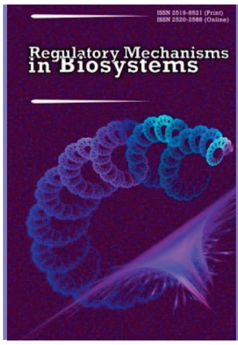

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Influence of aromatic substances on locomotor activity of *Deroceras agreste* slugs

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The global climate changes are causing an increase in the number and harmfulness of slugs. *Deroceras agreste* (Linnaeus, 1758) (Stylommatophora, Agriolimacidae) is a polyphagous phytophage that damages over 150 species of plants, including many vegetables, cultivated berries and grasses. Other than decrease in yield, slugs cause deterioration of consumer qualities of the products, promote infections of plants, and are intermediate hosts of some parasites of mammals and birds. Thus, slugs impose great losses on agricultural farming, and therefore the objective of our study was determining the variability of locomotor activity of *D. agreste* slugs in reaction to aromatic substances. We determined repellent or attractive effects of those substances for the purpose of further using the obtained data for plant protection. We tested 52 substances and their mixtures, which were conditionally divided into the following groups: chemical solvents, plant extracts, aromatizers, organic acids and synthetic cosmetic additives. Only dimethyl sulfoxide could be identified as an attractant. All the rest of the substances increased the speed of the slugs to various degrees, but had no significant effect on the direction of the animals' movement. Gasoline increased the speed of the slugs' movement by 3.20 times, xylene by 4.56. The most effective organic acids and aromatizers to increase the moving speed of slugs were avobenzone and formic acid: the first caused a 2.83-fold increase in the moving speed, the other a 3.16-fold increase. Only one of 13 aromatic substances changed the direction of the slugs' movement during the experiment – β-ionone. As with the plant extracts, the highest effect on locomotor activity of slugs was exerted by tree bark of *Quillaja saponaria* (3.64-fold) and *Aesculus hippocastanum* extract (4.33-fold). Furthermore, together with *Capsicum frutescens*, they changed the direction the mollusks were moving in, and therefore could be used as repellents. Synthetic cosmetic additives hydrolyzed silk and chrysalide oil exerted the greatest effects on the lcomotor activity of slugs (3.16 and 3.20 times, respectively). A total of 78.6% of the slugs moved away from chrysalide oil, and thus this oil may be suggested as a repellent, as well as mousse de babassu and cocamidopropyl betaine (84.6% and 78.6%, respectively). Therefore, a large amount of the tested substances to one or another extent made the slugs move faster, but most of them did not alter the direction in which the slugs were moving.

Keywords: repellents; attractants; protection from slugs; agricultural pests; terrestrial slugs; chemical pollution.

Introduction

Various groups of invertebrates are able to regulate the number of phytophages in the natural environment (Faly et al., 2017), but when people cultivate certain groups of plants, the number of zoophages decreases, and phytophages go out of control, especially phytophages with broad nutrition range (Brygadyrenko & Nazimov, 2015). The search for alternative ways of regulation of the number of phytophages attracts the attention of many researchers, though the attractive or repellent activity of certain substances or their mixes are usually studied on insects (Martynov et al., 2019a, 2019b; Titov & Brygadyrenko, 2021; Parhomenko et al., 2022) or Acari (Moshkin & Brygadyrenko, 2022), leaving mollusks out of the focus. Synthetic substances – food additives, essential oils and solvents – harmfully impacted not only arthropods, but nematodes as well (Boyko & Brygadyrenko, 2017, 2019, 2022). Therefore, it is practical to analyze the effect of substances that are broadly used in households on model species of phytophage mollusks.

Deroceras (*Deroceras*) *agreste* (Linnaeus, 1758) is a white gastropod (Stylommatophora, Agriolimacidae) with a slight brownish tone, which occurs in many countries of Eurasia (Wiktor, 2000). It probably inhabits the whole of Europe, undoubtedly lives throughout Central Europe, the British Isles, Iceland and Scandinavia, going as far as the Kola Peninsula, the Balkans, Crimea and Central Asia. In the Far East, it spreads to Sakhalin and the Kuril Islands (Wiktor, 2000). It occurs throughout Ukraine (Balashov, 2016).

The species is found in various biotopes with developed herbaceous cover. Field slugs can destroy up to 80% of the green parts of cultivated and ornamental plants. *Deroceras agreste* damages a broad spectrum of cultivated plants: grasses, vegetables, flowers, citrus and even weeds (Frank, 2003). The slugs are most harmful to lettuce, *Brassica oleracea* var. *capitata* and *Brassica oleracea* var. *botrytis*, young seedlings, leaves of wild bean and pea, fruits of cucombers, tomatoes and strawberries. Oats, flax, garlic, onion, *Brassica oleracea* var. *capitata* f. *rubra* and barley are consumed by slugs to a lesser degree. This species spreads viral and fungal infections among plants. Slugs infect plants with leaf spot of cabbage, powdery mildew, and *Phytophthora*. Along with other terrestrial mollusks, slugs are often the intermediate hosts of parasitic worms the primary hosts of which are mammals, birds and humans (Kafle et al., 2018; Hicklenton & Betson, 2019; Kim et al., 2019; Tolhurst et al., 2021). Among the commonest parasites, intermediate hosts of which are slugs, we should note *Angiostrongylus vasorum* (Hicklenton & Betson, 2019; Tolhurst et al., 2021), *Crenosoma vulpis*, *Aelurostrongylus abstrusus* and *Troglostrongylus brevior* (Segeritz et al., 2022), *Angiostrongylus cantonensis* (rat lungworm) (Kim et al., 2019), *Umingmakstrongylus pallikuu-*

kensis and *Varestrongylus eleguneniensis* (Kafle et al., 2018). Therefore, combating slugs is one of the relevant tasks for gardening and agriculture.

A number of methods of protecting plants against mollusks were proposed, based both on synthetic substances and biological organisms. Capinera & Dickens (2016) suggest using three fungicides based on copper hydroxide, copper octanoate and copper diacetate, and also note repellent properties of their high concentrations. The efficiency of using copper hydroxide to repel mollusks was confirmed by Capinera (2018a).

