The effect of grazing by the slug *Arion vulgaris*, *Arion rufus* and *Deroceras reticulatum* (Gastropoda: Pulmonata: Stylommatophora) on leguminous plants and other small-area crops

Jan Kozłowski, Monika Jaskulska*

Institute of Plant Protection – National Research Institute
Władysława Węgorka 20, 60-318 Poznań, Poland

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Abstract: Herbivorous slugs do significant damage to many species of crop plants. A laboratory study was conducted to determine the rate and extent of damage caused to 16 plant species by *Arion vulgaris*, *Arion rufus*, and *Deroceras reticulatum*. It was found, that levels of damage caused to young plants of *Brassica napus*, *Sorghum bicolor*, *Vicia faba*, and *Sinapis alba* by the slugs *A. vulgaris*, *A. rufus*, and *D. reticulatum* were similar, while levels of damage caused to the other studied plants by particular slug species differed significantly. Based on the results of the damage by the investigated slug species, plants were categorised as heavily or lightly damaged.

Key words: plant damage, slugs, small-area crops

Introduction

Small-area crops are gaining in economic importance in modern agriculture, particularly leguminous and oleaginous plants. Such plants may be an alternative to certain plants cultivated on large areas. The growth of interest in this type of cultivation results from the need to satisfy the increased requirements of consumers and animal breeders for appropriate plant products. Interest in this type of cultivation also results from a desire to maintain biodiversity in agricultural ecological communities. Many problems arise when cultivating small-area crops. These problems are chiefly related to plant protection. A basic task is to evaluate the degree to which various species of agricultural pests pose a threat to such crops. Significant pests include herbivorous terrestrial gastropods (Gastropoda: Pulmonata: Stylommatophora), which often do significant amounts of damage to crops of this type. In the last 20 years, these animals, particularly slugs, have been among the most significant pests of plants in central and north-western Europe (Port and Port 1986; South 1992; Frank 1998; Glen and Moens 2002; Moens and Glen 2002; Port and Ester 2002; Kozłowski 2012). They feed on living and dead plants and on animal food, although plants are the main component of their diet. They prefer to graze on fresh plant material, particularly the young and delicate organs of plants. They are identified among herbivores as organisms with a very wide dietary range (Speiser *et al*. 1992; Briner and Frank 1998; Clark *et al*. 1999; Keller *et al*. 1999). However, there are differing degrees of damage to particular species and varieties of plants. The various food preferences of the slugs are determined by a plants' biochemical composition, and particularly by a plant's secondary metabolites (Cates and Orians 1975; Dirzo 1980; Webbe and Lambert 1983; Molgaard 1986; Clark *et al*. 1997). Previous research has shown that particular slug species have specific nutritional requirements. This means that damage levels may differ significantly between plant species and varieties. This has been confirmed in research on different herbaceous and wildflower plants with respect to the slugs *Deroceras reticulatum* (O.F. Müller, 1774), *Arion lusitanicus* Mabille, 1868 and *A. ater* Linnaeus, 1758 (Duval 1971; Cates and Orians 1975; Jennings and Barkham 1975; Dirzo 1980; Molgaard 1986; Cook *et al*. 1996; Frank 1998; Kozłowski and Kozłowska 2000, 2009). There is also variation in the degree of damage done by slugs to crop plants. The existing information on this subject is fragmentary and relates only to a few plants, which including *Brassica napus* L. var. *oleifera, B. rapa* L. var. *pekinensis*, *Daucus carota* L., *Sinapis arvensis* L., *S. alba* L. and *Cichorium intybus* L. (Briner and Frank 1998; Frank 1998; Kozłowski 2005).

The slugs studied in the present work – *D. reticulatum*, *Arion vulgaris* Moquin Tandon, 1885 (previously known in central and north-western Europe as *A. lusitanicus* Mabille, 1868) (Anderson 2005), and *A. rufus* Linnaeus, 1758 are among the most significant and harmful slug species occurring on crops in Europe.

The most widespread is *D. reticulatum*. This species is common in many European and Asian countries, and also occurs in habitat islands in the Balkans (Port and

*Corresponding address:
j.kozlowski@iorpib.poznan.pl

Port 1986; South 1992). These slugs have been brought to, and spread in, North and South America, South Africa, the islands of the Atlantic and Indian Ocean, Australia, Tasmania, and New Zealand (Godan 1983; Barker 1999). Except in high mountain regions, *D. reticulatum* is found throughout Poland (Wiktor 2004). This slug attains a length of 45 mm. As a result of agricultural intensification, the use of new plant varieties, and changes in agricultural technology, *D. reticulatum* often appears in large numbers and does catastrophic damage to agricultural crops, particularly winter rape and winter wheat (Glen and Moens 2002; Moens and Glen 2002). It is also found in gardens and on small-area crops, where it damages vegetables, leguminous plants and others (Aguiar and Wink 1999; Byers 2002; Port and Ester 2002).

