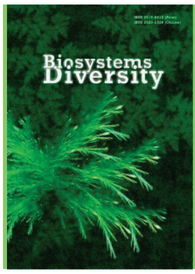

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Influence of organic acids on locomotor activity of *Stratiolaelaps scimitus* (Mesostigmata, Laelapidae)

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Increasing the activity of zoophage Acari in agrocenoses, for example luring them to concentrations of harmful insects, could be effectively performed using attractants, for example organic acids that people use in households and industry. In our experiment, we studied the influence of organic acids on the locomotor activity of *Stratiolaelaps scimitus* (Womersley, 1956) (Mesostigmata, Laelapidae). Different organic acids caused certain reactions in those zoophages. Acetic acid encouraged this mite to activity and attracted it, while thioacetic acid inhibited and repelled it. Fatty acids such as tridecylic and oleic acids had an activating effect on the locomotor activity of *S. scimitus*. Three isomers of valeric acid inhibited locomotor activity, and the mites exerted negative chemostasis to them. Maximum locomotor activity of the mites was observed when using asparagine, omithine, propionic acid, tridecanoic acid, boric acid, and arginine. Locomotor activity of the mites was inhibited by 3,3-dimethylbutanoic acid, thioacetic acid, pivalic acid, maleic acid, formic acid, succinic acid, 2-methylbutanoic acid, isovaleric acid, 6-aminohexanoic acid, and 2-oxoglutaric acid. We propose using attractiveness coefficient and coefficient of migratory activity, which reflect the effects of aroma compounds on mites. Those coefficients are helpful in identification of a behaviour model for mites exposed to aroma compound: attack, motionless state or escape. High attractiveness and migratory-activity coefficients mean attack on victim; low coefficients indicate motionless mites; high migratory activity and low attractiveness coefficient mean escape reaction. Our results indicate complexity of behaviour reactions of mites, which were sensitive to volatile chemical compounds in the environment. We found a high potential of using those compounds in attracting zoophages during their introduction in agrocenoses of greenhouses and open plots.

Keywords: Acari; exploratory activity; migration activity; attractants; repellents; plant protection; litter fauna.

Introduction

Organic compounds are able to affect the behaviour of invertebrates (Titov & Brygadyrenko, 2021), and this phenomenon has its roots in the trophic and sexual interactions of those organisms. Sexual behaviour is affected by sex pheromones (Shorey, 1973; Jackson & Morgan 1993), and trophic behaviour is subject to groups of factors and complexes of organic compounds, made of semiochemical molecules (kairomones) or their combinations. Kairomones create conditions for inter-species relations (Dicke & Sabelis, 1988; Kost, 2008), and also create signals for fast, short, and remote actions or complex of behaviour reactions of an organism (Afsheen et al., 2008; Heil & Ton, 2008).

As human civilization developed, the production and use of various aroma compounds, in particular organic acids, grew. Most aroma compounds are allowed in the food industry, medicine, and cosmetology (Boyko & Brygadyrenko, 2019). Those chemical compounds usually enter the natural environment in purer form and greater concentration than natural compounds. Taxonomic diversity of litter invertebrates exposed to them can undergo dramatic changes (Faly et al., 2017). Therefore, it would be relevant to study effects of those compounds on the behaviour of natural fauna. Predatory and plant-eating invertebrates can adapt to changes in the chemical composition of their surroundings, and this affects their trophic activity in natural conditions (Martynov et al., 2017).

