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INITIAL EVALUATION OF THE EFFECTIVENESS OF SELECTED ACTIVE SUBSTANCES IN REDUCING DAMAGE TO RAPE PLANTS CAUSED BY *ARION LUSITANICUS* (GASTROPODA, PULMONATA, ARIONIDAE)

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Abstract: Spray forms of various chemical compounds including compounds of plant origin, molluscicides, and insecticides were tested in order to investigate their possibilities for reducing damage to young rape plants caused by the slug *Arion lusitanicus* Mabille, 1868. Among them, abamectin (0.2%), methiocarb (0.5%) and metaldehyde (1.0%) reduced damage to the plants, although metaldehyde remained active for only nine days. These three chemical compounds were not phytotoxic to rape plants, and none of them proved lethal to the slugs at the concentration used. The reduction in rape plant damage was obtained as a result of their deterrent and/or antifeedant action. The results indicate that abamectin has high potential usefulness in protecting winter rape seedlings from slugs.

Key words: *Arion lusitanicus*, laboratory tests, rape plants, chemical compounds, effectiveness

INTRODUCTION

Slugs are among the most significant pests to crop plants in central and northern Europe (South 1992; Frank 1998; Glen and Moens 2002; Moens and Glen 2002; Port and Ester 2002; Kozłowski 2003). The slugs causing the greatest damage to crops are *Deroceras reticulatum* (Müller), and recently *Arion lusitanicus* Mabille. This slug originates from the Iberian peninsula, and has spread through many countries of Europe (Schmid 1970; Reischütz 1984; Davies 1987; Risch and Backeljau 1989; De Winter 1989; von Proschwitz 1992; von Proschwitz and Winge 1994; Kozłowski and Kornobis 1995; Wiktor 1996; Frank 1998). This invasive slug species most frequently occurs in mass numbers and damages many species of crops and other plants. These include almost all species of vegetables, and certain agricultural, decorative, orchard and herbal plants (Kozłowski 2005, 2008). *A. lusitanicus* can totally destroy young vegetable plants in gardens and sprouting winter rape and winter wheat at the edges of farmed fields (Frank 1998; Kozłowski 2007).

At present, chemical protection of plants against harmful slugs is mostly based on the use of commercial pelleted molluscicides containing methiocarb or metaldehyde as the active ingredients. Methiocarb and metaldehyde act as contact and gastric poisons. The effectiveness of these agents in crop cultivation is often unsatisfactory. Farmers and growers often make several applications a year. If there is slug damage to crops, farmers are forced to sow and grow their crops a second time (Bailey and Wedgwood 1991; Moens and Glen 2002; Kozłowski 2003). The reasons for the weak action of pelleted molluscicides are: their limited durability, the short time for which slugs are lured, and the deterrent action of the active substances (Henderson and Parker 1986). Apart from their low effectiveness, the use of pelleted molluscicides creates many adverse effects on organisms which are not the target of the treatment. Metaldehyde is toxic to vertebrates and acts as a poison to cats, dogs, sheep and poultry (Homeida and Cooke 1982). Methiocarb has a toxic effect on beneficial soil invertebrates including earthworms and carabid beetles (Purves and Bannon 1992) and farm animals (Fletcher *et al*. 1994). Both molluscicides are very dangerous for hedgehogs, toads, singing birds and other animals which eat slugs as an important dietary component. In recent years, in some European countries (Germany, Netherlands, Great Britain) new molluscicide pellets with iron phosphate as an active substance was registered. This molluscicide is attractive to slugs and

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shows weak toxicity for mammals and useful organisms (Speiser and Kistler 2002). It is mainly used in gardens and organic farms.

The unsatisfactory effectiveness of methiocarb and metaldehyde and their adverse effect on invertebrates and vertebrates have led to a search for new active substances against slugs. Many compounds have been identified, chiefly of vegetable origin, which may reduce slug grazing on crop plants (Kloos and McCullough 1982; Webbe and Lambert 1983; Stahl 1988; Adewunmi and Monache 1989; Airey *et al*. 1989). In recent years there have been studies of numerous new molluscicides acting on slugs as repellents, deterrents and antifeedants. These new molluscicides which come in spray form (Barone and Frank 1999; Schüder *et al*. 2004), pelleted baits (Clark *et al*. 1997) or seed dressings (Scott *et al*. 1977; Charlton 1978; Ester 1996; Ester and Nijënstein 1995, 1996a, 1996b; Watkins *et al*. 1996; Nijënstein and Ester 1998; Simms *et al*. 2002) have been tested against slugs.

The most promising of the studied substances were cinnamamide, 3.5-dimethoxycinnamic acid (DMCA), copper ammonium carbonate, ureaformaldehyde (Watkins *et al*. 1996; Simms *et al*. 2002; Schüder *et al*. 2002, 2003, 2004), azadirachtin, carvone, limonene (Ester and Nijënstein 1995; Port and Ester 2002; Frank *et al*. 2002), geraniol (Barone and Frank 1999), acetylacetonate, chelates of aluminium, iron and copper (Moens *et al*. 1992) and pesticides such as thiodicarb, thiocyklam, bromoxynil and ioxynil (Nijënstein and Ester 1998). Most of these compounds reduced slug grazing on plants, but were not suitable as molluscicides in view of their phytotoxicity and lack of stability.