A. vulgaris originates from the Iberian Peninsula. This invasive species has spread to many European countries, including Poland (Frank 1998; Grimm 2001; Glen and Moens 2002; Moens and Glen 2002; Port and Ester 2002; Kozłowski 2005, 2012). It does very serious damage to various species of vegetables and to certain agricultural, ornamental, orchard, and herbaceous plants. It is most destructive to young garden plants and to germinating winter rape and winter wheat on the edges of farm fields (South 1992; Frank 1998; Frank and Friedli 1998; Port and Ester 2002; Moens and Glen 2002; Kozłowski 2005, 2007). It appeared in Poland in the late 1980s. *A. vulgaris* initially occurred only in the region of Rzeszów (Kozłowski and Kornobis 1995) but it is now found on crops in 10 of the 16 Polish provinces, chiefly in the south-eastern, central, and western parts of the country (Kozłowski 2012). As in many other countries of Europe, it has become the most significant slug pest in gardens and on small-area crops (Kozłowski 2012).

A. rufus is found in continental western Europe and parts of central Europe (Riedel and Wiktor 1974; Wiktor 2004). In northern Europe it is found in Great Britain and in Scandinavia (Anderson 2005). It has also been carried to the United States and Canada (Forsyth 2004). The northern boundary of the natural range of this slug runs along the southern Baltic coast, while its eastern boundary passes through Poland, the Czech Republic, Austria, and Hungary. In the case of Poland, it is found in the west of the country and in certain places in the south (Riedel and Wiktor 1974). Originally, *A. rufus* occurred in forests and in the vicinity of watercourses and water bodies, but it now colonises various crop plants (Wiktor 2004; Kozłowski 2012). It can be encountered in gardens and on the edges of fields, where it occurs in very large numbers. Similar to *A. vulgaris*, adult specimens of this slug are up to 150 mm long. *A. rufus* causes the most damage to vegetable crops and ornamental and herbaceous plants. Locally it damages certain agricultural crops, such as winter rape and winter wheat, as well as leguminous plants and some others (Kozłowski 2012). Over the last two decades, *A. rufus* has come to be displaced by *A. vulgaris*, and the intensity of the occurrence of *A. rufus* is decreasing in certain places (Keller *et al*. 1999; Kozłowski and Kozłowska 2000, 2009).

The purpose of the present research was to compare the degree of damage done to small-area crop plants by the slugs *A. vulgaris*, *A. rufus*, and *D. reticulatum*, and to determine the potential threat posed by those slugs to particular species of plants.

Materials and Methods

The slugs of the species *A. vulgaris* and *A. rufus* used in the experiments were hatched from eggs collected in autumn 2012, in gardens in the vicinity of the city of Poznań (*A. vulgaris*) and Wronki (*A. rufus*). The eggs were kept in closed containers (16 × 11 × 7 cm) containing soil. These containers were kept in the dark at a temperature of 16°C. After hatching, the slugs were transferred to larger semi-transparent plastic containers (26 × 26 × 14 cm) one-fifth full of soil. Food was provided and replaced three times a week (cabbage leaves, potato tubers, carrot roots, and wheat bran with calcium carbonate). The slugs were kept in a climate chamber at a temperature of 16°C, relative humidity (RH) 70±3%, with a day length of 12 h. Before the start of the tests, the slugs (3–3.5 months old) were starved for 48 h. The slugs' average weights (±standard deviation) were as follows: *A. vulgaris* 1.43±0.17 g, *A. rufus* 1.23±0.06 g, *D. reticulatum* 0.38±0.06 g.