Besides repellent substances, Schüder et al. (2003) and Hoyer & Myrick (2012) considered the efficiency of various variants of barriers to repel terrestrial mollusks. Copper sheet, copper grid, copper-based ablative antifouling paint, copper-based non-ablative antifouling paint and copper foil were tested for their properties to be a factor of repelling pests. According to the results of the studies, those authors recommend using copper sheet barriers and copper grid of 250 cm length. Efficiency of treating leaves with copper was confirmed by Schüder et al. (2004); also the repellent effect of copper-amonia carbonate was determined. Furthermore, the study (Schüder et al., 2004), and two more studies (Watkins et al., 1996; Schüder et al., 2003), noted the efficiency of cinnamide against terrestrial mollusks. This substance decreased locomotor activity of slugs by 94%, the track length – by 96%, and increased the death rate of the pests to 95%. In the concentration of 0.23%, cinnamide significantly decreased the damage the slugs caused to wheat, and its 0.54% concentration provided complete protection of plants. Also, it is very important to note that coating wheat seeds with cinnamide had no significant effect on seed vitality. Slugs are also fought with repellent tape and mollusk-repelling paint, the efficiency of which (95.2% and 82.3%, respectively) was determined by Behnam (2009).

It would be practical to consider several methods of combating slugs, such as diatomit, hydrated lime, sulfur, silica dioxide, tree ash. Capinera (2018b) presented the results of the studying those materials compared with essential oil-based repellents. Hydrated lime and sulfur effectively prevented leaf damage compared with other three materials used as barriers. Also, an effective agent was a cinnamon-based repellent, whereas oil from cedar, pine, pepper mint and white pepper exerted no sufficient activity. Iron-phosphate and sulfur baits were less effective, but they produced some decrease in the intensity of plant consumption. Soil moisture negatively affected the efficiency of barrier materials, significantly decreasing their functionality compared with relatively dry soils.

Ecologically clean methods of plant protection are becoming increasingly relevant now. The most important of them is the use of biological agents against pests. To regulate the number of *D. agreste*, there are often used protozoans *Tetrahymena rostrata* (Haites et al., 2021), nematodes of *Phasmarhabditis* genus (Brophy et al., 2020; McDonnell et al., 2020): *Phasmarhabditis hermaphrodita* (Cutler & Rae, 2021; Schurkman et al., 2021), *Ph. thesamica* (Gorgadze et al., 2022), *Ph. akhaldaba* (Ivanova et al., 2021). More rarely, zoophages are used in agriculture: *Tetanocera elata* (Diptera: Sciomyzidae) (Ahmed et al., 2019) and various species of carabid beetles (Guenay-Greunke et al., 2022). Those methods could be combined with technological means, particularly sowing (Egleton et al., 2021) or creating barriers to hold off mollusks (Schüder et al., 2003; Hoyer & Myrick, 2012).

One of the most effective methods of combating terrestrial mollusks is traps. The traps are often made of bottles or boxes, which in some countries are commercially produced. However, the studies by Hagnell et al. (2006) found them no more effective than DIY traps. The trap itself, its shape and material are not factors on the activity of slugs; only the attractant determines the results of the studies. In such traps, various attractants are used (most often – beer and fruit juice), and commercially made baits, usually based on recipes of brans or pasta with metaldehyde as a pesticide ingredient. Also, as a lure, Ferricol, is used, also known as phosphate of iron and sulfur (Behnam, 2009).

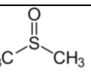
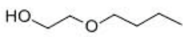
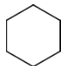
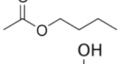
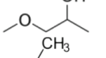
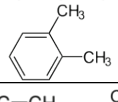
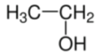
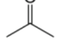
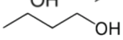
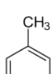
One of the best attractants is simple dough, comprising only flour, water and yeasts. Its advantages are simplicity of preparation, low cost and availability of the ingredients; such dough maintains its attractant activity for 8 days (Veasey et al., 2021). Components of leaves of rapeseed (*Brassica napus*) – a mix of monoterpenes and beta-ocimene from seedlings of this plant – were identified as expected attractants (Shannon et al., 2016). One of the commonest plant repellents is cinnamon; its efficiency was confirmed by various researchers (Watkins et al., 1996; Capinera 2018b). In one of the studies, the authors found 3,5-dimethoxycinnamic acid inefficient, unlike cinnamic amide. Furthermore, plants can produce repellents for the protection against slugs (Linhart & Thompson, 1995; Dodds et al., 1996; Clark et al., 1997; Wood & Ligare, 2008; Shannon et al., 2016; Jaskulska et al., 2017). Jeong et al. (2012) conducted laboratory studies with natural products, such as nicotine extract and caffeine, or their mix with ethyl alcohol as molluscicides. Also, oil from birch tar is an efficient repellent of plant origin is (Lindqvist et al., 2010).

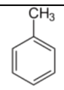
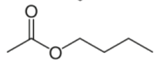
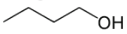
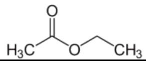
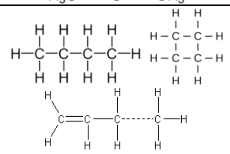
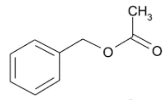
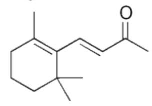
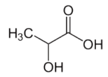
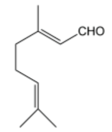
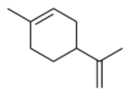
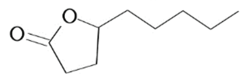
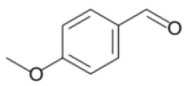
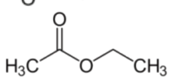
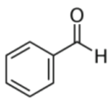
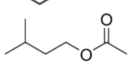
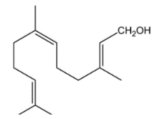
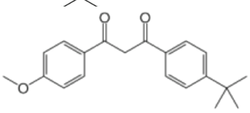
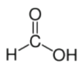
The objective of the study was the search for new cheap alternative methods against *Deroceras agreste* slug based on aromatic substances of various origins.

Materials and methods

For the experiment, we selected 52 substances that were conditionally divided into chemical solvents, aromatizers and organic acids (Table 1), plant extracts (Table 2) and synthetic cosmetic additives (Table 3).

