slug mortality was also confirmed in treatments *A. fruticosa* (10%), *F. japonica* (10%), and *S. canadensis* (20%). In all the other treatments, slug mortality was not confirmed (Fig. 1B).

### Experiment B

The feeding inhibitor effect towards the slugs after 24 and 48 hrs is presented in Fig. 2A. Results of our study showed that 20% of the slugs treated with powder of *S. canadensis* did not feed on the lettuce after 24 hrs. The feeding inhibitor effect was also confirmed after 24 hrs in treatments with *A. fruticosa*, *R. typhina*, and *S. gigantea* (30%, 20%, 10% of the slugs tested did not eat the lettuce, respectively). In all other treatments, the feeding inhibitor effect was not confirmed. After 48 hrs, 30% of the slugs treated with the powder of *R. typhina* did not feed on the lettuce. The feeding inhibitor effect was also confirmed after 48 hrs in treatments with *F. japonica* (20% of the slugs did not eat the lettuce), *S. canadensis* (20% of the slugs tested did not eat the lettuce), *A. altissima* (20% of the slugs tested did not eat the lettuce) and *S. gigantea* (10% of the slugs did not eat the lettuce). In all other treatments, the feeding inhibitor effect was not confirmed (see Fig. 1A).

### Results

General analysis of the events at different experiments is presented in Tables 2 and 3.

#### Individual analysis

**Experiment A**

The feeding inhibitor effect on the slugs after 24 and 48 hrs is presented in Fig. 1A. Results of our study showed that 40% of the slugs treated with the powder of *S. canadensis* did not feed on the lettuce after 24 hrs. The feeding inhibitor effect was also confirmed after 24 hrs in treatments with *A. fruticosa*, *R. typhina*, and *S. gigantea* (30%, 20%, 10% of the slugs tested did not eat the lettuce, respectively). In all other treatments, the feeding inhibitor effect was not confirmed. After 48 hrs, 30% of the slugs treated with the powder of *R. typhina* did not feed on the lettuce. The feeding inhibitor effect was also confirmed after 48 hrs in treatments with *F. japonica* (20% of the slugs did not eat the lettuce), *S. canadensis* (20% of the slugs tested did not eat the lettuce), *A. altissima* (20% of the slugs tested did not eat the lettuce) and *S. gigantea* (10% of the slugs did not eat the lettuce). In all other treatments, the feeding inhibitor effect was not confirmed (see Fig. 1A).

Slug mortality after 24 and 48 hrs is presented in Fig. 1B. Results of our study showed that 20% of the slugs treated with powder of *S. canadensis* died after 24 hrs. Slug mortality was confirmed after 24 hrs in *R. typhina* (10%). In all the other treatments, slug mortality was not confirmed (see Fig. 1B). The results of our study showed that 30% of the slugs treated with the powder of *R. typhina* died after 48 hrs. Slug mortality was also confirmed in treatments *A. fruticosa* (10%), *F. japonica* (10%), and *S. canadensis* (20%). In all the other treatments, slug mortality was not confirmed (Fig. 1B).

#### Experiment B

The feeding inhibitor effect towards the slugs after 24 and 48 hrs is presented in Fig. 2A. Results of our study showed that 20% of the slugs treated with powder of *S. canadensis* did not feed on the lettuce after 24 hrs. The feeding inhibitor effect was also confirmed after 24 hrs in treatments with *A. fruticosa*, *R. typhina*, and *S. gigantea* (30%, 20%, 10% of the slugs tested did not eat the lettuce, respectively). In all other treatments, the feeding inhibitor effect was not confirmed. After 48 hrs, 30% of the slugs treated with the powder of *R. typhina* did not feed on the lettuce. The feeding inhibitor effect was also confirmed after 48 hrs in treatments with *F. japonica* (20% of the slugs did not eat the lettuce), *S. canadensis* (20% of the slugs tested did not eat the lettuce), *A. altissima* (20% of the slugs tested did not eat the lettuce) and *S. gigantea* (10% of the slugs did not eat the lettuce). In all other treatments, the feeding inhibitor effect was not confirmed (see Fig. 1A).