Tests were carried out on plants of 16 species. The specified varieties (Table 1) used included winter oilseed rape and Chinese cabbage, which were used as the control treatments. The plants were obtained from the greenhouses of the Institute of Plant Protection – National Research Institute in Poznań, grown from seeds sown in palettes. Plants at the 3–5 true leaf stage were planted in a 5 cm layer of humic clay soil in closed plastic containers (26 × 26 × 14 cm). The containers were gauze-covered with ventilation holes. In each container, five plants of the same species were planted. One slug was put into each container. The containers with the plants and slugs were moved to a climate chamber with a temperature of 16°C, RH 70±3% and a photoperiod of 12 h. Observations were made every two days, with the degree of slug damage to the plants being evaluated according to a five-point scale (0; 25; 50; 75 and 100% damaged plant surface area). Five replications (containers) were made for each species of plant and slug. The averages obtained from the observations for each experimental unit were subjected to analysis of variance. Fisher's test was applied at a significance level of $\alpha = 0.05$ (Statistica ver. 10). For classification of the 16 studied plant species in terms of the incremental damage caused by the slugs, cluster analysis was performed, using Euclidean distance in a multidimensional space (Statistica ver. 10).

Results

Damage to plants caused by *A. vulgaris*

After the first day of grazing by *A. vulgaris*, the significantly most heavily damaged plants were *B. napus* and *Ornithopus sativus* L. (ca. 50% damage), and the least damaged were *Phacelia tanacetifolia* Benth. (5.0%) (Table 2). After three days, in addition to *B. napus* and *O. sativus*, heavy damage was also recorded for *Vicia sativa* L. and *Papaver somniferum* L. The degree of damage to these

Table 1. Species and varieties of plants used in the study

Species of plants		Varieties
species name	common name	
Brassica napus L. var. *oleifera*	oilseed rape	Bazyl
B. rapa L. var. *pekinensis*	Chinese cabbage	Hilton
Cichorium intybus L.	salad chicory	Monitor
Glycine max (L.) Merril	soya bean	Aldana
Helianthus annuus L.	sunflower	LG 53,85
Lens esculenta Mnch.	lentil	Anita
Lupinus luteus L.	yellow lupin	Dukat
Ornithopus sativus L.	serradella	Bazyl
Papaver somniferum L.	poppy	Mieszko
Phacelia tanacetifolia Benth.	phacelia	Stala
Pisum sativum L.	garden pea	Telefon
P. sativum L. subsp. *arvense*	field pea	Milwa
Sinapis alba L.	white mustard	Maryna
Sorghum bicolor (L.) Moench.	sorghum	Sucrosorgo
Vicia faba L.	field bean	Bobas
V. sativa L.	common vetch	Hanka

Table 2. Degrees of damage caused by *A. vulgaris* to various small-area crop plants (%), and results of Fisher's test at $\alpha = 0.05$

Species of plants	Days of slug feeding			
	1	5	9	13
Brassica napus var. *oleifera*	53.3 e	83.3 f	92.8 de	98.3
B. rapa var. *pekinensis*	12.0 ab	36.0 b	53.0 bc	67.5
Cichorium intybus	11.0 ab	68.0 de	98.0 de	100.0
Glycine max	18.0 bc	40.0 bc	64.0 c	76.0
Helianthus annuus	21.0 bcd	59.0 d	81.0 d	100.0
Lens esculenta	13.0 ab	54.0 cd	89.0 de	100.0
Lupinus luteus	10.0 ab	27.0 ab	41.0 ab	58.0
Ornithopus sativus	52.0 e	97.0 f	100.0 e	100.0
Papaver somniferum	32.0 cd	93.0 f	99.0 e	100.0
Phacelia tanacetifolia	5.0 a	32.0 ab	57.0 bc	65.0
Pisum sativum	11.0 ab	19.0 a	31.0 a	37.0
P. sativum subsp. *arvense*	12.0 ab	31.0 ab	40.0 ab	51.0
Sinapis alba	9.0 ab	28.0 ab	46.0 abc	57.0
Sorghum bicolor	7.0 ab	23.0 ab	30.0 a	41.0
Vicia faba	11.0 ab	28.0 ab	55.0 bc	67.0
V. sativa	37.0 d	80.0 ef	98.0 de	100.0

Numbers in columns with at least one letter the same do not differ significantly at $\alpha = 0.05$

plants was from 69.0% to 77.0%, while the least damaged were plants of *Sorghum bicolor* (L.) Moench (15.0%). After five days, the plants most heavily damaged by slugs were *O. sativus* (97.0%), *P. somniferum* (93.0%), and *B. napus* (83.3%). The least damaged plants were *Pisum sativum* L. (19.0%). After nine days, *O. sativus* plants had been 100% consumed, and *Cichorium intybus* L., *V. sativa*, and *P. somniferum* had 98–99% damage. The degree of damage to the *S. bicolor* and *P. sativum* plants after nine days, was significantly the least, being around 30%, increasing to about 40% after 13 days.