Table 1
Solvents, aromatizers and organic acids used for the study of locomotor activity of *Deroceras agreste* slugs

Name	Formula		Commonest uses
	molecular	structural	
Dimethyl sulfoxide	C_2H_6OS		Important bipolar aprotonic solvent; as local anti-inflammatory and anesthetic drug in the form of aquatic solutions (10–50%), and also in compound of salves – mostly for transdermal delivery of active substances
2-Butoxyethanol	$C_6H_{14}O_2$		Solvent of paint and varnish coatings, cellulose and resins; in printing ink; in organic synthesis; in oil chemistry
Cyclohexane	C_6H_{12}		Raw material for obtaining caprolactam, adipic acid and cyclohexanone; solvent of essential oils, waxes, varnishes, paints
n-Butyl acetate	$C_6H_{12}O_2$		Solvent of nitrocellulose, chlorinated rubber, glyptal resins and other film-forming substances, is included in various solvents
1-Methoxy-propan-2-ol	$C_4H_{10}O_2$		Solvent and antifreeze
Xylene	$(CH_3)_2C_6H_4$		Additive to fuel; for deparaffination during isolation of DNA from archived tissues that had been fixed in formaldehyde and embedded into paraffin block
Solvent 646 P	ethanol C_2H_5OH acetone $(CH_3)_2CO$ 1-butanol $C_4H_{10}O$ toluol C_6H_5-CH_3	   	Solvent; broadly used in household and industry to defatten surfaces and solve various types of paint

Name	Formula		Commonest uses
	molecular	structural	
Solvent 647	toluol C_6H_5-CH_3 n-butyl acetate $C_6H_{12}O_2$ 1-butanol $C_4H_{10}O$ ethyl acetate $C_4H_8O_2$	   	Solvent for removal of varnishes and paint and varnish coatings, to solve nitrocellulose film substances; is able to solve nitroenamels and nitrovarnishes that are used for painting cars
Kerosene	saturated aliphatic carbohydrate (20–60%), cycloalkane (20–50%), bicyclic arenes (5–25%), non-saturated carbohydrate (no more than 2%), sulfur/nitrogen/ oxygen admixtures		Gas, fuel, solvent, reagent for enrichment of fossil fuels (flotation, oil aggregation), raw material for oil-processing industry
Gasoline	Gasoline of catalytic cracking and catalytic reforming (73.4%), alkylate (5.1%), isomerizate (16.2%), additives (alcohols, ethers) (5.3%)	–	Gas, fuel, solvent
Benzyl acetate	$C_9H_{10}O_2$		As aromatizer in hygienic and healthcare goods; attractant for bees in beekeeping
β-Ionone	$C_{13}H_{20}O$		Component in perfumery; fragrance composition for soap and flavourings in food industry
Lactic acid	$C_3H_6O_3$		In pharmaceutics, cosmetics and food industry as an active and supporting substance; as pH regulator in pharmaceutic goods, cosmetics, beverages and foods, acidifier and preservative; as skin softener and cooler in drugs for local application; as a biocarbonate source in form of lactate in injection solutions in medical practice, is included in drugs for local application
Citral	$C_{10}H_{16}O$		Fragrance composition for perfumes, aromatizer in food industry; antiseptic and anti-inflammatory drug; raw material for obtaiing vitamin A
D-Limonene	$C_{10}H_{16}$		Dietary supplement and aromatic ingrediant in cospetics; solvent; agent for paint removal; used as a less toxic xylol substitute for removal of dehydrated samples when preparing the tissues for histology
γ-Undecalactone	$C_{11}H_{20}O_2$		Aromatic ingredient of cosmetics, hygienic and healthcare product
Anisaldehyde	$C_8H_8O_2$		Component of perfumery, food essences, raw material for obtaining fragrant substances, and also during the synthesis of some drugs
Ethyl acetate	$C_4H_8O_2$		Solvent in preparation of coatings, adhesive materials, ink, cosmetics, pharmaceutics; as extracting agent in production of caffeine-free coffee
Benzaldehyde	C_7H_6O		Precursor of some organic reagents; for the synthesis of colourings and fragrant substances; component of perfumeries; food aromatizers; solvent
Isoamyl acetate	$C_7H_{14}O_2$		Solvent in paint-and-varnish production, leather and other industries, in the production of film for videocameras, celluloid, and also aromatizer in fthe ood industry
Farnesol	$C_{15}H_{26}O$		Component for increasing the aroma of perfume; natural pesticide against Acari and pheromone for some insects
Avobenzone	$C_{20}H_{22}O_3$		In sunscreens for absorbing the entire spectrum of UVA rays
Formic acid	HCO_2H		Preservative and antibacterial agent during preparation of fodders; antiparasitic agent in beekeeping; solvent in some chemical reactions; is used to obtain formates that are used to improve properties of concrete; for preparation of solvents of performic acid in medicine

Note: the data are generalized baced on Ashurst (1991), Guzmán & Lucia (2001), Reichardt & Welton (2010) and the data from open sources.

Table 2
Use of plant extracts to study the locomotor activity of *Deroceras agreste* slugs