The aim of our studies was to evaluate the activity of molluscicides, insecticides and compounds of plant origin, used as sprays, in reducing damage to rape plants by the slug *A. lusitanicus*. The laboratory tests we describe here were aimed at identifying compounds with molluscicidal properties of use in slug control.

MATERIALS AND METHODS

Slugs and plants used in the study

The *A. lusitanicus* slugs used in the study came from eggs collected in November 2008, from a population occurring in the vicinity of Łańcut (Sub-Carpathian subregion). The eggs were collected together with soil, placed in containers and kept in the dark at a temperature of 16°C. The hatched slugs were transferred to plastic containers (50x35x40 cm) filled with a 5 cm layer of humus-clay soil. The containers had several ventilation holes, protected with gauze. Three times a week the hatched slugs were given new food (wheat bran, vegetable leaves, carrot roots, potato tubers, powdered milk, calcium carbonate). The slugs were kept in a growth chamber at a temperature of 18°C by day and 14°C by night, RH 93±2%, length of day was 15 hours. Before the start of the tests the slugs were starved for 48 hours. The average mass of the slugs used in the tests ranged between 0.71 and 1.29 g. The plants used in the experiment were the Lisek variety of winter rape, at the stage of two true leaves (BBCH-12). The plants were grown in a greenhouse, from seeds sown in a 4 cm layer of gardening soil placed in semitransparent plastic containers (22x18x13 cm). There were 10 plants per container.

Chemical compounds used in the study

The study involved chemical compounds which have or may have a toxic, deterrent or antifeedant effect on slugs or other herbivorous invertebrates and vertebrates. These were molluscicides, and compounds with molluscicidal properties (methiocarb, metaldehyde, copper carbonate, copper sulphate), insecticides and acaricides (abamectin, teflubenzuron, dieldrin), and substances of plant origin, such as alkaloids (capsaicin, sparteine, caffeine nicotinae), monoterpenes (thymol, pinene, terpineol, linalool, geraniol, carvone, lavandulol), aromatic acids (cinnamamide), quinones (methylanthraquinone) and coumarins (scopoletin).

Among the selected chemical compounds, only methiocarb and metaldehyde are registered as active substances of pelleted molluscicides generally used against slugs (Henderson and Triebskorn 2002; Bailey 2002; Kozłowski 2003). Copper compounds, such as copper carbonate, copper sulphate and others, may have molluscicidal properties (Gould 1962; Moens *et al*. 1992). Teflubenzuron and dieldrin are known insecticides used on crops against various pests. Abamectin is an active substance in several commercial plant protection products used against insects and mites. Capsaicin is a synthetic tetronic acid derived from the fruit of *Capsicum annuum*. This alkaloid causes excessive slime secretion and dehydration in slugs (Scott *et al*. 1977; Airey *et al*. 1989). Geraniol is a terpene alcohol from the plants Geraniaceae and has significant deterrent action against slug grazing, but because of its high volatility, it is a compound with low stability (Barone and Frank 1999). Carvone is a product obtained from seeds of *Carum carvi*, as a component of the essential oils of that plant. It is used to suppress the sprouting of potatoes in storage and showed high efficacy against slugs (Ester and Nijënstein 1995; Nijënstein and Ester 1998; Frank *et al*. 2002). Another component of essential oils from caraway seeds is limonene, which also occurs as the main component of orange oil (*Oleum Aurantii*) and in the oils of other plants. The forms (R) limonene and (S) limonene are moderately effective in combating slugs on wheat, barley and perennial ryegrasses (Nijënstein and Ester 1998). Cinnamamide is among the precursors of cinnamonic acid, and deters several vertebrate species from feeding. It is active against birds (Crocker and Reid 1993; Gill *et al*. 1994) and mammals (Crocker *et al*. 1993). Research on the activity of cinnamamide, used in the form of seed dressings, has demonstrated a strong reduction in slug grazing on treated plants (Watkins *et al*. 1996; Simms *et al*. 2002; Schüder *et al*. 2003, 2004). The other selected chemical compounds occurring in the essential oils of various species of plants, such as pinene (*Pinus silvestris*, *Ruta graveolens*), terpineol (*Majorana hortensis*), linalool and lavandulol (*Lavendula* sp.), may affect the grazing activity of slugs. Antifeedant effects on slugs are displayed by scopoletin which is isolated from the roots of *Scopolina carniolica* (Solanaceae) and from *R. graveolens* (Adewunmi and Monache 1989).

The other selected compounds – sparteine, thymol, methylanthraquinone – are listed as displaying molluscicidal activity (Duke 2006).