Slug mortality after 24 and 48 hrs is presented in Fig. 1B. Results of our study showed that 20% of the slugs treated with powder of *S. canadensis* died after 24 hrs. Slug mortality was confirmed after 24 hrs in *R. typhina* (10%). In all the other treatments, slug mortality was not confirmed (see Fig. 1B). The results of our study showed that 30% of the slugs treated with the powder of *R. typhina* died after 48 hrs. Slug mortality was also confirmed in treatments *A. fruticosa* (10%), *F. japonica* (10%), and *S. canadensis* (20%). In all the other treatments, slug mortality was not confirmed (Fig. 1B).

### Table 2. ANOVA results for the experiments A (df for the error term: 159), B (df for the error term: 159), and C (df for the error term: 259).

| Source          | Slug mortality | Feeding ability |
|-----------------|----------------|-----------------|
|                 | F   | df | p    | F   | df | p    |
| Expt. A Treatment (T) | 2.76 | 7  | 0.0100 | 2.22 | 7  | 0.0355 |
| Exposure time (DAT)   | 1.80 | 1  | 0.1818 | 0.00 | 1  | 1.0000 |

| Source          | Barrier crossing | Feeding ability |
|-----------------|------------------|-----------------|
|                 | F   | df | p    | F   | df | p    |
| Expt. B Treatment (T) | 15.83 | 7  | <0.0001 | 21.06 | 7  | <0.0001 |
| Exposure time (DAT)   | 11.84 | 1  | 0.0007 | 20.29 | 1  | <0.0001 |

### Table 3. ANOVA results for the experiment D (df for the error term: 238).

| Source          | Slug mortality | % damaged plants | % damaged leaves |
|-----------------|----------------|------------------|-----------------|
|                 | F   | df | p    | F   | df | p    | F   | df | p    |
| Expt. D Treatment (T) | 6.22 | 4  | <0.0001 | 6.39 | 4  | <0.0001 | 4.92 | 4  | <0.0001 |
| Exposure time (DAT)   | 11.68 | 2  | <0.0001 | 24.09 | 2  | <0.0001 | 16.50 | 2  | <0.0001 |
study showed that after 24 hrs, 100% of the slugs did not feed on the lettuce when the barriers were made from the powders of *S. canadensis*, *R. typhina* and *S. gigantea*. Positive results were also observed in the treatments *A. altissima* and *F. × bohemica* (90% of the slugs tested did not eat the lettuce). For more details, see Fig. 2A. The results of our study showed that after 48 hrs, when barriers were made from the powders of *R. typhina* and *S. gigantea*, 100% of slugs did not feed on the lettuce. Positive results were also observed in the *A. altissima* treatment (80% of the slugs tested did not eat the lettuce).

The efficacy of the barrier after 24 and 48 hrs is presented in Fig. 2B. Results of our study showed that after 24 hrs, the efficacy of powders (*R. typhina*, and *S. gigantea*) as slug barriers was 100%. Positive results were also observed in the *A. altissima* and *F. × bohemica* treatments (90% of the slugs tested did not cross the barrier). The results of our study showed that after 48 hrs, the efficacy of powder *R. typhina* as a slug barrier was 100%. Positive results were also observed in the *S. gigantea* treatment (90% of the slugs tested did not cross the barrier). For more details, see Fig. 2B.

**Experiment C**

The antifeedant effect of the slugs after 24 and 48 hrs at 2.5% concentration is presented in Fig. 3A.
Efficacy of invasive alien plants in controlling Arionidae slugs

Results of our study showed that after 24 hrs, 30% of the slugs did not feed on the lettuce when the leaves were treated with a liquid preparation of *S. gigantea* and *F. japonica*. Antifeedant activity was also confirmed in treatments with *S. canadensis* (20% of the slugs tested did not eat the lettuce) and *R. typhina* (10% of the slugs tested did not eat the lettuce). In all other treatments, the antifeedant effect was not confirmed. The results of our study showed that after 48 hrs, when the lettuce leaves were treated with liquid preparation of *R. typhina*, 20% of the slugs did not feed on the lettuce. Antifeedant activity was also confirmed in treatments with *S. canadensis* (10% of the slugs tested did not eat the lettuce), and *F. japonica* (10% of the slugs tested did not eat the lettuce). In all other treatments, the antifeedant effect was not confirmed (see Fig. 3A).