Name of substance	Main constituents	Commonest uses	References
Calendula officinalis extract	α-Thujene, 1,8-cineole, δ-cadinene, α-pinene, γ-cadinene	Has antiseptic, bactericidal, anti-inflammatory, regenerating, wound-healing, softening and sunscreen effects	Okoh et al. (2008), Kaškonienė et al. (2011)
Capsicum frutescens extract	Octadecane, eicosane, docosane, 9,12-Octadecadienoic acid, methyl ester, hexadecanoic acid	Helps stimulating blood circulation and removes blood clotting; in hair cosmetics against dandruff and for nutrition of hair follicles; increases blood flow, antioxidant	Gurnani et al. (2016)
Oil ricini	Ricinoleic acid, oleic acid, linoleic acid, stearic acid, dihydroxystearic acid	Castor oil and its derivatives are used in production of Soap, lubricants, hydraulic and brake fluids, paints, colourings, coatings, ink, cold-resisting plastic, wax and polish, neulon and perfumes	Wool (2005), Naik et al. (2018)
AHA fruit acids	Glycolic acid, lactic acid, citric acid, tartaric acid, malic acid	Used in cosmetics and dermatology	Babilas et al. (2012)
Sapindus mukorossi nuts	Palmitic acid, stearic acid, arachidic acid, oleic acid, linoleic acid, linolenic acid, eicosenoic acid, triolein, eicoseno-di-oleins	Antibacterial and antifungal agent; as a detergent, biosurface-active substance and an agent for removal of organic contamination of soil	Sengupta et al. (1975)
Camelina sativa oil	Saturated acid, polyunsaturated acid, linoleic, α-linolenic, erucic acid	The oil is rich in Omega-3 and natural antioxidants, such as tocopherols, may be used as biofuel and biolubricants; as additive for fodders of cattle in the USA, and also as ingredient (up to 10% of the diet) in fodders for broiler chickens and laying hens; in cosmetics, as an ingredient that provides protective and antioxidant actions	Abramovi & Abram (2005)
Ruscus aculeatus extract	Schaftosid, orientin, vitexin, vitexin-2″-O-β-d-glucopyranoside, vitexin-2″-O-α-l-rhamnoside, rutin, isoquercitrin, nicotiflorin, narcissin, caffeic, p-coumaric acid, trans-feruloyl-2″-hexaracid-lactone, trans-feruloyl-3″-hexaracidlactone, trans-feruloyl-methoxyhexaracid-lactone derivate, (S)-N-trans-caffeoyloctopamine, (S)-N-trans-Cumaroyloctopamine, (S)-N-trans-feruloyloctopamine, N-trans-caffeoyltyramine, N-trans-cumaroyl-tyramine, N-trans-feruloyltyramine	Has anti-inflammatory and anti-edema effects; exerts tonic and calming effects on the skin	Hadžifejzovićad et al. (2013)
Salvia officinalis extract	Camphor, α-thujone, 1,8-cineole, viridiflorol, β-thujone, β-caryophyllene	Antiseptic and binding agent	Khedher et al. (2017)
Cucumis sativus extract	Palmitic acid, stearic acid, oleic acid, linoleic acid, linolenic acid	Used in a broad range of products, including bath products, soap and detergents, lotions, cleansing products, agents for healthcare of nails, eye makeup, and also agents for hair health	Burnett et al. (2017)
Malva sylvestris extract	1-Heptacosanol, 17-pentatriacontene, 6,9,12,15-docosatetraenoic acid, ethyl ester	Other than use in cuisine, there are reports on pharmaceutical and clinical effects. In ethnopharmacological literature, there is a long history of recognition of its powerful anti-inflammatory, antioxidant, anti-cancer and anti-ulcerogenic properties. It is used as a broncholitic, expectorant, cough suppressor, antidiarrhetic agent, and is recommended for skincare against acne, as antiseptic, softening and calming agent	Fathi et al. (2021)
Punica granatum extract	Punicic acid, conjugated linolenic acid, phenolic acids, quercetin, naringenin, 3-methyl-1-butanol, 2,3-butanediol, phenylethyl alcohol	In many cosmetics and drugs, since its constituents relieve irritation and fatigue, improve blood circulation and stimulate collagen expression	Costa et al. (2019)
Petroselinum crispum extract	Menthatriene, β-phellandrene, apiol, myristicin, terpinolene	As diarrhetic and spasmolitic agent for diseases of kidneys, intestinal cramps and meteorism, has antibacterial properties	Snoussi et al. (2016)
Tree bark *Quillaja saponaria*	Piscidic acid, p-coumaric acid, glucosyringic acid, vanillic acid	Acts as foam foaming agent, cleaner, emulsifier, surfactant, skin conditioning agent in hygienic agents; as emulsifier for emulsion of coal tar, cleansing of industrial Equipment, solutions of tar and polishing agent for metals; is added in local drugs against skin diseases, and also as a protective agent in fractures, bruises, frostbite and insect bites; the drug causes significant irritations and vomiting, also is expectorant for peroral consumption; diuretic and skin stimulator	Maier et al. (2015)
Aesculus hippocastanum extract	Stearic acid, palmitic acid, oleic acid, linoleic acid, linolenic acid	In cosmetic agents, chestnut extract helps the skin to remain moistened and elastic; improves blood flow, improves skin metabolism; counters free radicals	Ehlers & Hill (1951)

At the preparation stage (September 2021), we formed a group of *D. agreste* slugs, containing 150 individuals. The slugs were collected manually. During several weeks, the slugs were kept in a plastic bucket with leaf foliage, leaves of lettuce, cabbage and cut carrot. We provided constant temperature (25 °C) and moisture (45–47%) using a heater and pulverizer with water. The experiments were carried out in the same conditions of light, humidity and temperature. On the bed of a large container, we put a 36 × 26 cm sheet of paper, charted into 3cm sided squares (Fig. 1).

We installed a camera above the container. In one corner of the sheet, we put ¼ of a cotton disk with one drop of aromatic substance, and placed 10 slugs in the center of the list. For 5 minutes, the videocamera was recording the slugs moving on the sheet. After each experiment, the cotton disk, sheet and slugs were replaced. The experiment with each substance was carried out in four repetitions. Also, we carried out experiments with no substances for the control. Using the footage, we counted the number of squares each slug travelled for 5 min from the start of the experiment. We introduced those results intothe table and identified the variability in their locomotor activity using ANOVA. Furthermore, we noted the location of each specimen at the end of the experiment to determine the direction of their movement. Moreover, we conditionally divided the sheet into two parts; the division line was the middle of the sheet, where the slugs were put at the beginning of the experiment. We separately counted slugs that moved toward the part with the substance or in the opposite direction. The representatives that had not moved or moved on the division line were not counted when calculating the repellence degree. Using the obtained results, we determined the repellent or attractive actions of the studied substances. Statistical analysis of the obtained results was performed using Statistica12.0 software (StatSoft Inc., Tulsa, USA).