Laboratory tests with slugs

Before the start of the experiment, the cultivated plants were sprayed with the tested chemical compounds which had been prepared to a specified concentration (Table 1). The solutions contained Break-Thru S240 emulsifier (0.05%). The control consisted of rape plants sprayed with a solution of the emulsifier. After the plants had dried out, one starved slug was placed in each container.

The study was carried out in a growth chamber, at a temperature of 18°C by day and 14°C by night, RH 93±2%, length of day was 15 h. The slugs were kept in semitransparent plastic containers (22x18x13 cm). For the tested chemical compounds and mixtures, 6 repetitions were made for each, with the exception of methiocarb (0.5%) and the control, for which 12 repetitions each were made. Every two days, a determination was made of the condition and quantity of damage to the plants, and the longevity of the slugs. The quantity of slug damage to the plants was defined on a five-point scale: 0% (no damage), 25%, 50%, 75% and 100% plant surface area consumed. The average percentage of consumed plant surface was calculated for the 10 plants in each container. These data were subjected to statistical analysis. With regard to the different weights of the slugs, covariance analysis and Fischer's LSD procedure at significance a = 0.05 were applied.

Table 1. Corrected average damage to rape seedlings caused by *A. lusitanicus* after treatment with various compounds (average in % from ANCOVA) and results of Fischer's LSD procedure at 0.05

Compounds	Average slug masses [g]	St. dev.	Dose [%]	Days of feeding						
				1	3	5	7	9	15	19
Control	0.983	0.2637	0.05	14.3	30.6	43.0	52.4	58.7	77.8	87.3
Methiocarb (Mesurol 500 FS)	0.974	0.3003	0.5	4.8*	7.2*	12.0*	13.4*	21.0*	42.1*	61.7*
Abamectin	1.227	0.1896	0.2	1.7* g–i	5.7* h	5.3* i	5.0* i	7.9* h	12.6* g	23.9* f
Metaldehyde	1.174	0.1068	1.0	0.3* i	5.5* h	10.4* hi	23.3* hi	38.5* d–g	75.3 a–e	94.3 ab
Cinnamamide	0.970	0.0646	1.0	3.6* f–i	13.5* d–h	25.4* d–h	44.4 b–g	57.9 a–e	87.2 ab	97.0 a
Copper carbonate	0.957	0.3684	1.0	8.6 b–h	19.0* c–g	32.7 b–f	38.8 c–h	49.0 c–g	65.2 b–f	75.0 a–d
Copper sulfate pentahydrate	1.020	0.1456	1.0	0.8* h–i	12.4* e–h	16.1* g–i	21.9* hi	27.4* gh	53.7* ef	65.0* de
Thymol	1.293	0.2494	1.0	6.3* c–i	10.3* f–h	16.6* g–i	29.3* f–h	40.7 d–g	61.4 d–f	74.2 b–e
(–)–Sparteine	1.075	0.2564	1.0	1.7* g–i	12.6* e–h	23.5* e–h	34.8 d–h	48.8 c–g	74.7 a–e	84.6 a–d
(S)–(+)–α–Pienne	0.951	0.3221	0.5	13.7 a–d	29.1 a–c	48.6 ab	55.6 a–c	65.0 a–c	90.3 a	94.6 a
(R)–(+)–Limonene	1.020	0.4380	0.5	10.8 b–f	32.8 ab	48.6 ab	63.2 ab	72.4 ab	81.6 a–d	86.2 a–d
2–Methylanthraquinone	0.918	0.4043	0.5	15.9 ab	33.7 ab	47.1 ab	59.7 ab	66.0 a–c	78.6 a–d	84.9 a–d
Caffeine nicotinae	1.177	0.1813	1.0	3.7* e–i	9.2* gh	16.2* g-i	27.4* gh	35.9* e–g	59.0 d–f	73.8 b-e
Capsaicin	1.192	0.4180	0.5	19.0 a	40.3 a	58.0 a	70.0 a	78.1 a	86.3 a–c	89.5 a–c
Dieldrin	1.201	0.2129	1.0	4.8* e–i	13.9* d–h	17.8* f–i	34.8 d–h	42.5 d–g	60.0 d–f	76.6 a–d
Teflubenzuron	0.829	0.3063	0.5	14.4 a–c	23.5 b–e	35.0 b–e	46.4 b–g	55.3 b–f	64.6 b–f	72.6 b–e
(–)–α–Terpineol	1.257	0.2789	1.0	6.1* d–i	11.5* f–h	15.1* g–i	27.1* gh	36.8* e–g	72.6 a–e	84.1 a–d
Methiocarb + N-Acetyl-L-Cysteine	0.806	0.2485	0.5	7.0* c–i	15.5* d–h	29.6 c–g	39.0 c–h	35.3* fg	54.0* ef	70.2 c–e
Copper sulfate pentahydrate + N-Acetyl-L-Cysteine	0.818	0.1070	0.1	8.2 b–i	12.4* e–h	17.7* f–i	28.7* f–h	34.3* fg	43.0* f	52.7* e
Metaldehyde + N-Acetyl-L-Cysteine	1.251	0.3981	1.0	3.7* e–i	13.7* d–h	15.7* g–i	46.9 b–g	55.7 a–f	80.2 a–d	90.8 a–c
Geraniol	0.788	0.2044	1.0	12.5 a–e	24.5 b–d	37.0 b–e	50.7 a–e	60.3 a–d	75.9 a–de	83.3 a–d
(+/–)–Linalool	0.781	0.1069	0.5	8.8 b–g	21.2 c–f	34.6 b–e	44.6 b–g	49.6 c–f	58.5 d–f	66.7* de
(+/–)–Lavandulol	1.294	0.3478	1.0	6.3* c–i	10.7* f–h	22.4* e–h	32.2* e–h	45.3 c–g	80.2 a–d	89.2 a–c
Scopoletin	0.713	0.1015	0.2	12.1 a–e	27.1 bc	40.0 b–d	49.1 b–f	53.0 b–f	63.4 c–f	65.1* de
(S)–(+)–Carvone	0.721	0.2179	0.5	14.6 a–c	29.1 a–c	44.4 a–c	55.2 a–d	59.1 a–d	66.2 b–f	69.2 c–e