Damage to plants caused by *A. rufus*

After the first day of grazing by *A. rufus*, the greatest damage was observed on the *V. sativa* (35.0%) and *Glycine max* (L.) Merril (28.0%) plants, while the least was found on *O. sativus* (4.0%) (Table 3). After three days, the most damaged plants were *C. intybus*, *V. sativa*, and *Helianthus annuus* L. (ca. 50% damage), while the least damaged were *V. faba* and *S. bicolor* (up to 11.0%). After five days, significantly the most heavily damaged plants were *C. intybus* (75.0%), *H. annuus* (60%), and *V. sativa*

(58.0%), while the least damaged were *V. faba* (8.0%) and *S. bicolor* (12.0%). After nine days, the degree of damage to *C. intybus*, *H. annuus*, and *V. sativa* had risen to 87.0%, 78.0%, and 77.0%, respectively, while the least damaged were again *V. faba* (13.0%) and *S. bicolor* (18.0%). After a further two days' grazing by slugs, there was a slight rise in the degree of damage. The differentiation in the degree of damage to the studied plant species was similar as on previous days.

Damage to plants caused by *D. reticulatum*

As in the case of the two aforementioned slugs, the amount of damage to plants caused by *D. reticulatum* was significantly differentiated after just 24 h of grazing (Table 4). The greatest damage was observed on the *H. annuus* and *B. rapa* plants (12.0–13.0%), and the least on *G. max* (2.0%). After five days, there was heavy damage to *B. rapa* (38.3%) and *B. napus* (32.7%), while the least dam-

Table 3. Degrees of damage caused by *A. rufus* to various small-area crop plants (%), and results of Fisher's test at $\alpha = 0.05$

Species of plants	Days of slug feeding			
	1	5	9	13
Brassica napus var. *oleifera*	11.7 abc	41.7 cd	65.6 def	82.8 e–h
B. rapa var. *pekinensis*	16.0 bcd	58.5 de	66.5 def	74,0 efg
Cichorium intybus	23.0 cde	75.0 e	87.0 f	95.0 h
Glycine max	28.0 e	38.0 cd	66.0 def	86.0 fgh
Helianthus annuus	25.0 de	60.0 de	78.0 ef	98.0 h
Lens esculenta	10.0 abc	27.0 abc	43.0 bcd	72.0 d–g
Lupinus luteus	7.0 ab	39.0 cd	67.0 def	92.0 gh
Ornithopus sativus	4.0 a	32.0 abc	51.0 cde	63.0 cde
Papaver somniferum	10.0 abc	37.0 bcd	52.0 cde	76.0 e–h
Phacelia tanacetifolia	22.0 b–e	42.0 cd	57.0 cde	67.0 c–f
Pisum sativum	10.0 abc	23.0 abc	33.0 abc	45.0 bc
P. sativum subsp. *arvense*	6.0 ab	24.0 abc	31.0 abc	39.0 ab
Sinapis alba	13.0 a–d	27.0 abc	35.0 abc	52.0 bcd
Sorghum bicolor	7.0 ab	12.0 ab	18.0 ab	32.0 ab
Vicia faba	6.0 ab	8.0 a	13.0 a	20.0 a
V. sativa	35.0 e	58.0 de	77.0 ef	86.0 fgh

Numbers in columns with at least one letter the same do not differ significantly at $\alpha = 0.05$

Table 4. Degrees of damage caused by *D. reticulatum* to various small-area crop plants (%), and results of Fisher's test at $\alpha = 0.05$

Species of plants	Days of slug feeding			
	1	5	9	13
Brassica rapa var. *oleifera*	9.0 b–e	32.7 de	48.7 ef	70.0 e
B. rapa var. *pekinensis*	12.3 e	38.3 e	55.0 f	72.3 e
Cichorium intybus	8.0 a–e	14.0 abc	21.0 a–d	21.0 abc
Glycine max	2.0 a	19.0 abc	30.0 a–e	43.0 cd
Helianthus annuus	13.0 e	18.0 abc	25.0 a–d	36.0 cd
Lens esculenta	12.0 cde	28.0 cde	34.0 cde	44.0 cd
Lupinus luteus	7.0 a–e	10.0 ab	15.0 abc	20.0 abc
Ornithopus sativus	12.0 cde	24.0 bcd	29.0 a–d	34.0 bcd
Papaver somniferum	3.0 ab	15.0 abc	27.0 a–d	36.0 cd
Phacelia tanacetifolia	7.0 a–e	16.0 abc	42.0 def	56.0 de
Pisum sativum	6.0 a–d	10.0 ab	20.0 a–d	34.0 bcd
P. sativum subsp. *arvense*	8.0 a–e	23.0 bcd	34.0 cde	55.0 de
Sinapis alba	3.0 ab	5.0 a	10.0 ab	10.0 ab
Sorghum bicolor	4.0 ab	5.0 a	8.0 a	20.0 abc
Vicia faba	4.0 ab	6.0 a	6.0 a	7.0 a
V. sativa	5.0 abc	19.0 abc	32.0 b–e	42.0 cd