Fig. 1. Location of slugs during the experiment: on the 0th second (*a*), 30th (*b*), 60th (*c*), 90th (*d*), 120th (*e*), 150th (*f*)

Table 3
Synthetic cosmetic additives used in the study of locomotor activity of *Deroceras agreste* slugs

Substance	INCI name	Commonest uses
Mousse de Babassu	Babassuipropyl betaine	Surfactant for increasing foam formation; has conditioning and antistatic effects
Honeyquat	Hydroxypropyltrimonium honey	Quaternized conditioning agent, is able to bind moisture, can increase hair gloss and decrease the accumulation of static electricity
Ceramide A2	Aqua, glycerin, PEG-8, PEG-8 / SMDI copolymer, palmitoyl myristyl serinate, sodium polyacrylate	Recovers the structure, protects and coats damaged hair; used in production of shampoos, masks and balsams for hair
Biogold	Aurum metallicum d6.	Used in hardware cosmetology; provides deep penetration into the skin, preserves turgor pressure
Acrylates W 2000	Acrylates/palmeth-25 acrylate copolymer	as a viscocity emulsion in cosmetics
Sodium benzoate and potassium sorbate	Sodium benzoate, potassium sorbate	Antifungal preservative; in products with low pH, used to obtain synergic effect of ingredients against yeasts and mold

Substance	INCI name	Commonest uses
Royal jelly extract	Aqua, glycerin, royal jelly extract, citric acid, sodium benzoate, potassium sorbate	Has bactericidal and antiviral actions, promotes skin regeneration, toning
Chitosan	Chitosan	In hair cosmetics, anti-acne agents; used for moistening and regeneration of skin, improves the hair structure, has bactericidal and rejuvenating effects
Cocamidopropyl betaine	Cocamidopropyl betaine	Surfactant used in many personal care and household cleaning products.
Sodium alginate	Algin	Foam intensifier in shampoos; emulsifier, antiseptic in hygienic products, stabilizer and emulsifier and gel-forming agent in food industry; as a drug for skin conditioning and moisturing
Polysorbate 80	Polyoxyethylene (20), sorbitan monooleate	Emulsifier that is used in pharmaceutics and food industry; in cosmetics, to dissolve essential and aromatic oils; is a good solubilizer of essential oils, viscosity modifier, stabilizer and dispersing agent
Leucidal	Lactobacillus ferment	Is suitable for moistening, conditioning of the skin of head and has antimicrobial action
Hydrolyzed Silk	Hydrolyzed silk	Is usedfor hair gloss, firmness and makes hair less frizzy; in skincare, is known for its high ability to Bind moisture, creating protective barrier
Chrysalide oil	Silkworm chrysalis oil	Has regenerating effect

Note: the data are generalized based on the data from open sources.

Results

The greatest effects caused by the chemical solvents on the movement of slugs were exerted by gasoline and xylene (Fig. 2). Gasoline increased the speed of slugs by 3.2 times ($P < 0.001$), and xylene by 4.56 ($P < 0.001$, Table 4). Analysis of the locations of each animal at the end of the experiment revealed that neither substance altered the direction in which the slugs were travelling compared with the control (58.1% of individuals moved in opposite direction from gasoline and 44.4% – away from xylene, in the control – 51.1%). Therefore, the studied solvents had no notable repellent or attractive properties. Dimethyl sulfoxide made 70% of the studied mollusks change the direction they were moving, and thus can be identified as an attractant. Avobenzone and formic acid had the greatest effects on slugs out of aromatizers and organic acids (Fig. 3).

The first of them caused a 2.83-fold ($P < 0.001$) increase in the speed of slugs' movement, the second – 3.16 fold ($P < 0.001$, Table 5). Both substances insignificantly changed the direction of the mollusks' movement (41.9% of slugs moved away from avobenzone, 51.5% – from formic acid). In the indicated group of substances, repellent properties were seen in the experiment with β-ionone (68.0%).

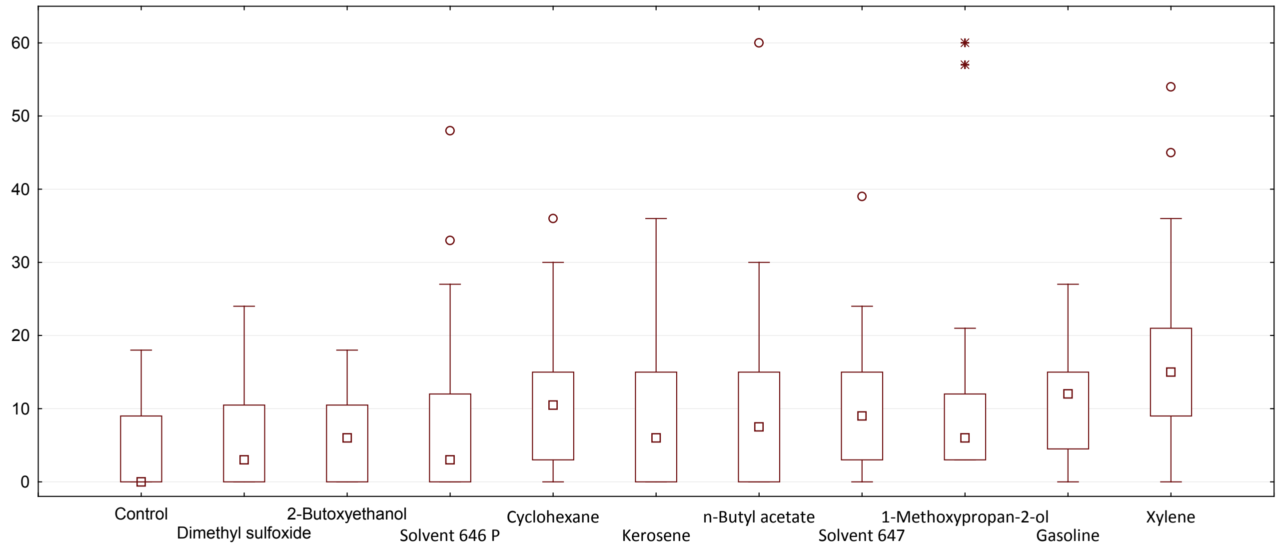


Fig. 2. Variability of locomotor activity of *Deroceras agreste* exposed to solvents ($n = 40$): on abscissa axis – chemical substances, on ordinate axis – distance (cm) the slugs travelled in 5 min

Table 4
Locomotor activity of *Deroceras agreste* exposed to solvents ($n = 40$)

Substance	Distance (cm) the slugs travelled in 5 min, x ± SD	Compared to the control	P
Control	3.6 ± 5.5	100.0	–
Dimethyl sulfoxide	5.6 ± 7.0	156.3	0.154
2-Butoxyethanol	5.6 ± 5.4	156.3	0.099
Solvent 646 P	7.1 ± 10.0	197.9	0.054
Cyclohexane	7.7 ± 8.1	212.5	0.010
Kerosene	8.6 ± 8.5	237.5	$2.7*10^{-3}$
n-Butyl acetate	9.6 ± 11.5	266.7	$3.9*10^{-3}$
Solvent 647	9.9 ± 8.4	275.0	$1.6*10^{-4}$
1-Methoxypropan-2-ol	10.8 ± 12.6	300.0	$1.4*10^{-3}$
Gasoline	11.6 ± 7.5	320.8	$6.9*10^{-7}$
Xylene	16.4 ± 10.7	456.3	$2.5*10^{-9}$

Note: x – mean value, SD – standard error, P – significance of differences from the control according to the results of ANOVA taking into account Bonferroni's correction.