The antifeedant effect towards the slugs after 24 and 48 hrs at 10.0% concentration is presented in Fig. 3B. Overall, the non-tested plant powders showed satisfactory results. Moreover, the results of our study showed that after 24 hrs, 60% of the slugs did not feed on the lettuce. Antifeedant activity was also confirmed in treatments with *S. canadensis* (10% of the slugs tested did not eat the lettuce), and *F. japonica* (10% of the slugs tested did not eat the lettuce). In all other treatments, the antifeedant effect was not confirmed (see Fig. 3A).

![Figure 2](image-url). Antifeedant effect of slugs (A) and efficacy of barrier (B) among different treatments within 24/48 hrs, respectively. Average values of events (± S.E.) during experiment B, in which we studied substances as barriers for slugs (n = 10). Means with the same capital/small letter above the histogram bars are not significantly different at $p = 0.05$ (Duncan’s multiple range test) among different treatments within 24/48 hrs, respectively. Event 3: slug fed on lettuce; event 4: slug did not feed on lettuce; event 5: slug crossed the barrier; event 6: slug did not cross the barrier.
lettuce when the leaves were treated with a liquid preparation of *F. japonica*. Antifeedant activity was also confirmed in the treatments with *S. canadensis* (10% of the slugs tested did not eat the lettuce), *S. gigantea* (20% of the slugs tested did not eat the lettuce), and *A. fruticosa* (20% of the slugs tested did not eat the lettuce). The results of our study showed that after 48 hrs, 40% of the slugs did not feed on the lettuce when the leaves were treated with a liquid preparation of *F. japonica*. Antifeedant activity was also confirmed in the treatments with *S. canadensis* (10% of the slugs tested did not eat the lettuce), *F. × bohemica* (10% of the slugs tested did not eat the lettuce), and *A. fruticosa* (20% of the slugs tested did not eat the lettuce). In all other treatments, the antifeedant effect was not confirmed (see Fig. 3B).

**Experiment D**

Analysis of the percentage of the plants attacked after 24 hrs showed that there were no significant differences (F=0.70; p=0.6022) among the different treatments. Damage on the plants was recorded in all treatments except in the positive control (without slugs) (see Fig. 4A). Analysis of the percentage of attacked plants after 48 hrs showed that among the different treatments, there were significant differences (F=3.09; p=0.0391). When the lettuce was sprinkled with a liquid formulation of the compound tested, an average of 36% of the plants were attacked by slugs. When powder was used (as the slug barrier), 28% of plants were attacked. In combination with both treatments, 4% of the plants were attacked.

![Graph A](image1.png)

**Figure 3.** Antifeedant effect of slugs after 24 and 48 hrs at two concentrations: 2.5% (A) and 10.0%. Average values of events (± S.E.) during experiment C, in which we studied substances in liquid formulation against slugs (n = 10). Means with the same capital/small letter above the histogram bars are not significantly different at p = 0.05 (Duncan’s multiple range test) among different treatments within 24/48 hrs, respectively. Event 3: slug fed on lettuce; event 4: slug did not feed on lettuce.
while in the negative control, 56% of plants were attacked. For more details, see Fig. 4A. Analysis of the percentage of plants attacked after 72 hrs showed that among the different treatments, there were significant differences (F=8.04; p=0.0005). When the lettuce was sprinkled with a liquid formulation of the compound tested, an average of 44% of the plants were attacked by slugs. When powder was used (as the slug barrier), 60% of the plants were attacked. In combination with both treatments, 8% of plants were attacked, while in the negative control, 72% of the plants were attacked. For more details, see Fig. 4A.

Analysis of the percent damage after 24 hrs showed that among the different treatments, there were no significant differences (F=0.89; p=0.4864). When the lettuce was sprinkled with a liquid formulation of the tested compound, an average of 10% of the plants were damaged by slugs. When powder was used (as the slug barrier), 7% of the plants were damaged. In the negative control, 1% of the plants were damaged. Analysis of the percent damage after 48 hrs showed that among the different treatments, there were no significant differences (F=0.87; p=0.4991). When the lettuce was sprinkled with a liquid formulation of the compound tested, an average of 22% of the plants were damaged by slugs. When powder was used (as the slug barrier), 18% of the plants were damaged. In the negative control, 24% of the plants were damaged. Analysis of the percent of damage after 72 hrs showed that among the different treatments, there were no significant differences (F=2.51; p=0.0743). When the lettuce was sprinkled with a liquid formulation of the compound tested, an average of 27% of the plants were damaged by slugs. When powder was used (as the slug barrier), 40% of the plants were damaged. In the negative control, 47% of the plants were damaged. For more details, see Fig. 4B.