Numbers in columns with at least one letter the same do not differ significantly at $\alpha = 0.05$

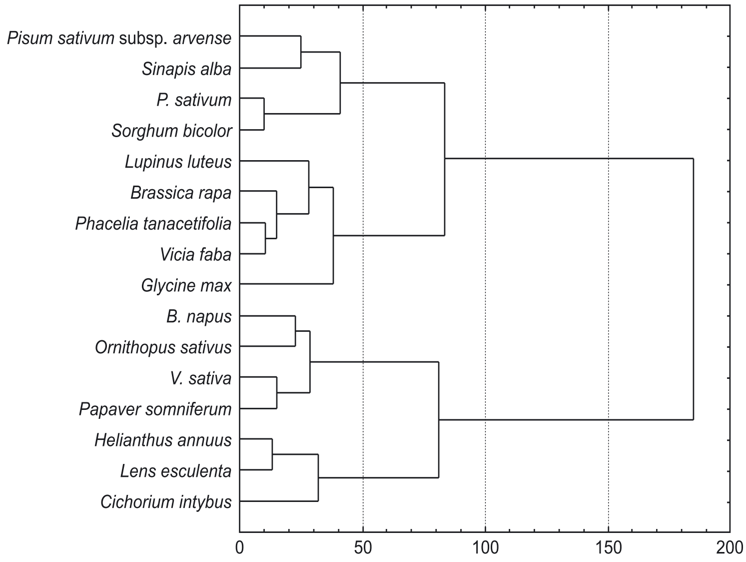

Fig. 1. Cluster analysis – a dendrogram using Euclidean distance for 16 plant species damaged by *A. vulgaris*

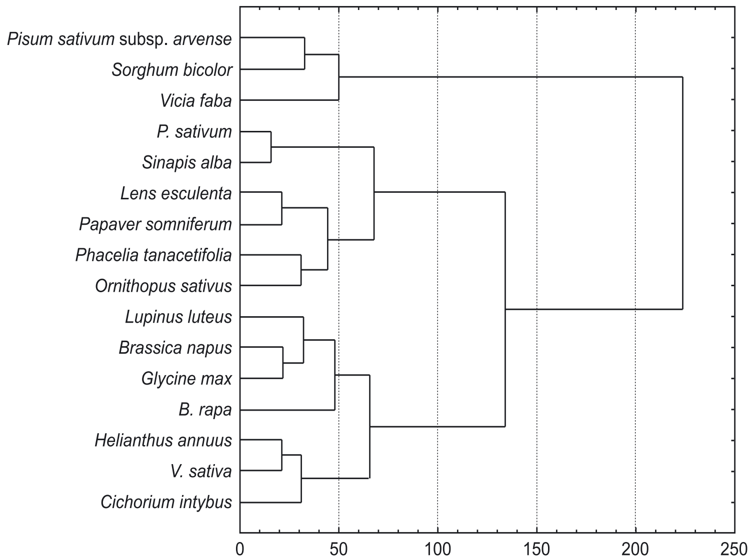

Fig. 2. Cluster analysis – a dendrogram using Euclidean distance for 16 plant species damaged by *A. rufus*