Of special interest is *Stratiolaelaps scimitus* (Womersley, 1956) (Mesostigmata, Laelapidae) – a popular worldwide entomophage, used in both greenhouses and open plots for the control of number of pests (Jess & Schweizer, 2009; Park et al., 2021b; Yan et al., 2021). *Stratiolaelaps scimitus* feeds on soil stages of development of many species of thrips (Berndt et al., 2004a, 2004b; Jung et al., 2019; Park et al., 2021a). This species is used for the protection of plants against *Bradysia matogrossensis* (Lane, 1959) (Diptera, Sciaridae); to protect cultivated muschrooms *Agaricus bisporus* (J. E. Lange) Imbach, 1946 (Agaricales, Agaricaceae) from *Coboldia fuscipes* (Meigen, 1830) (Diptera, Scatopsidae) and *Bradysia cellarum* Frey, 1948 (Diptera, Sciaridae) (Wen et al., 2017; Duarte et al., 2020); to protect Chinese chives *Allium tuberosum* Rottler ex Spreng, 1825 (Asparagales, Amaryllidaceae) from *Bradysia ocellaris* (Comstock, 1882) (Yan et al., 2022). It is used in terrariums for the treatment of reptiles *Pogona vitticeps* (Ahl, 1926) (Squamata, Agamidae) against parasitic mites (Trombidiformes, Trombiculidae) (Schilliger et al., 2013; Mendyk, 2015) and in industrial breeding of the Roman snail *Helix pomatia* Linnaeus, 1758 (Stylommatophora, Helicidae) for prophylaxis of breeding of parasitic mites *Riccardoella limacum* (Schrank, 1776) (Trombidiformes, Ereynetidae).

However, there are currently insufficient data about the reaction of mites to organic compounds that can lure or repel those mites. Understanding of trophic behaviour of those zoophages can improve the existing systems of biological protection from plant-eating pests (Mills & Wajnberg, 2008; Gunton & Pöyry, 2016; Mills & Heimpel, 2018). In this article, we present the research specifics of effects of 32 various organic compounds on the locomotor activity of *S. scimitus*. The results can be useful in development of modern strategies of integrated protection of plants and cultivation of mushrooms in greenhouses.

Materials and methods

Laboratory culture of mites. The *S. scimitus* mites (125,000 specimens) were obtained from the Bioprotection laboratory (Ukraine), in a 5 L plastic bucket (28 cm width, 18 cm depth, and 15 cm height). *S. scimitus* mites were kept in a mixture of peat and vermiculite, together with the *Tyrophagus putrescentiae* mites (Schrank, 1781) (Sarcoptiformes, Acaridae). To maintain purity of the population, we kept it in a 30 L box, with 2 L of water at the bottom, according to the two-box technology (Jung et al., 2018). The mites were kept in the laboratory at 26 ± 2 °C and 60 ± 10% relative humidity.

Laboratory stand. To measure the impact of evaporations of organic acids on the locomotor activity of the *S. scimitus* mites, we used a polypropylene (PP) cylinder, 44 cm in diameter and 24 cm in height. On the bottom of the cylinder, there was experimental field with a coordinate system (grey lines formed circles, after each 10 mm). For each experiment, in the system of coordinates, we put a new transparent 40 µm thick disposable polypropylene (BOPP) sheet. In the center of the coordinate system, we put a cup for cotton swab (carrier of aroma compound). The cylinder was covered by a transparent 5 mm-thick polymethyl methacrylate (PMMS) sheet. A video-recording device was put on it. The videocamera had optical stabilization and autofocus (Samsung S20 FE, Vietnam, 2020) and 1,440 × 1,440 pixel resolution.

Migration circle. To obtain a group of *S. scimitus* (50–150 mites), we used a migration circle, made of polyesterol (PET), 500 µm thick, with 9 cm inner and 11 cm outer diameter, and the weight of 1.8 g. In order for mites to perceive the migration circle as a part of substrate, it was put in the bucket with mites on the surface of the substrate.