Analysis of the percent damage after 24 hrs showed that among the different treatments, there were no significant differences (F=0.89; p=0.4864). When the lettuce was sprinkled with a liquid formulation of the tested compound, an average of 10% of the plants were damaged by slugs. When powder was used (as the slug barrier), 7% of the plants were damaged. In the negative control, 1% of the plants were damaged. Analysis of the percent damage after 48 hrs showed that among the different treatments, there were no significant differences (F=0.87; p=0.4991). When the lettuce was sprinkled with a liquid formulation of the compound tested, an average of 22% of the plants were damaged by slugs. When powder was used (as the slug barrier), 18% of the plants were damaged. In the negative control, 24% of the plants were damaged. Analysis of the percent of damage after 72 hrs showed that among the different treatments, there were no significant differences (F=2.51; p=0.0743). When the lettuce was sprinkled with a liquid formulation of the compound tested, an average of 27% of the plants were damaged by slugs. When powder was used (as the slug barrier), 40% of the plants were damaged. In the negative control, 47% of the plants were damaged. For more details, see Fig. 4B.

Figure 4. Average% (± S.E.) of attacked plants (A) and damage (B) in experiment D (semi-field trial). Means with the same capital/small letter above the histogram bars are not significantly different at p = 0.05 (Student’s multiple range test) among different treatments within 24/48/72 hrs, respectively.
detected in surface water bodies above the EU statutory drinking water limit (Castle et al., 2017). There are also reports of the negative impact of molluscicides on non-target organisms (Bailey, 2002). Furthermore, growers and farmers often experience difficulty controlling terrestrial gastropods with conventional bait pellets containing molluscicides such as methiocarb (this molluscicide is already being withdrawn from use following the recent ban by the European Commission) and metaldehyde. Due to these problems, researchers are looking for new, more environmentally acceptable ways of protecting plants against harmful organisms, including slugs (Laznik & Trdan, 2016). Recently, the use of environmentally acceptable substances for slug control in agriculture and horticulture has gained unprecedented impetus all over the world (El-Sherbini et al., 2009; Laznik et al., 2011; González-Cruz & San Martín, 2013; Laznik & Trdan, 2016). Different natural substances are promoted due to their wide range of ideal properties, such as high target toxicity, low mammalian toxicity, low cost, and easy bio-degradability (Laznik & Trdan, 2016). One of these measures is also the use of plant extracts against slugs and snails (Barone & Frank, 1999; El-Sherbini et al., 2009; González-Cruz & San Martin, 2013). In our research (laboratory and semi-field), we studied both the contact efficacy, antifeedant and barrier efficacy with the use of plant material of seven invasive plant species, including knotweeds, goldenrods, staghorn sumac, tree of heaven, and false indigo. A novelty in our research was the idea of how invasive plants could be used to control arionid slugs.

When we rolled the slugs in tested plant powders, the highest mortality of the individuals tested was detected in surface water bodies above the EU statutory drinking water limit (Castle et al., 2017). There are also reports of the negative impact of molluscicides on non-target organisms (Bailey, 2002). Furthermore, growers and farmers often experience difficulty controlling terrestrial gastropods with conventional bait pellets containing molluscicides such as methiocarb (this molluscicide is already being withdrawn from use following the recent ban by the European Commission) and metaldehyde. Due to these problems, researchers are looking for new, more environmentally acceptable ways of protecting plants against harmful organisms, including slugs (Laznik & Trdan, 2016). Recently, the use of environmentally acceptable substances for slug control in agriculture and horticulture has gained unprecedented impetus all over the world (El-Sherbini et al., 2009; Laznik et al., 2011; González-Cruz & San Martín, 2013; Laznik & Trdan, 2016). Different natural substances are promoted due to their wide range of ideal properties, such as high target toxicity, low mammalian toxicity, low cost, and easy bio-degradability (Laznik & Trdan, 2016). One of these measures is also the use of plant extracts against slugs and snails (Barone & Frank, 1999; El-Sherbini et al., 2009; González-Cruz & San Martin, 2013). In our research (laboratory and semi-field), we studied both the contact efficacy, antifeedant and barrier efficacy with the use of plant material of seven invasive plant species, including knotweeds, goldenrods, staghorn sumac, tree of heaven, and false indigo. A novelty in our research was the idea of how invasive plants could be used to control arionid slugs.