The greatest effects exerted by plant extracts were those of tree bark of *Quillaja saponaria* and *Aesculus hippocastanum* extract (Fig. 4).

Tree bark of *Quillaja saponaria* increased the slugs' moving speed by 3.64 times ($P < 0.001$) and also exhibited repellent activity (66.7% of the slugs moved away from the substance, and in the tests with *Aesculus hippocastanum* extract, 96.8% of the slugs moved away from the substance, their speed increased 4.33-fold ($P < 0.001$) compared with the control, Table 6).

Other than the indicated aromatizers, extract of red pepper Chili may be classified as repellent (*Capsicum frutescens* extract – 70.0% of the slugs moved away from this substance) and *Cucumis sativus* extract could be classified as an attractant (89.7% of the mollusks moved toward the substance).

Out of the synthetic cosmetic additives, hydrolyzed silk and chrysalide oil had the highest effects on the locomotor activity of slugs (Fig. 5). Hydrolyzed silk increased it 3.16-fold ($P < 0.001$), 40.7% of the slugs moved away from the substance. Chrysalide oil increased the mollusks' speed 3.20-fold ($P < 0.001$), 78.6% of the slugs moved away from the substance (Table 7).

In the list of synthetic additives, we should note repellent properties of mousse de babassu and cocamidopropyl betaine, characterized by significant effects on direction of slugs' movement (84.6% and 78.6%, respectively).

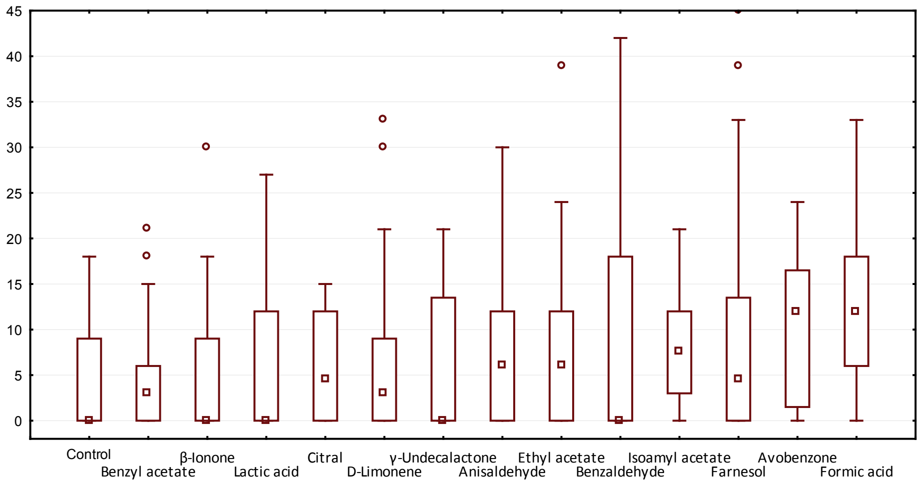


Fig. 3. Variability in the locomotor activity of *Deroceras agreste* slugs exposed to aromatizers and organic acids (n = 40): on abscissa axis – chemical substances, on ordinate axis – distance (cm) the slugs travelled in 5 min

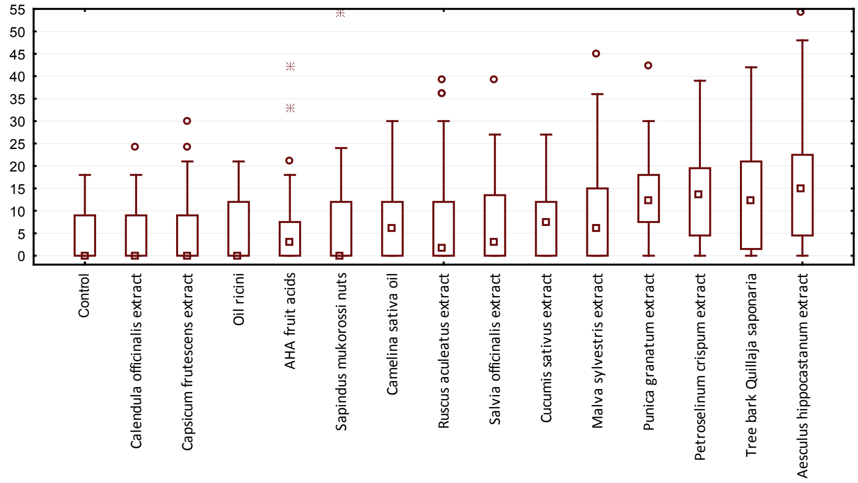


Fig. 4. Variability of locomotor activity of *Deroceras agreste* slugs exposed to plant extracts (n = 40): on abscissa axis – mixtures of chemical substances, on ordinate axis – distance (cm) the slugs travelled in 5 min

Table 5
Locomotor activity of *Deroceras agreste* slugs exposed to aromatizers and organic acids (n = 40)

Substance	Distance (cm) the slugs travelled in 5 min, x ± SD	Compared to the control, %	P
Control	3.6 ± 5.5	100.0	–
Benzyl acetate	4.5 ± 5.0	125.0	0.447
β-Ionone	4.7 ± 7.2	131.3	0.437
Lactic acid	5.3 ± 7.1	145.8	0.250
Citral	5.7 ± 5.8	158.3	0.099
D-Limonene	5.9 ± 8.3	164.6	0.144
γ-Undecalactone	6.4 ± 10.2	177.1	0.134
Anisaldehyde	7.2 ± 8.4	200.0	0.026
Ethyl acetate	7.2 ± 8.2	200.0	0.024
Benzaldehyde	8.0 ± 11.3	220.8	0.032
Isoamyl acetate	8.0 ± 6.3	220.8	$1.5*10^{-3}$
Farnesol	8.9 ± 11.2	247.9	$8.7*10^{-3}$
Avobenzone	10.2 ± 7.6	283.3	$2.7*10^{-5}$
Formic acid	11.4 ± 7.8	316.7	$1.7*10^{-6}$

Note: see Table 4.