*values differing from the control; a–f – values in columns marked with the same letters do not differ significantly
St. dev. – standard deviation

RESULTS

Effect of the tested substances on the quantity of damage and condition of the plants

Significant differences in the quantities of damage to rape plants caused by *A. lusitanicus* were recorded even after the first day of slug grazing (Table 1). The least damaged plants were those sprayed with metaldehyde, copper sulphate pentahydrate and sparteine applied at a concentration of 1.0%, and abamectin at a concentration of 0.2%. After three days, the significantly least damaged plants were those sprayed with metaldehyde and abemactin, for which damage amounted to 5.5 and 5.7%, respectively, compared with 30.6% for the control. Moreover significant reduction in plant damage after three days was produced by methiocarb at a concentration of 0.5% and caffeine nicotinae at a concentration of 1.0%, for which plant damage was 7.2 and 9.2%, respectively. After seven days the high effectiveness of reduction in plant damage was maintained on plants sprayed with abamectin, and to a lesser degree on those sprayed with methiocarb, copper sulphate pentahydrate and metaldehyde. The percentage damage to plants sprayed with those compounds was, respectively, 5.0, 13.4, 21.9 and 23.3%, compared with 52.4% for the control. On subsequent days, the highest activity in reducing plant damage continued to be shown by abamectin, and to a lesser degree by methiocarb.

Analysis of the quantity of damage to rape plants throughout the period of slug grazing (a total of 19 days) showed that reduction in slug damage was produced by abamectin, metaldehyde, copper sulphate pentahydrate, caffeine nicotinae (1.0%), thymol (1.0%), terpineol (1.0%) and a 1 : 1 mixture of copper sulphate pentahydrate with n-acetyl-l-cysteine (1.0%). The effectiveness of these chemical compounds in reducing slug damage to plants did not differ significantly from the effectiveness of methiocarb used at a concentration of 0.5%. The high effectiveness of abamectin was maintained for 19 days. A similar effectiveness, also for 19 days, took place with copper sulphate pentahydrate and the mixture of copper sulphate pentahydrate with n-acetyl-l-cysteine (1.0%). Metaldehyde, caffeine nicotinae and terpineol were effective for the first nine days. The other tested chemical compounds had no significant effect on the quantity of damage done to plants by the slugs.

To sum up the results, the highest effectiveness in reducing damage to plants caused by the slug *A. lusitanicus* was obtained with abamectin, used in the form of a plant spray at a concentration of 0.2%. Relatively good effectiveness was also obtained with methiocarb at a concentration of 0.5%, metaldehyde at a concentration of 1.0% and copper sulphate pentahydrate at a concentration of 1.0%. Caffeine nicotinae (1.0%) and a mixture of copper sulphate pentahydrate with n-acetyl-l-cysteine (0.1%) are also worth paying attention to.

Most of the tested chemical compounds, used in the form of spray, did not have any effect on the condition of the rape plants. Exceptions were the geraniol and copper sulphate pentahydrate mixture with n-acetyl-l-cysteine, used at 1.0% concentration, which had a weak and short-lasting (1–2 days) phytotoxic effect on a small number of rape plants.

Effect of the tested substances on slug condition and survival

None of the chemical compounds used caused slug mortality. Some of the compounds caused excessive slime secretion and partial paralysis of the slugs, which lasted, with breaks, for 1 and 3 days. However after this period the slugs revived and grazed on the plants. This reaction was observed when the following were applied: methiocarb at a concentration of 0.5% (first day of observation, 2 slugs), metaldehyde (1.0%) (1–3 days, 3 slugs), linalool (0.5%) (9–11 days, 1 slug), copper sulphate pentahydrate 1.0% (1–3 days, 3 slugs), terpineol 1.0% (3–7 days, 1 slug).