Discussion

Due to the price and other benefits, molluscicides represent the most common strategy in terrestrial gastropod control programmes. Molluscicides are considered emerging pollutants and are frequently detected in surface water bodies above the EU statutory drinking water limit (Castle et al., 2017). There are also reports of the negative impact of molluscicides on non-target organisms (Bailey, 2002). Furthermore, growers and farmers often experience difficulty controlling terrestrial gastropods with conventional bait pellets containing molluscicides such as methiocarb (this molluscicide is already being withdrawn from use following the recent ban by the European Commission) and metaldehyde. Due to these problems, researchers are looking for new, more environmentally acceptable ways of protecting plants against harmful organisms, including slugs (Laznik & Trdan, 2016). Recently, the use of environmentally acceptable substances for slug control in agriculture and horticulture has gained unprecedented impetus all over the world (El-Sherbini et al., 2009; Laznik et al., 2011; González-Cruz & San Martín, 2013; Laznik & Trdan, 2016). Different natural substances are promoted due to their wide range of ideal properties, such as high target toxicity, low mammalian toxicity, low cost, and easy bio-degradability (Laznik & Trdan, 2016). One of these measures is also the use of plant extracts against slugs and snails (Barone & Frank, 1999; El-Sherbini et al., 2009; González-Cruz & San Martin, 2013). In our research (laboratory and semi-field), we studied both the contact efficacy, antifeedant and barrier efficacy with the use of plant material of seven invasive plant species, including knotweeds, goldenrods, staghorn sumac, tree of heaven, and false indigo. A novelty in our research was the idea of how invasive plants could be used to control arionid slugs.

When we rolled the slugs in tested plant powders, the highest mortality of the individuals tested was detected in surface water bodies above the EU statutory drinking water limit (Castle et al., 2017). There are also reports of the negative impact of molluscicides on non-target organisms (Bailey, 2002). Furthermore, growers and farmers often experience difficulty controlling terrestrial gastropods with conventional bait pellets containing molluscicides such as methiocarb (this molluscicide is already being withdrawn from use following the recent ban by the European Commission) and metaldehyde. Due to these problems, researchers are looking for new, more environmentally acceptable ways of protecting plants against harmful organisms, including slugs (Laznik & Trdan, 2016). Recently, the use of environmentally acceptable substances for slug control in agriculture and horticulture has gained unprecedented impetus all over the world (El-Sherbini et al., 2009; Laznik et al., 2011; González-Cruz & San Martín, 2013; Laznik & Trdan, 2016). Different natural substances are promoted due to their wide range of ideal properties, such as high target toxicity, low mammalian toxicity, low cost, and easy bio-degradability (Laznik & Trdan, 2016). One of these measures is also the use of plant extracts against slugs and snails (Barone & Frank, 1999; El-Sherbini et al., 2009; González-Cruz & San Martin, 2013). In our research (laboratory and semi-field), we studied both the contact efficacy, antifeedant and barrier efficacy with the use of plant material of seven invasive plant species, including knotweeds, goldenrods, staghorn sumac, tree of heaven, and false indigo. A novelty in our research was the idea of how invasive plants could be used to control arionid slugs.
recorded in R. typhina (30%). These results also led to very low feeding inhibitor effects in experiment A. Klingauf et al. (1988) reported that plant extracts from R. typhina have insecticidal efficacy against aphids (up to 70%). Furthermore, laboratory studies have shown that R. typhina plant extracts also have bactericidal and fungicidal efficacy (Mosch et al., 1989; Rayne & Mazza, 2007). Until now, there had been no reports on the molluscicidal efficacy of R. typhina.

In the second experiment (B), the plant powder of selected plants was used as a barrier for the slugs. After 48 hrs, none of tested slugs fed on lettuce when the barrier was made from the plant powder of R. typhina and S. gigantea. None of the slugs crossed the barrier made of R. typhina; however, 10% of the slugs that crossed the barrier made of S. gigantea did not feed on the lettuce. In all the treatments, the slugs observed produced a large amount of mucus. The effect of the plant powders is similar to that of wood ash and hydrated lime, as all substances cause dehydration of the cuticle and blockage of the airways (Laznik & Trdan, 2016). Prior (1985) reported that slugs are susceptible to dehydration due to evaporative water loss across their body and lung surface and through the deposition of their slime trail. Mucus production is an energy-wasting process that could also impact the feeding behaviour of slugs. More detailed experiments are merited to confirm this thesis in the future.