The study revealed that most of the substances and mixes did not alter the direction of the slugs' movement. Nine substances significantly increased the number of slugs moving away from them, i.e. exhibited repellent activity. Attractive properties were exerted by *Cucumis sativus* extract, which attracted 89.7% of individuals, and dimethyl sulfoxide, which attracted 70.0%.

Table 6
Locomotor activity of *Deroceras agreste* slugs exposed to plant extracts (n = 40)

Substance	Distance (cm) the slugs travelled in 5 min, x ± SD	Compared to the control, %	P
Control	3.6 ± 5.5	100.0	–
Calendula officinalis extract	4.6 ± 6.4	127.1	0.467
Capsicum frutescens extract	5.0 ± 7.5	137.5	0.362
Oil ricini	5.6 ± 7.3	156.3	0.164
AHA fruit acids	5.8 ± 9.2	160.4	0.203
Sapindus mukorossi nuts	6.2 ± 10.8	172.9	0.173
Camelina sativa oil	7.7 ± 7.9	212.5	$9.4*10^{-3}$
Ruscus aculeatus extract	7.8 ± 11.4	216.7	0.038
Salvia officinalis extract	7.8 ± 9.6	215.8	0.019
Cucumis sativus extract	8.0 ± 7.6	220.8	$4.5*10^{-3}$
Malva sylvestris extract	9.2 ± 10.7	254.2	$4.5*10^{-3}$
Punica granatum extract	12.3 ± 9.2	341.7	$2.1*10^{-6}$
Petroselinum crispum extract	13.1 ± 10.3	362.5	$2.1*10^{-6}$
Tree bark *Quillaja saponaria*	13.1 ± 10.8	364.6	$3.8*10^{-6}$
Aesculus hippocastanum extract	15.6 ± 13.7	433.3	$2.2*10^{-6}$

Note: see Table 4.

Discussion

Difficulty of countering slugs is that the main products used for this purpose can pose a threat to non-target species, including beneficial. The issue of creating an integral method of combating pests remains relevant today. A lot of attention in countering slugs is paid to plant extracts or specifically plant components that may be attractants or repellents (Shannon et al., 2016). In the studies by Hollingsworth et al. (2002, 2005), the action of 1% and 2% solutions of caffeine were tested. After spraying plants, caffeine repelled 100% of slugs. However, over time, all slugs died of caffeine poisoning. Treatment of soil with 2% solution caused death to 95% of *Zonitoides arboreus* snails and produced better results than the standard method based on metaldehyde. The slugs avoided leaves that had been treated with 0.1% concentration of caffeine solution. Experiments with caffeine were also carried out by other authors. Jeong et al. (2012) studied the natural products, such as nicotine extract and caffeine, or their mixtures with ethyl alcohol. Various concentrations of those components were tested, for example 10% solution of ethyl alcohol caused 90% mortality of slugs, but mix of caffeine and alcohol had phytotoxic effect. Mixture of 0.5% nicotine extract and 7% ethyl alcohol was effective against slugs and caused no harm to plants.

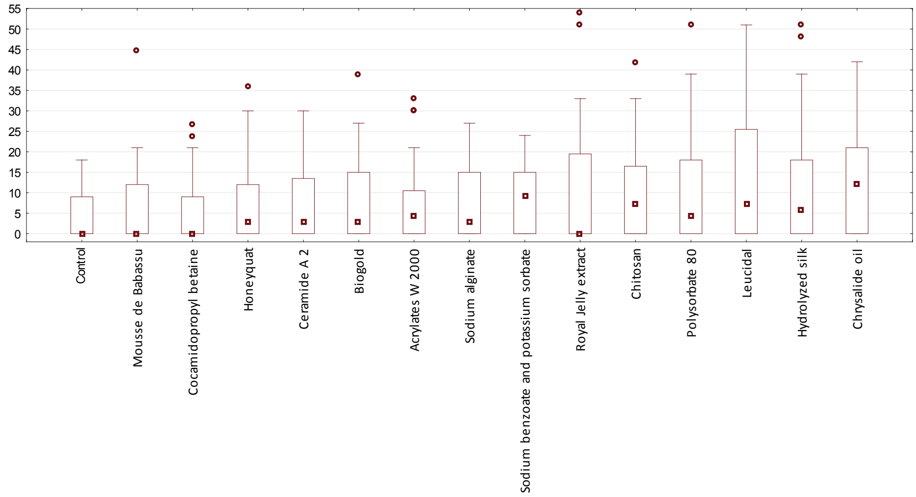


Fig. 5. Variability of locomotor activity of *Deroceras agreste* slugs exposed to synthetic cosmetic substances (n = 40): on abscissa axis – chemical substances; on ordinate axis – distance (cm) the slugs travelled in 5 min

Aladesanmi (2006) studied the locomotor activity of slugs exposed to aqueous and alcohol extracts of bark, leaves, and shoots of Nigerian tree *Tetrapleura tetraptera*. The tests using the extract mixed with 4% solution of metaldehyde in 50:50 proportion caused a high level of slugs mortality.

Table 7
Locomotor activity of *Deroceras agreste* slugs exposed to synthetic cosmetic additives (n = 40)

Substance	Distance (cm) the slugs travelled in 5 min, x ± SD	Compared to the control, %	P
Control	3.6 ± 5.5	100.0	–
Mousse de Babassu	5.6 ± 9.2	154.2	0.251
Cocamidopropyl betaine	5.6 ± 8.2	154.2	0.216
Honeyquat	6.7 ± 9.0	185.4	0.069
Ceramide A2	7.3 ± 9.5	202.1	0.037
Biogold	7.3 ± 9.4	202.1	0.036
Acrylates W 2000	7.4 ± 9.3	206.3	0.027
Sodium alginate	7.5 ± 8.7	208.3	0.019
Sodium benzoate and potassium sorbate	8.7 ± 8.4	241.7	$1.9*10^{-3}$
Royal jelly extract	10.0 ± 14.1	277.1	$9.4*10^{-3}$
Chitosan	10.1 ± 10.6	279.2	$1.0*10^{-3}$
Polysorbate 80	10.3 ± 12.5	285.4	$2.8*10^{-3}$
Leucidal	14.0 ± 15.0	387.5	$9.8*10^{-5}$
Hydrolyzed Silk	11.4 ± 13.4	316.7	$1.0*10^{-3}$
Chrysamide oil	11.6 ± 12.0	320.8	$2.8*10^{-4}$

Note: see Tabe 4.