Execution of the experiment. During the experiment, to collect active mites, the migration circle was put on the substrate into the bucket for 90–180 seconds using a pincette. The experimental field was covered with a clean 40 µm-thick polypropylene (BOPP) sheet. On it, in the center of the coordinate system, we placed a cup with a cotton swab, saturated with an aroma compound. After 10–15 s, we put a migration circle with a group of mites on the field, so the cup with aroma compound stood in the center of the migration circle. Time of placing of the migration circle with mites in the field was considered to be the beginning of the experiment. Video recording of the experiment lasted for at least 60 seconds. After the experiment, the group of mites was put into another bucket with substrate to release them to greenhouse. To prevent mites from escaping, the open bucket was put in a container with 1 L of water. All of this occurred in the laboratory at 26 ± 1 °C and 60 ± 10% relative humidity in 24 h, in artificial light with no sunrays (Martynov et al., 2019).

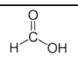
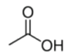
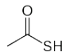
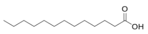
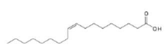
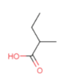
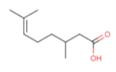
Analysis of results of video recording and digital data. Work with the footage was carried out on a computer with high-resolution monitor. Mites of *S. scimitus* constantly moved on the migration circle and experimental field, which made them easily distinguishable from immobile parts of the substrate. In case of doubtful moments, we rewatched a second prior and a second after the count. For convenience of counting, the experimental field was divided into four zones. We decided to measure mobility of the mites on the 10th second of the experiment. We measured the shortest-route distance from the circle margin to each mite in millimeters and incorporated those data in the table. Mites on the migration circle received the rank 0, and the mites on the experimental field inside the circle received a value in millimeters with + sign, and the mites beyond the circle – values in millemeters with – sign. The data were analyzed using the standard variation statistics, estimating the mean value, mean-square deviation, median, and the first and third quartiles.

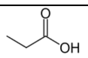
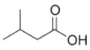
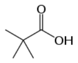
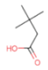
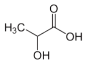
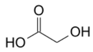
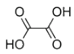
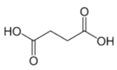
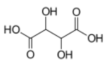
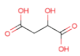
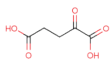
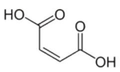
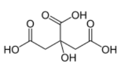
Experimental compounds. Within the framework of the experiment, we used 32 organic acids, which have a broad range of application: feeding people and animals, pharmaceutics, and industry (Table 1).

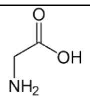
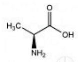
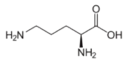
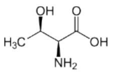
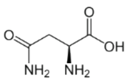
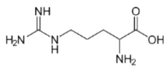
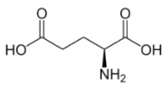
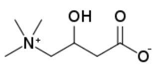
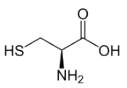
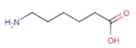
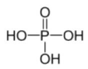
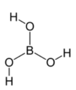
Results

When exposed to organic acids, locomotor activity of the mites significantly changed (Fig. 1). In the control variant of the experiment, subject to vapors of organic acids, a large number of mites did not leave the shelter (the median is at the level of 0 mm), and only subject to L-ornithine the median equaled 2 mm. The range of fluctuations of the first and third quartiles was the greatest for asparagine and L-ornithine and the smallest for 3,3-dimethylbutanoic acid and 6-aminohexanoic acid.

Table 1
Brief characteristics of organic acids used in the experiment with locomotor activity of *Stratiolaelaps scimitus mites*