In experiment C, our goal was to determine whether the foliar application of the tested plant material in a liquid formulation has any effect on reducing the feeding ability of the individuals tested. In our investigation, the concentration of plant water extracts (2.5% or 10% w/v) had no influence on slug feeding behaviour. At both concentrations tested, the best anti-feedant effect was confirmed with the F. japonica plant water extract, with slug feeding reduced by up to 40%. The use of knotweed plant extracts had only been cited to control plant diseases, such as powdery mildew (Herger et al., 1988; Neuhaus & Pallut, 1992; Konstantinidou-Doltcins et al., 2006), or mites (Tetranychus urticae) (Tomczyk, 2006).

In experiment D, our goal was to investigate different techniques of using plant material (as a barrier or foliar liquid formulation) under semi-field conditions. For this matter, only S. gigantea plant material was used. The best results were obtained when we used the combination of both techniques (only 7% of plants were attacked by slugs). In the control treatment, over 70% of plants were attacked by slugs. The most important biologically active compounds in goldenrod plants are flavonoids, saponins and terpenes (Starks et al., 2010). The literature concerning the use of plant extracts with a high content of saponins for the control of terrestrial gastropods is limited. The published reports are mainly related to egg control, feed deterrence, seed treatment and the formulation of baits (Winder & Friedrich, 1996; Barone & Frank, 1999; Iglesias et al., 2002; González-Cruz & San Martin, 2013). González-Cruz & San Martín (2013) concluded in their investigation that the application of plant extracts with a high content of saponins could be a good means for controlling slugs because saponin residues have been demonstrated to be safe in foods and agronomic products in the USA, EU and Japan. However, the results of our investigation confirmed a high level of phytotoxicity when the lettuce was treated with a combination of powder and liquid formulation. More than 10% of lettuce leaves showed phytotoxic symptoms. Phytotoxicity could be related to the use of a high concentration (10%) of plant extract in our investigation. To support our assumption, further investigation is needed.

The underlying principle of integrated slug control is to reduce the risk of slug damage by means of cultural practices, if possible, and apply molluscicides if necessary. Biological control (P. hermaphroditus) has a role to play, together with other techniques that are especially relevant to organic growers (Wilson et al., 1993; Schüder et al., 2003; Laznik et al., 2011; Laznik & Trdan, 2016). It is important not to attempt to eradicate slugs completely but simply aim to limit their damage to economically acceptable levels. Slug control in organic systems presents particular problems because the use of chemicals is substantially restricted. Various methods of slug control are recommended for organic growers, but most are untested and unproven. Our study showed that plant material (dry or in liquid formulation) could represent an alternative solution for private gardens in plant protection against slugs. However, there are still many challenges to overcome (phytotoxicity and economics) in further studies. In addition, the potential challenges are the risk of using products derived from invasive pants, as many of the plant species tested in our paper are controlled by legislation throughout the EU.

Acknowledgements

Special thanks are given to Jaka Rupnik, Kaja Ber- gant, Sergeja Adamič and Tilen Zamljen for their technical assistance.
References

Ahmadi E, 2004. A faunal study on snails and slugs on canola as a second cropping in paddy fields in Guilan and Mazandaran provinces. J Agric Sci 1: 69-82 [In Persian].

Azwani A, 2015. A review on the extraction methods use in medicinal plants, principle, strength and limitation. Med Aromat Plants 4, 196.

Bailey SER, 2002. Molluscidical baits for control of terrestrial gastropods. In: Molluscs as crop pests; Barker GM (ed.). CAB Int, Wallingford, UK, pp. 33-54. https://doi.org/10.1079/9780851993201.0033

Barker GM, 2002. Gastropods as pests in New Zealand pastoral agriculture, with emphasis on Agriolimacidae, Arionidae and Milacidae. In: Molluscs as crop pests; Barker GM (ed.). CAB Int, Wallingford, UK, pp. 361-421. https://doi.org/10.1079/9780851993201.0361

Barone M, Frank T, 1999. Effects of plant extracts on the feeding behaviour of the slug Arion lusitanicus. Ann Appl Biol 134: 341-345. https://doi.org/10.1111/j.1744-7348.1999.tb05274.x