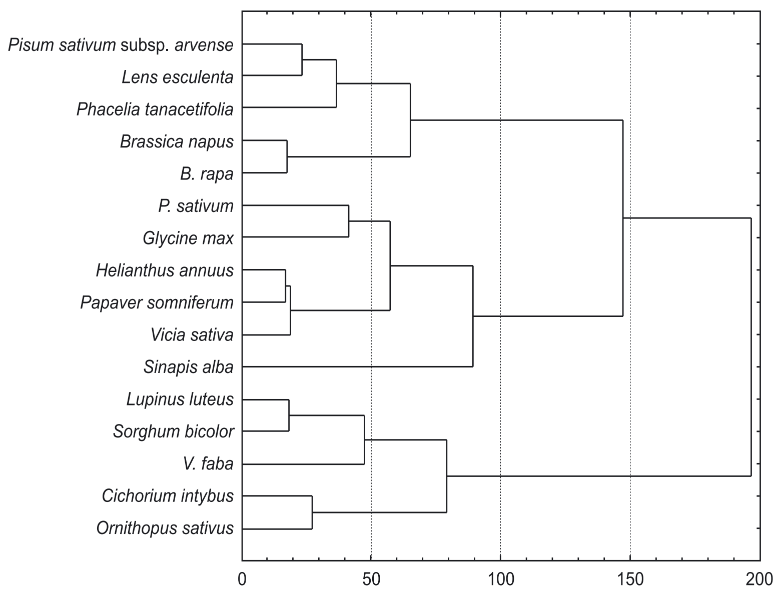

Fig. 3. Cluster analysis – a dendrogram using Euclidean distance for 16 plant species damaged by *D. reticulatum*

aged plants were *S. bicolor*, *S. alba*, and *V. faba* (5.0–6.0%). From the ninth day onwards, the most damaged plants were *Brassica rapa* and *B. napus* as well as *P. tanacetifolia*. On the ninth day, the levels of damage to *B. rapa*, *B. napus*, and *P. tanacetifolia* were 55.0%, 48.7%, and 42.0%, respectively. The damage to *V. faba*, *S. bicolor*, and *S. alba* was significantly less (7.0–10.0%). After 13 days, the most damaged plants were *B. napus* and *B. rapa* (70.0% and 72%, respectively). Damage to the *V. faba* and *S. alba* plants was significantly the smallest, amounting to 7.0% and 10.0%, respectively. Relatively little damage (approximately 20%) was observed for *Lupinus luteus* L., *S. bicolor*, and *C. intybus*. Observations of damage to plants caused by *D. reticulatum* were continued for 19 days. In that period, none of the studied plant species were 100% damaged.

Incremental slug damage to plants

In view of the differentiation in the incremental damage to the 16 plant species caused by the slugs, exploratory techniques were applied to analyse these multi-dimensional data. Cluster analysis was used to combine the plant species into clusters in such a way that their degree of similarity within a group was as high as possible, and the degree of similarity with species in other groups as low as possible. Comparison of the incremental damage to plants based on Euclidean distances made it possible to group them for each slug species (Figs 1, 2 and 3). For all three species of slugs, clusters were identified at a Euclidean distance of 57 units. In this way, four, five, and six clusters of plant species were obtained, respectively, for *A. vulgaris, A. rufus,* and *D. reticulatum*. Each cluster contains plant species for which similar levels of incremental damage were recorded.

For *A. vulgaris*, the following four clusters of plant species were identified: I – *B. napus*, *O. sativus*, *V. sativa*, *P. somniferum* (average total damage from 86% to 92%); II – *H. annuus*, *Lens esculenta* Mnch, *C. intybus* (from 72% to 79%); III – *L. luteus*, *B. rapa* var. *pekinensis*, *P. tanacetifolia*, *V. faba*, *S. bicolor* (from 47% to 57%); and IV – *P. sativum* subsp. *arvense*, *S. alba*, *P. sativum*, *S. bicolor* (from 31% to 44%).

For *A. rufus*, the following five clusters were identified: I – *H. annuus*, *V. sativa*, *C. intybus* (average total damage from 79% to 83%); II – *L. luteus*, *B. napus*, *G. max*, *B. rapa* var. *pekinensis* (from 68% to 72%); III – *L. esculenta*, *P. somniferum*, *P. tanacetifolia*, *O. sativus* (from 56% to 66%); IV – *P. sativum*, *S. alba* (from 48% to 51%); and V – *P. sativum* subsp. *arvense*, *S. bicolor*, *V. faba* (from 21% to 34%).

For *D. reticulatum*, the following six clusters were identified: I – *B. napus*, *B. rapa* var. *pekinensis* (average total damage from 59% to 61%); II – *P. sativum* subsp. *arvense*, *L. esculenta*, *P. tanacetifolia* (from 43% to 47%); III – *P. sativum*, *G. max*, *H. annuus*, *P. somniferum*, *V. sativa* (from 31% to 43%); IV – *C. intybus*, *O. sativus* (from 26% to 30%); V – *S. alba* (25%); and VI – *L. luteus*, *S. bicolor*, *V. faba* (from 7% to 18%).

Summary of analysis results

Based on the results of Fisher's procedure and of the cluster analysis, an attempt was made to make a summary classification of the 16 studied plant species. The summary classification considered each slug species separately, in terms of the degree of damage caused by slugs, or in other words – the susceptibility to slug grazing.