Name	Formula	Melting point,°C	Boiling point,°C	Aggregate condition at +20 °C	Use as food for people and animals	Use in pharmaceutics	Use in industry
Formic acid CH_2O_2		8.4	100.8	liquid	used as a preservative in food industry, is added to some types of fodders for animals and foods to prevent development of bacteria and fungi. E236	is used for the treatment of skin diseases and as an antiseptic	is used in production of leather, textile goods, rubber and plastic; in processes of galvanization for cleaning metals, in production of paints and varnishes
Acetic acid $C_2H_4O_2$		16.0	118.0	fluid	essential ingredients of vinegar, is used for food preservation and aromatization of products, in particular vegetables and fruits. E260	treatment of dermatological problems or removal of warps; for production of drugs	used in production of plastic, paints, varnishes, solvents, fertilizers, and other chemical substances
Thioacetic acid C_2H_4OS		– 58.0	93.0	fluid	is not used in food for people or animals because of its potential toxicity	for production of paracetomol	for producing various chemical compounds or as industrial catalizer
Tridecanoic acid $C_{13}H_{26}O_2$		42.0	236.0	solid	rarely used in food industry	is not used in pharmaceutics for medical purposes	used for production of biofuel
Oleic acid $C_{18}H_{34}O_2$		16.3	360.0	fluid	is present in plant and animal oils, important constituent of diet of people and animals	is included in pharmaceutic products, promotes moistening and soothing skin	used in production of soap, cosmetics, and detergents
2-Methylbutanoic acid $C_5H_{10}O_2$		– 90.0	176.0	fluid	is not a standard food product for people and animals	is not a component of drugs	in chemical studies and synthesis of some chemical compounds
Citronellic acid $C_{10}H_{18}O_2$		122.0	257.0	solid	is not used in food for people or animals, but citronellic scent, can be used in aroma compounds for food	is included in some pharmaceutical and cosmetic products as an aroma compound	is used in perfumery and cosmetics, is added to perfumes, creams, lotions for creating pleasant aromas; included in insect repellents

Name	Formula	Melting point,℃	Boiling point,℃	Aggregate condition at +20 ℃	Use as food for people and animals	Use in pharmaceutics	Use in industry
Propionic acid $C_3H_6O_2$		–20.5	141.1	fluid	as a preservative in food industry; added to bread, cheese to prevent mold and other microorganisms; used in fodders for animals, to increase shelf life of fodders	salts of propionic acid are used in some medical procedures	as a reagent for synthesis of various organic compounds, such as plastic, for regulation of pH level in some industrial processes
Isovaleric acid $C_5H_{10}O_2$		–29.3	176.5	liquid	is not used as an individual product or supplement in food industry for people or animals	is not a component of drugs	initial reagent for producing other chemical compounds
Pivalic acid $C_5H_{10}O_2$		35.5	163.8	solid	is not used in food industry; has a specific aroma and taste, toxic	is not a component of drugs	is used for synthesis of various chemical compounds or reagent in chemical reactions
3,3-Dimethylbutanoic acid $C_6H_{12}O_2$		6.5	190.0	liquid	is not used in food	is not used in pharmaceutics	is used in chemical reactions, synthesis of various chemical compounds or reagents
Lactic acid $C_3H_6O_3$		16.8	122.0	liquid	naturally forms during fermentation of milk and dairy products; regulator of acidity; is used for food preservation; provider of acidic aroma and pH regulator in beverages	is broadly used in pharmaceutics and cosmetology; for skin care; in drugs for treatment of stomach hyperacidity	is included in agents for cleaning and disinfection in industrial processes
Glycolic acid $C_2H_4O_3$		79.5	100.0	solid	is not used in food industry (for food of people and animals) because of acidity and possible toxicity	is used for production of peeling agents, creams, lotions, helps removing keratinized skin layers, reduces pigmentation; used for treatment of skin diseases	production of textile leather; as a chemical reagent and solvent
Oxalic acid $C_2H_2O_4$		189.5	sublimes	solid	promotes formation of oxylate stones in the kidneys and damages health, and therefore is not used as a food supplement	is not a regular component of pharmaceutical drugs	production of oxalates, bleaches, reagent for chemical processes; for removal of residuals of metal ions with water and for cleaning equipment; as a cellulose solvent
Succinic acid $C_4H_6O_4$		188.0	235.0	solid	safe for food; food supplement (E363) for regulation of acidity; used for improval of taste and preservation of food; is involved in cellular respiration	is used in pharmaceutics as an ingredient for production of various drugs; has antiseptic and antioxidant properties; is used in medical researches; rejuvenating procedures	is used in production of plastic, resins, paints and varnishes
Tartaric acid $C_4H_6O_6$		169.0	399.3	solid	is broadly used in food industry as a food supplement (E334); for regulation of acidity in foods and beverages, stabilization and improvement of structure of confectionery products, pancakes, and biscuits	for production of pharmaceutic drugs	production of salts of tartaric acids (tartars), use in electrochemistry, as wine stabilizer
L-Malic acid $C_4H_6O_5$		131.0	no data	solid	it occurs in many fruits, especially in apples; food supplement (E296) for regulation of acidity and as antioxidant; used for increasing taste qualities of beverages and confectionery	as a component of pharmaceutic drugs or in reserach	for synthesis of chemical compounds; as a reagent or catalizer in chemical reactions
2-Oxoglutaric acid $C_5H_6O_5$		114.0	no data	solid	is not used as food supplement or product; is involved in metabolic processes in living organisms	is important in biological systems, in particular in the Krebs cycle and oxidation processes; key component for transferring energy and carbon in chemical reactions of oxidation	use is limited compared with other chemical compounds
Maleic acid $C_4H_4O_4$		130.5	356.0	solid	rarely used in food industry as a supplement due to its acidic nature and sour taste	is included in pharmaceutic drugs; used in chemical studies	is used in synthesis of plastic, resins, paints, varnishes, glues; used in production of synthetic fibrils, polymers and various chemical products
Citric acid $C_6H_8O_7$		153.0	310.0	solid	is rarely used in food industry as food supplement because of its acidic nature and bitter taste; broadly used food supplement (E330), acidic regulator and preservative; is present in many fruits, including citrus; is used in production of beverages, confectionery, jam, and sweets	is included in pharmaceutic drugs. Is used in chemical research	is used in synthesis of plastic, resins, paints, varnishes, glues; used in production of synthetic fibrils, polymers and various chemical products of detergents and household chemicals; included in chemical products for metal chelating