Berger B, Dallinger R, 1989. Accumulation of cadmium and copper by the terrestrial snail Arianta arbustorum L.: Kinetics and budgets. Oecologia 79 (1): 60-65. https://doi.org/10.1007/BF00378270

Carne-Cavagnaro VL, Keller MA, Baker GH, 2006. Soil moisture and soil type influence the breeding behavior of the pest snail Cernuella virgata (da Costa). Appl Soil Ecol 33: 235-242. https://doi.org/10.1016/j.apsoil.2005.10.005

Castle GD, Mills GA, Gravell A, Jones L, Townsend I, Cameron DG, Fones GR, 2017. Review of the molluscicide metaldehyde in the environment. Environ Sci Water Res Technol 3: 415-428. https://doi.org/10.1039/C7EW00039A

Douglas MR, Tooker JF, 2012. Slug (Mollusca: Agriolimacidae, Arionidae) ecology and management in no-till field crops, with an emphasis on the mid-Atlantic region. J Integr Pest Manag 3: 1-9. https://doi.org/10.1603/IPM11023

El-Sherbini GT, Zayed RA, El-Sherbini ET, 2009. Molluscidical activity of some Solanum species extracts against the snail Biomphalaria alexandrina. J Parasitol Res 2009: 1-5. https://doi.org/10.1155/2009/474360

Garthwaiq DG, Thomas MR, 1996. The usage of molluscicides in agriculture and horticulture in Great Britain over the last 30 years. In: Slug & snail pests in agriculture and horticulture in Great Britain over the last 30 years. In: Slug & snail pests in agriculture; Henderson IF (ed), Brit Crop Prot Council, Farnham, UK, pp. 39-46.

González-Cruz D, San Martin R, 2013. Molluscidical effects of saponin-rich plant extracts on the grey field slug. Cien Inv Agr 40: 341-349. https://doi.org/10.4067/S0718-16202013000200009

Hammond RB, Byers RA, 2002. Agriolimacidae and Arionidae as pests in conservation-tillage soybean and maize cropping in North America. In: Molluscs as crop pests; Barker GM (ed.). CAB Int, Wallingford, UK, pp. 301-314. https://doi.org/10.1079/9780851993201.0301

Hata TY, Hara AH, Hu BKS, 1997. Molluscicides and mechanical barriers against slugs Vaginula plebeia Fischer and Veronica cubensis (Pfeiffer) (Stylommatophora: Veronicellidae). Crop Prot 16: 501-506. https://doi.org/10.1016/S0261-2194(97)00034-3

Henderson I, Triebkorn R. 2002. Chemical control of terrestrial gastropods. In: Molluscs as crop pests; Barker GM (ed.). CABI Publ, Wallingford, UK, pp. 1-31. https://doi.org/10.1079/9780851993201.0001

Herger G, Klingauf F, Mangold D, Pommer E-H, Scherer M, 1988. Efficacy of extracts of Reynoutria sachalinensis F. Schmidt Nakai Polygonaceae, against fungal diseases, especially powdery mildew. Nachrbl Deut Pflanzen schutz 40: 56-60.

Hoshmand AR, 2006. Design of experiments for agriculture and the natural science, 2nd ed. Chapman & Hall/CRC Press, Boca Raton, FL, USA. 456 pp.

Iglesias J, Castillejo J, Ester A, 2002. Laboratory evaluation of potential molluscicides for the control of eggs of the pest slug Deroceras reticulatum (Muller) (Pulmonata: Limacidae). Int J Pest Manage 48: 19-23. https://doi.org/10.1080/09670870110062553

Iglesias J, Castillejo J, Castro R, 2003. The effects of repeated applications of the molluscicide metaldehyde and the biocontrol nematode Phasmarhabditis hermaphroditida on molluscs, earthworms, nematodes, acarids and colembolans: a two-year study in north-west Spain. Pest Manag Sci 59: 1217-1224. https://doi.org/10.1002/ps.758

Klingauf F, Stein U, Bestmann HJ, Vostrowsky O, Classen B, Kobold U, 1988. Herbal insecticides. 6. Effects of an ethanolic leaf extract of Buck’s horn (Rhus typhina L.) on different pest insects. J Appl Entomol 105: 41-47.