A. vulgaris caused the greatest damage to the plants *O. sativus*, *P. somniferum*, *B. napus*, and *V. sativa* (Table 5). The plants least damaged by that slug were *S. bicolor*, *P. sativum*, *P. sativum* subsp. *arvense*, and *S. alba*. The slug *A. rufus* most heavily damaged *C. intybus*, *H. annuus*, and *V. sativa* plants. The slug, *A. rufus,* caused the least damage significantly to the *S. bicolor*, *V. faba* and *P. sativum*

Table 5. Degrees of damage caused to selected plant species by *A. vulgaris*, *A. rufus*, and *D. reticulatum* defined for each slug separately

Species of plants	*A. vulgaris*	*A. rufus*	*D. reticulatum*
Brassica napus	++[c]	+	++
B. rapa	x[b]	+	++
Cichorium intybus	+[d]	++	---
Glycine max	x	+	---
Helianthus annuus	+	++	---
Lens esculenta	+	---[e]	+
Lupinus luteus	x	+	xx
Ornithopus sativus	++	---	---
Papaver somniferum	++	---	---
Phacelia tanacetifolia	x	---	+
Pisum sativum	xx[a]	x	---
P. sativum subsp. *arvense*	xx	xx	+
Sinapis alba	xx	x	x
Sorghum bicolor	xx	xx	xx
Vicia faba	x	xx	xx
V. sativa	++	++	---

[a] least damaged; [b] lightly damage; [c] most heavily damaged; [d] heavily damaged; [e] average damaged

subsp. *arvense* plants. In the case of *D. reticulatum*, the greatest damage was observed on plants of *B. rapa* var. *pekinensis* and *B. napus*, while the plants lightly damaged by that slug included *S. bicolor*, *V. faba*, and *L. luteus*.

It should be noted, that certain plant species are less or more susceptible to grazing and damage from all of the three studied slug species. The least susceptible to damage by *A. vulgaris*, *A. rufus*, and *D. reticulatum* were the *S. bicolor* plants, while *S. alba* and *V. faba* were weakly susceptible. On the other hand, the plants that were most susceptible to damage by all of the studied slug species were *B. napus* and, to a somewhat less degree, *V. sativa*, *C. intybus*, and *H. annuus*.

Discussion

The phenomenon of different food preferences of slugs with respect to certain plants is well known. It has been reported in studies relating to herbaceous and wildflower plants. These plants show significant differences in terms of sensitivity to damage by slugs (Duval 1971; Cates and Orians 1975; Jennings and Barkham 1975; Dirzo 1980; Webbe and Lambert 1983; Molgaard 1986; Cook *et al*. 1996; Clark *et al*. 1997; Briner and Frank 1998; Frank 1998; Kozłowski and Kozłowska 2000, 2009). In the present work, we have described the results of laboratory experiments determining the extent of damage to 16 species of crop plants caused by the slugs *A. vulgaris*, *A. rufus*, and *D. reticulatum*. The studies involved leguminous and other plants, most of which are grown as small-area crops. Chinese cabbage *B. rapa* var. *pekinensis* and oilseed rape *B. napus* var. *oleifera* (a variety with a low content of glucosinolates) were used as the controls. They are plants which are heavily damaged by slugs (Moens and Glen 2002; Port and Ester 2002). The studies used young plants at the 3–5 true leaf stage. These young plants are known to be more sensitive to damage than mature plants (Byers and Bierlein 1982; Hanley *et al*. 1995).

Plants found to be heavily damaged by all of the studied slug species (*A. vulgaris*, *A. rufus*, and *D. reticulatum*) were *B. napus*, *C. intybus*, *H. annuus*, and *V. sativa*, while lightly damaged were *S. bicolor*, *S. alba*, and *V. faba*. The degree of damage to the remaining plants differed depending on the slug species. Plants of *L. luteus*, which were more heavily damaged by *A. rufus*, were only lightly damaged by *A. vulgaris* and *D. reticulatum*. On the other hand, plants of *P. sativum* subsp. *arvense*, which were more heavily damaged by *D. rerticulatum*, suffered only slight damage from *A. vulgaris* and *A. rufus* (Table 5). This confirms the fact, that the amount of slug damage done to crops depends not only on the number of slugs, but also on the species composition of the crop (Moens and Glen 2002; Glen and Moens 2002; Port and Ester 2002).