DISCUSSION

The study shows that abamectin sprayed on young rape plants (at the stage of two true leaves) at a concentration of 0.2% caused a strong reduction in rape plant damage by the slug *A. lusitanicus*. Similar action was obtained for methiocarb applied at a concentration of 0.5%, although in the third week after application it was significantly weaker then abamectin. High effectiveness in reducing slug damage to plants was also displayed by metaldehyde (1.0%), but it acted for a significantly shorter period (9 days). The chemical compounds mentioned protected the rape plants from damage from the first day. In the case of abamectin and methiocarb their protective action continued for a period of almost three weeks. The effective action of abamectin, methiocarb and metaldehyde in reducing grazing by *A. lusitanicus* has also been confirmed in tests without choice, on discs of Chinese cabbage leaves (Kozłowski and Kozłowska 2007). Moreover, a high effectiveness in reducing damage done to plants by *A. lusitanicus* has been shown for abamectin and methiocarb used in the form of a spray on seedlings of the Kana variety of rape (Kozłowski *et. al.* 2008). Methiocarb and metaldehyde were also effective against slugs when they were used in the form of seed dressings (Ester and Nijënstein 1995; Nijënstein and Ester 1998). It is important that these three compounds did not demonstrate phytotoxicity to the rape plants. Similar results on the lack of phytotoxicity or low level of phytotoxicity of methiocarb and metaldehyde have been obtained by other authors (Gould 1962; Ester and Nijënstein 1995, 1996a, 1996b; Watkins *et al*. 1996; Nijënstein and Ester 1998; Simms *et al*. 2002).

In the study, the tested chemical compounds were not found to act lethally on slugs. Methiocarb, metaldehyde, copper sulphate, linalool, and terpineol caused temporary poisoning symptoms in slugs. The symptoms were in the form of excessive slime secretion and muscular paralysis, but these were not fatal to the slugs. In earlier studies, methiocarb and metaldehyde used on leaf discs and in the form of sprays on rape seedlings caused the death of isolated slugs. However, no such effect was found for abamectin (Kozłowski *et al*. 2008).

The main reason for the reduction in slug damage to plants following the application of abamectin, methiocarb and metaldehyde was the reduced slug grazing due to their deterrent and/or antifeedant effects. According to some authors, apart from their toxic action, metaldehyde and methiocarb have strong deterrent properties with respect to slugs (Wedgwood and Bailey 1988; Nijënstein and Ester 1998; Simms *et al*. 2002), and this was confirmed in the present work. The results suggest that the deterrent action of methiocarb lasts significantly longer than that of metaldehyde. The longest-lasting deterrent action (19 days) was demonstrated by abamectin.

Our results suggest that methiocarb, metaldehyde and abamectin, used in spray form, may cause significant reduction in damage to young rape plants by the slug *A. lusitanicus*. The first two compounds are currently used as the active substances of pelleted molluscicides. These compounds are registered in many countries of Europe for use against slugs on plant crops. Results from our own studies and those of other authors suggest that these compounds may be of potential importance as sprays, and above all, as treatments for seeds of rape, wheat and other cultivated plants (Gould 1962; Ester and Nijënstein 1995; 1996a, 1996b; Ester 1996; Watkins *et al*. 1996; Nijënstein and Ester 1998; Iglesias *et al*. 2002; Simms *et al*. 2002; Port and Ester 2002; Schüder *et al*. 2004; Kozłowski *et al*. 2008). Although according to the decision of the European Commission, it will only be possible to use metaldehyde until 31, December 2010. Therefore, it will be necessary to replace metaldehyde with other active substances, effective in slug control. There is a promising compound characterized by a strong deterrent effect on *A. lusitanicus* and without phytotoxicity to rape plants – it is abamectin. This compound is a glycoside derived from the soil bacteria *Streptomyces avermitilis*. Abamectin demonstrates strong action against a wide range of pests. It is an active ingredient in several registered insecticides and acaricides with contact and gastric action. These insecticides and acaricides are intended for use against insects and herbivorous mites on vegetable and decorative plants grown in the soil and under cover. Abamectin (syn. avermectin) used in the form of a mixture of isomers B_{1a} and B_{1b} was toxic to *D. reticulatum* (LD_{50} 15 μg/slug) (Airey *et al*. 1989). Moreover, used as a repellent in traps (in a dose of 250 g/ha on humid soil) it showed strong action against slugs. Its lethal effect was maintained for 4 days, and a vestigial effect for 15 days after application (Airey *et al*. 1989). Our earlier studies showed this compound to be highly active in reducing grazing and damage to plants by *A. lusitanicus* (Kozłowski and Kozłowska 2007; Kozłowski *et al*. 2008). These results were also confirmed in the present study.

Future research should be undertaken to develop various methods of application and determine effective doses of abamectin and other chemical compounds which are found to be active against slugs. It is also necessary to investigate their effectiveness in field conditions.