Konstantinidou-Doltsinis S, Markellou E, Kasselaki AM, Fanouraki MN, Koumaki CM, Schmitt A, Liopa-Tsakalidis A, Malathrakis NE, 2006. Efficacy of Miliana®, a formulated plant extract from Reynoutria sachalinensis, against powdery mildew of tomato (Leveillula taurica). BioControl 51: 375-392. https://doi.org/10.1007/s10526-005-5247-1

Kozłowski J, 2005. Host plants and harmfulness of the Arion lusitanicus Mabille, 1868 slug. J Plant Prot Res 45: 221-233.

Kozłowski J, 2007. The distribution, biology, population dynamics and harmfulness of Arion lusitanicus Mabille, 1868 (Gastropoda: Pulmonata: Arionidae) in Poland. J Plant Prot Res, 47: 219-230.

Laznik Z, Križaj D, Trdan S, 2011. The effectiveness of electrified fencing using copper electrodes for slug (Arion spp.) control with direct electric current and voltage. Span J Agric Res 9: 894-900. https://doi.org/10.5424/sjar/20110903-412-10

Laznik Z, Križaj D, Trdan S, 2011. The effectiveness of electrified fencing using copper electrodes for slug (Arion spp.) control with direct electric current and voltage. Span J Agric Res 9: 894-900. https://doi.org/10.5424/sjar/20110903-412-10

Laznik Z, Trdan S, 2016. Is a combination of different natural substances suitable for slug (Arion spp.) control? Span J Agric Res 14 (3): e1004. https://doi.org/10.5424/sjar/2016143-9053

Laznik Z, Bohine T, Trdan S, 2018. Applicability of invasive alien plants in controlling harmfull organisms of cultivated plants. Acta Agron Slovenica 111: 501-509 [In Slovenian]. https://doi.org/10.14720/aas.2018.111.2.22

Mosch J, Klingauf F, Zeller W, 1989. On the effect of plant extracts against fireblight (Erwinia amylovora). Acta Hortic 273: 355-361. https://doi.org/10.17660/ActaHortic.1990.273.52
Efficacy of invasive alien plants in controlling Arionidae slugs

Simms LC, Ester A, Wilson MJ, 2006. Control of slug damage to oilseed rape and wheat with imidacloprid seed dressings in laboratory and field experiments. Crop Prot 25: 549-555. https://doi.org/10.1016/j.cropro.2005.08.011

Slotsbo S, Hansen LM, Holmstrup M, 2011. Low temperature survival in different life stages of the Iberian slug, Arion lusitanicus. Cryobiology 62: 68-73. https://doi.org/10.1016/j.cryobiol.2010.12.005

Slotsbo S, Damgaard C, Hansen LM, Holmstrup M, 2013. The influence of temperature on life history traits in the Iberian slug, Arion lusitanicus. Ann Appl Biol 162: 80-88. https://doi.org/10.1111/aab.12003

Speiser B, Kistler C, 2002. Field tests with a molluscicide containing iron phosphate. Crop Prot 21: 389-394. https://doi.org/10.1016/S0261-2194(01)00120-X

Starks CM, Williams RB, Goering MG, O’Neil-Johnson M, Norman VL, Hu JF, Hough GW, Rice SM, Eldridge GR, 2010. Antibacterial clerodane diterpenes from Goldenrod (Solidago virgaurea). Phytochemistry 71: 104-109. https://doi.org/10.1016/j.phytochem.2009.09.032

Tomczyk A, 2006. Nutritious attractiveness of cucumber leaves to spider mites after treatment with selected inducers of plant resistance. Prog Plant Prot 46: 433-436. https://www.redalyc.org/pdf/302/30211234009.pdf

Rowson B, Anderson R, Turner JA, Symondson WOC, 2014. The slugs of Britain and Ireland: undetected and undescribed species increase a well-studied, economically important fauna by more than 20%. PLoS ONE 9: 1-21. https://doi.org/10.1371/journal.pone.0091907

Ryder TA, Bowen ID, 1977. The slug foot as a site of uptake of copper molluscicide. J Invertebr Pathol 30: 381-386. https://doi.org/10.1016/0022-1911(77)90149-5

Schüder I, Port G, Bennison J, 2003. Barriers, repellents and antifeedants for slug and snail control. Crop Prot 22: 1033-1038. https://doi.org/10.1016/S0261-2194(03)00120-0

Spanish Journal of Agricultural Research

March 2020 • Volume 18 • Issue 1 • e1001