A clear preference of *A. vulgaris* for certain species of plants was shown by Briner and Frank (1998) in studies of 78 species of wildflower plants sown on strips at the edge of rape fields. As in our study, they found that oilseed rape *B. napus* is a preferred plant for that slug. Other preferred plants reported by those authors included *Papaver rhoeas* L., *Sinapis arvensis* L., *Capsella bursa-pastoris* L. (Med.), and *Lamium purpureum* L. A preference of *A. vulgaris* prefers the plants *C. intybus*, *P. rhoeas* and *S. arvensis*. This preference is somewhat greater than for rape plants. These preferences of *A. vulgaris* were identified in previous studies conducted on 95 species of herbaceous plants (Kozłowski and Kozłowska 2009). On the other hand, the plants *S. alba*, *P. tanacetifolia*, and *P. sativum* subsp. *arvense* were poorly accepted by that slug (Kozłowski 2005). Frank (1998), in studies of the effect of *A. vulgaris* and *D. reticulatum* on the growth of seven wildflower plant species, found that density of *P. rhoeas* (field poppy) was significantly reduced by *A. vulgaris*, while numbers of plants of *S. alba* remained unaffected by both slug species. In our studies, *S. alba* was also the plant which was more lightly damaged by all of the slug species. The information cited above and the results of the present study, indicate that *A. vulgaris* have a strong preference for the plants *B. napus*, *P. rhoeas*, *P. somniferum*, and *C. intybus*, while plants damaged to a lesser degree by that slug are *S. alba*, *P. sativum*, and *P. sativum* subsp. *arvense*. Another plant heavily damaged by that slug is *O. sativus*, and another lightly damaged plant is *S. bicolor*. The data presented here on the extent of damage to the studied species of plants caused by *A. rufus* and *D. reticulatum* (Tables 3, 4 and 5), have not been previously reported.

The study shows that the susceptibility of plants to slug grazing, measured by the degree of damage suffered by the plants, differs significantly for particular species of slugs. This confirms previous data indicating that slugs choose the plants whose taste they find most acceptable, leading to selective grazing (Hanley *et al*. 1995; Cook *et al*. 1996; Frank and Friedli 1999). The choice of food is affected by the physical structure of the leaves (Dirzo 1980), the content of nutrients (Port and Port 1986; Spaull and Eldon 1990), and the quantity and quality of secondary plant metabolites. Of greatest significance are chemical compounds contained in plants such as glycosides, flavonoids, phenols, saponins, terpenes, tannins, which affect both the choice of plants and the grazing behaviour of the slugs. These chemical compounds play a large role in attracting the slugs or in the plants' defence mechanisms against these pests (Cates and Orians 1975; Webbe and Lambert 1983; Molgaard 1986; Hanley *et al*. 1995; Clark *et al*. 1997). It can be assumed, that the reason for the lower level of damage caused to *S. bicolor* (sorghum) by *A. vulgaris*, *A. rufus*, and *D. reticulatum* was the cyanogenic glycosides contained in that plant. As in the case of cyanogenic forms of *Trifolium repens* L., the cyanogenic glycosides caused a reduction in slug grazing and damage to plants (Dirzo 1980; Dirzo and Harper 1982a, b). A similar effect may have come from the tannins contained in plants of *V. faba* var. Bobas. According to some authors, these phenol derivatives often play a defensive role against various agricultural pests (Boesewinkel and Bouman 1995). The lower amount of damage to *S. alba* can probably be explained by the sinalbin glycoside present in that plant, which in *S. arvensis* may not be present or exists in too small a quantity to have an effect on slugs. In the case of *P. sativum*, the reduction in grazing by *A. vulgaris* and *A. rufus* may be due to the phenolic compound xylohydroquinone (Kohlmünzer 2000). Particular attention should be paid to plants of the genus *Lupinus*, particularly bitter varieties of *L. angustifolius*, which contain quinolizidine alkaloids (QA) that bring about a significant reduction in slug grazing. These compounds constitute a potential system of defence for leguminous plants against herbivores (Aguiar and Wink 1999; Chevalier *et al*. 2000). We studied the alkaloids contained in the plants of *L. luteus*. The alkaloids may have contributed to the lower levels of damage caused to those plants by *A. vulgaris* and *D. reticulatum.*

The results obtained in this work provide certain indications concerning the degree of risk posed and amount of damage done, to leguminous and other small-area crop plants by the slugs *A. vulgaris*, *A. rufus*, and *D. reticulatum*. They do not explain, however, which specific plant substances affect the grazing behaviour of slugs and by what mechanism they operate. Studies will continue on different varieties of selected plant species, to investigate their defence mechanisms against slug grazing and their potential use in integrated plant protection programmes.

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