REFERENCES

Adewunmi C.O., Monache F.D. 1989. Molluscicidal activity of some coumarins. Fitoterapia 60: 79–82.

Airey W.J., Henderson I.F., Pickett J.A., Scott G.C., Stephenson J.W., Woodcock C.M. 1989. Novel chemical approaches to mollusc control. p. 301–307. In: "Slugs and Snails in World Agriculture" (I. Henderson, ed.). Monograph No. 41. British Crop Protection Council, 422 pp.

Bailey S.E.R. 2002. Molluscicidal baits for control of terrestrial gastropods. p. 33–54. In: "Molluscs as Crop Pests" (G.M. Barker, ed.). Landc. Res. Hamilton New Zealand, CABI Publishing, Wallingford, UK, 468 pp.

Bailey S.E.R., Wedgwood M.A. 1991. Complementary video and acoustic recordings of foraging by two pest species of slugs on non-toxic and molluscicidal baits. Ann. Appl. Biol. 119 (1): 163–176.

Barone M., Frank T. 1999. Effects of plant extracts on the feeding behaviour of the slug *Arion lusitanicus*. Ann. Appl. Biol. 134: 341–345.

Charlton J.F.T. 1978. Slugs as a possible cause of establishment failure in pasture legumes over sown in boxes. N. Z. J. Exp. Agric. 6: 313–317.

Clark S.J., Dodds C.J., Henderson I.F., Martin A.P. 1997. A bioassay for screening materials influencing feeding in the field slug *Deroceras reticulatum* (Müller) (Mollusca, Pulmonata). Ann. Appl. Biol. 130 (2): 379–385.

Crocker D.R., Reid K. 1993. Repellency of cinnamic acid derivatives to rooks and chaffinches. Wildl. Soc. Bull. 21 (4): 456–460.

Crocker D.R., Scanlon C.B., Perry S.M. 1993. Repellency and choice: feeding responses of wild rats (*Rattus norvegicus*) to cinnamic acid derivatives. Appl. Anim. Behav. Sci. 38 (1): 61–66.

Davies M.J. 1987. *Arion flagellus* Collinge and *A. lusitanicus* Mabille in the British isles: A morphological, biological and taxonomic investigation. J. Conch. 32: 339–354.

Duke J.A. 2006. Chemicals with molluscicide activity. In: Dr. Duke's Phytochemical and Ethnobotanical Databases. http://www.ars-grin.gov/cgi-bin/duke/chemical_activity.pl.

Ester A. 1996. Integrated control of slugs in a sugar beet crop growing in a rye cover crop. p. 445–450. In: BCPC Symposium Proceedings 66: Slug and Snail Pests in Agiculture. University of Kent. Canterbury, UK. 24–26. Sep. 1996, 450 pp.

Ester A., Nijënstein J.H. 1995. Control of the field slug *Deroceras reticulatm* (Müller) (Pulmonata: Limacidae) by pesticides applied to winter wheat seed. Crop Protect. 14 (5): 409–413.

Ester A., Nijënstein J.H. 1996a. Mollusscicidal seed treatment of barley, wheat and perennial ryegrass to control the field slug (*Deroceras reticulatum*). Neth. J. Agric. Sci. 44: 241–248.

Ester A., Nijënstein J.H. 1996b. Control of field slug (*Deroceras reticulatm* Müller) by seed-applied pesticides in perennial ryegrass assessed by laboratory tests. J. Plant Dis. Protect. 103: 42–49.

Fletcher M.R., Hunter K., Barnet E.A. 1994. Pesticide Poisoning of Animals. Ministry of Agriculture Fishing and Food (MAFF) Publications, London, UK, 52 pp.

Frank T. 1998. Slug damage and numbers of the slug pests, *Arion lusitanicus* and *Deroceras reticulatum*, in oilseed rape grown beside sown wildflower strips. Agric. Ecos. Env. 67 (1): 67–78.

Frank T., Biert K., Speiser B. 2002. Feeding deterent effect of carvone, a compound from caraway seeds, on the slug *Arion lusitanicus*. Ann. Appl. Biol. 141 (2): 93–100.

Gill E.I., Serra M.B., Canavelli S.B., Feare C.J., Zaccagnini M.E., Nadian A.K., Hefferaan M.L., Watkins R.W. 1994. Cinnamamide prevents captive Chestnut-capped Blackbirds (*Agelaius ruficapillus*) from eating rice. Int. J. Pest Mgmt. 40: 195–198.

Glen D.M., Moens R. 2002. Agriolimacidae, Arionidae and Milacidae as pests in west European cereals. p. 271–300. In: "Molluscs as Crop Pest" (G.M. Barker, ed.). Landc. Res. Hamilton New Zealand. CABI Publishing, Wallingford UK, 400 pp.

Gould H.J. 1962. Tests with seed dressings to control grain hollowing of winter wheat by slugs. Plant Pathol. 11 (4): 147–152.