Some alkaloids and terpenoids may be used to protect leaves against mollusks. Kozłowski (2016) revealed that the highest efficiency in reducing the harm for all concentrations (0.2%, 0.7% and 1.2%) was achieved for sparteine and thymol. The death rate among slugs of *Arion vulgaris* Moquin-Tandon, 1855 after 48 h of consumption of leaves treated with 1.2% solution of thymol was 66.7%, whereas after application of sparteine (0.7% and 1.2%), the mortality increased to 66.7% and 83.3%, respectively. Use of 1.2% solution of thymol produced death of 66.7% of slugs, and 0.7% and 1.2% solutions of sparteine – 66.7% and 83.3%, respectively. Volatile organic substances of several rapeseed varieties (3-hexen-1-ol, 3-hexen-1-ol acetate and the monoterpene α-terpinene) were identified as a possible repellent mix (Shannon et al., 2016). Linhart & Thompson (1995) revealed that out of the extracted monoterpenes, carvacrol significantly decreased the locomotor activity of slugs. Vokou et al. (1998) tested several oils that contained phenol compounds. Significant repellent action was demonstrated only by those oils that contained largest concentrations of carvacrol.

Resins of some plants can affect the locomotor activity of slugs. Kozłowski et al. (2010) conducted a number of experiments: mixed plant resins with sawdust, sand and granules of maize ears; all the experiments confirmed the repellent properties of the mentioned resins. An effective repellent of plant origin is oil of birch tar. Its efficiency was determined by Lindqvist et al. (2010): applying the oil to slugs made them ineffective, such a method remained effective for up to several months. Application of oil to plants or the pots they were in required its additional application every two weeks for remaining the barrier properties. However, the mixture of oil and vaseline solved this problem, and therefore is a good molluskocide.

Piechowicz et al. (2018) revealed that components of volatile fraction of beer such as: t-muurolol, aristolene epoxide, decanoic acid, 9Z,12Z)-9,12-octadecadienoic acid 2-acetyloxy-1-(acetyloxymethyl)ethyl ester, t-cadinol and oleic acid attracted mollusks, and g-elemene and bicyclo[4,1,0]heptane,3,7,7 trimethyl neagatively affected the attractiveness of beer aroma for slugs. Oleic acid was present in the compounds of several extracts we studied (Oil ricini, *Sapindus mukorossi* nuts and *Cucumis sativus* extract), but only the results with cucumber extract confirm their attractiveness for *Deroceras agreste*. Fragmented cucumber (*Cucumis sativus*) was found to be the most powerful attractant for another two species of slugs - *Cornu aspersum* (O. F. Müller, 1774) (Stylommatophora, Helicidae) and *Deroceras reticulatum* (Cordoba et al., 2018).

As with the plant extracts we studied, repellent properties were observed for *Quillaja saponaria*, a similar effect of this plant on mollusks was described by González-Cruz & San Martín (2013). Extracts of soapnut, *Sapindus mukorossi* Gaertn. (Sapindaceae) displayed molluscicidal effects against the golden apple snail, *Pomacea canaliculata* Lamarck. (Ampullariidae) with LC_{50} values of 85, 22, and 17 ppm after treating for 24, 48, and 72 h, respectively. During our study, *Deroceras agreste* did not change the direction of its movement when exposed to this extract.

The main advantage of essential oils and plant extracts over other repellents is their safety for the environment (Nollet & Rathore, 2017; Radwan & Gad, 2021). Therefore, using essential oils may be a good alternative to synthetic substances.

Conclusion

Out of chemical solvents, the greatest effect on locomotor activity of the studied species of slug was produced by gasoline and xylene. The first increased the speed of slugs by 3.20 times (P < 0.001), the second by 4.56 times (P < 0.001). Gasoline and xylene did not significantly change the direction the slugs were moving in compared with the control, i.e. they displayed no notable repellent or attractive properties.

Dimethyl sulfoxide changed the direction of the movement of 70% of the studied mollusks and may be identified as attractant for *Deroceras agreste*.

Avobenzone and formic acid were the aromatizers and organic acids that exerted the greatest effects on slugs. The first of them increased the speed of slugs by 2.83 times (P < 0.001), and the second by 3.16 times (P < 0.001). Nonetheless, neither of those substances altered the direction the mollusks were moving in.

Repellent properties were observed in the experiment with β-ionone.

As for plant extracts, the highest effects on locomotor activity of slugs were exerted by tree bark of *Quillaja saponaria* and *Aesculus hippocastanum* extract. *Quillaja saponaria* increased the speed of slugs by 3.64 times (P < 0.001). It also exhibited repellent activity: 66.7% of slugs moved away from the substance. In tests with *Aesculus hippocastanum* extract, 96.8% of slugs moved away from the substance, and their speed increased by 4.33 times (P < 0.001) compared with the control. Such an effect may be related to monoterpenes and saponines they contain, repellent action of which was confirmed by many studies.

As repellents, we can consider the extract of red chili pepper (*Capsicum frutescens* extract) – 70% of slugs moved away from the extract. *Cucumis sativus* extract attracted the mollusks, causing 90.0% of the slugs to move toward the aroma source.

Out of the synthetic cosmetic additives, the greatest effects on locomotor activity of slugs were displayed by hydrolyzed silk and chrysalide oil. Hydrolyzed silk increased it 3.16-fold (P < 0.001). Chrysalide oil increased the speed of mollusks 3.20-fold (P < 0.001); 78.6% of the slugs moved away from the aroma source, and thus it may be considered a repellent. In the list of synthetic additives, we should note repellent properties of mousse de babassu and cocamidopropyl betaine, characterized by significant effect on the direction of slugs (84.6% and 78.6% of individuals respectively were moving away from the aroma source). Thus, the studies determined that most of the studied substances to a certain degree made the slugs move faster, but most of them caused no significant change in the direction of the slugs' movement.

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