Henderson I., Triebskorn R. 2002. Chemical control of terrestrial gastropods. p. 1–31. In: "Molluscs as Crop Pests" (G.M. Barker, ed.). Landc. Res. Hamilton New Zealand. CABI Publishing, Wallingford UK, 400 pp.

Henderson I.F., Parker K.A. 1986. Problems in developing chemical control of slugs. Asp. Appl. Biol. 13: 341–347.

Homeida A.M., Cooke R.G. 1982. Pharmacological aspects of metaldehyde poisoning in mice. J. Vet. Pharmacol. Therap. 5 (1): 77–81.

Iglesias J., Castillejo J., Ester A. 2002. Laboratory evaluation of potential molluscicides for the control of eggs of the pest slug *Deroceras reticulatum* (Müller) (Pulmonata: Limacidae). Int. J. Pest Manage. 48 (1):19–23.

Kloos H., McCullough F.S. 1982. Plant molluscicides. Planta Medica 46: 195–209.

Kozłowski J. 2003. Stan badań nad metodami zwalczania szkodliwych ślimaków. Post. Nauk Rol. 5: 25–42.

Kozłowski J. 2005. Host plants and harmfulness of the *Arion lusitanicus* Mabille, 1868 slug. J. Plant Protection Res. 45 (3): 221–233.

Kozłowski J. 2007. The distribution, biology, population dynamics and harmfulness of *Arion lusitanicus* Mabille, 1868 (Gastropoda: Pulmonata: Arionidae) in Poland. J. Plant Protection Res. 47 (3): 219–230.

Kozłowski J. 2008. Obcy inwazyjny ślimak nagi ślinik luzytański – *Arion lusitanicus*. Charakterystyka, metody zwalczania i rejestracji stanowisk występowania w Polsce. Rozpr. Nauk. Inst. Ochr. Roślin 17, 48 pp.

Kozłowski J., Kałuski T., Jaskulska M. 2008. Badania laboratoryjne nad ograniczeniem uszkodzeń roślin rzepaku przez ślinika luzytańskiego (*Arion lusitanicus* Mabille). Prog. Plant Protection/Post. Ochr. Roślin 48 (3): 889–892.

Kozłowski J., Kornobis S. 1995. *Arion lusitanicus* Mabille, 1868 (Gastropoda: Arionidae) w Polsce oraz nowe stanowisko *Arion rufus* (Linnaeus, 1758). Przegl. Zool. 39 (1–2): 79–82.

Kozłowski J., Kozłowska M. 2007. Nowe możliwości ochrony roślin przed szkodliwymi ślimakami (Gastropoda: Pulmonata). Fragm. Agron. 3: 245–251.

Moens R., Couvreur R., Cors F. 1992. Influence de la teneur en glucosinolates des variétés de colza d'hiver sur les dégats de limaces. Bull. Rech. Agr. Gemb. 27: 289–307.

Moens R., Glen D.M. 2002. Agriolimacidae, Arionidae and Milacidae as pests in west European oilseed rape. p. 425–439. In: "Molluscs as Crop Pests" (G.M. Barker, ed.). Landc. Res. Hamilton New Zealand, CABI Publishing, Wallingford, UK, 468 pp.

Nijënstein J.H., Ester A. 1998. Phytotoxicity and control of the field slug *Deroceras reticulatum* by seed applied pesticides in wheat, barley and perennial ryegrass. Seed Sci. Technol. 26 (2): 501–513.

Port G., Ester A. 2002. Gastropods as pests in vegetable and ornamental crops in western Europe. p. 337–351. In: "Molluscs as Crop Pests" (G.M. Barker, ed.). Landc. Res. Hamilton New Zealand, CABI Publishing, Wallingford, UK, 400 pp.

Purves G., Bannon J.W. 1992. Non-target effects of repeated methiocarb slug pellet application on carabid beetle (Coleoptera, Carabidae) activity in winter-sown cereals. Ann. Appl. Biol. 121 (2): 215–223.

Reischütz P.L. 1984. Zum massenhaften Auftreten von Arion lusitanicus Mabille in den Jahren 1982 und 1983. Mitt. Zool. Ges. Braunau. 4: 253–254.

Risch P., Backeljau T. 1989. On the occurrence of *Arion lusitanicus* Mabille, 1868, in Belgium. Ann. Soc. Zool. Belgique 118: 25–38.

Schmid G. 1970. *Arion lusitanicus* in Deutschland. Arch. Moll., Frankfurt a. M. 100: 95–102.

Schüder I., Port G., Bennison J. 2002. Novel pesticides for slug and snail control in horticulture. p. 873–878. In: Proceedings of BCPC Conference on Pest and Diseases. Brighton, UK. 18–21 Nov. 2002, 1000 pp.

Schüder I., Port G., Bennison J. 2003. Barriers, repellents and antifeedants for slug and snail control. Crop Protect. 22 (8): 1033–1038.

Schüder T., Port G., Bennison J. 2004. The dose-dependent responses Deroceras panormitanum and Oxyloma pfeifferi to potential novel molluscicides. Crop Protect. 23 (10): 945–953.

Scott G.C., Griffiths D.C., Stephenson J.W. 1977. A laboratory method for testing seed treatments for the control of slugs in cereals. p. 129–134. In: Proceedings of the BCPC Conference on Pest and Diseases. Brighton, UK. 21–24 Nov. 1977, 565 pp.

Simms L.C., Mullins C.E., Wilson M.J. 2002. Seed dressings to control slug damage in oilseed rape. Pest Manag. Sci. 58 (7): 687–694.

South A. 1992. Terrestrial Slugs: Biology, Ecology and Control. Chapman and Hall, London, 444 pp.

Speiser B., Kistler C. 2002. Field test with a molluscicide containing iron phosphate. Crop Protect. 21 (5): 389–394.

Stahl E. 1988. Pflanzen und Schnecken. Jenaische Zeitschrift. 22: 557–684.

von Proschwitz T., Winge K. 1994. Iberia skogsnegl – en art pä spredning i Norge (*Arion lusitanicus* Mabille – an anthropochorous slug spreading in Norway). Fauna 47: 195–300.

von Proschwitz T.. 1992. Spanska skogssnigeln - *Arion lusitanicus* Mabille - en artisnabb spridning med människan i sverige. Göteborgs Naturhistorika Museum, Ärstryck: 35–42.

Watkins R.W., Mosson H.J., Gurney J.E., Cowan D.P., Edwards J.P. 1996. Cinnamic acid derivatives: novel repellent seed dressings for the protection of wheat seed against damage by the field slug, *Deroceras reticulatum*. Crop Protect. 15 (1): 77–83

Webbe G., Lambert J.D.H. 1983. Plants that Kill Snails and Prospects for Disease Control. Nature 302, 754 pp.

Wedgwood M.A., Bailey S.E.R. 1988. The inhibitory effects of the molluscicide metaldehyde on feeding, locomotion and faecal elimination of three pest species of terrestrial slug. Ann. Appl. Biol. 112 (3): 439–458.

Wiktor A. 1996. The slugs of the former Yugoslavia (Gastropoda terrestria nuda – Arionidae, Milacidae, Limacidae, Agriolimacidae). Annal. Zool. 46 (1): 1–110.

Winter A.J. de. 1989. *Arion lusitanicus* Mabille in Nederland (Gastropoda, Pulmonata, Arionidae). Basteria 53 (1–3): 49–51.

POLISH SUMMARY

WSTĘPNA OCENA SKUTECZNOŚCI DZIAŁANIA WYBRANYCH SUBSTANCJI AKTYWNYCH W OGRANICZANIU USZKODZEŃ ROŚLIN RZEPAKU PRZEZ *ARION LUSITANICUS* (GASTROPODA, PULMONATA, ARIONIDAE)

W ramach prowadzonych badań nad oceną różnych związków chemicznych w zwalczaniu ślimaków, wykonano testy bez wyboru nad efektywnością moluskocydów, insektycydów i związków pochodzenia roślinnego. Do testów wybrano związki chemiczne, które wykazują lub mogą wykazywać deterentne lub antyfidantne działanie w stosunku do ślimaków. Eksperyment przeprowadzono na rzepaku ozimym odmiany Lisek, w fazie 2–3 liści właściwych, które po opryskaniu badanym związkiem w określonym stężeniu, eksponowano na żerowanie ślimaków *A. lusitanicus*. W kolejnych dniach żerowania ślimaków określano kondycję i wielkość uszkodzeń roślin oraz żywotność ślimaków.

Przeprowadzone badania wykazały, że abamektyna zastosowana w stężeniu 0,2% powodowała silne ograniczenie uszkodzeń roślin przez ślimaki. Podobne działanie uzyskano dla metiokarbu zastosowanego w stężeniu 0,5%, przy czym w trzecim tygodniu po aplikacji tego związku ograniczenie uszkodzeń roślin było istotnie słabsze niż dla abamektyny. Wysoką skuteczność wykazał także metaldehyd w stężeniu 1,0%, ale jego działanie było znacznie krótsze i wynosiło dziewięć dni. Te trzy związki chroniły rośliny rzepaku przed uszkodzeniami już w pierwszym dniu po ich zastosowaniu, a w przypadku abamektyny i metiokarbu ich ochronne działanie utrzymywało się prawie przez okres trzech tygodni. Wykazano, ze żaden z wymienionych związków w zastosowanym stężeniu nie był fitotoksyczny dla roślin rzepaku i nie był letalny dla ślimaków. Uzyskana redukcja uszkodzeń roślin rzepaku była wynikiem ich deterentnego i/lub antyfidantnego działania. Wysoka skuteczność abamektyny w ograniczaniu uszkodzeń roślin rzepaku przez *A. lusitanicus* pozwala sądzić, że związek ten może być w przyszłości wykorzystany w ochronie roślin przed ślimakami.