Name	Formula	Melting point,°C	Boiling point,°C	Aggregate condition at +20 °C	Use as food for people and animals	Use in pharmaceutics	Use in industry
Glycine $C_2H_5NO_2$		262.2	no data	solid	component of proteins consumed by people and animals; plays an important role in the structure of proteins and functioning of the organism	is used in pharmaceutics as an amino-acid drug; used as additional therapy for correcting a number of medical conditions; used in pharmaceutical research and production of medical drugs	used in synthesis of chemical compounds (plastic, solvents, etc)
L-Alanine $C_3H_7NO_2$		258.0	no data	solid	one of 20 amino acids that comprise proteins; present in many products	component of some drugs or dietary supplements	is not used in industry
L-Ornithine $C_5H_{12}N_2O_2$		140.0	no data	solid	is not a component of proteins consumed in food; important in ammonia metabolism	is included in drugs used to improve liver function or management of ammonia concentration in the organism	is not used in industry
L-Threonine $C_4H_9NO_3$		256.0	no data	solid	one of 20 amino acids that comprise proteins; present in many products consumed by people and animals	is used as a component of drugs or dietary supplements	is used in the chemical industry
Asparagine $C_4H_8N_2O_3$		234.0	438.0	solid	one of 20 amino acids that comprise proteins; present in many products consumed by people and animals	component of drugs and dietary supplements	used in the chemical industry
L-Arginine $C_6H_{14}N_4O_2$		222.0	368.0	solid	it is not necessary for feeding, because the organism can synthesize this amino acid individualy with other amino acids	is included in drugs used to treat problems with the cardiovascular system	is not used in industry
L-Glutamic acid $C_5H_9NO_4$		224.0	sublimes at 175 °C	solid	one of the amino acids that comprise proteins; monosodium salt of glutamic acid, is used as a tastant; food supplement E621	component of drugs or dietary supplements	in chemical and biotechnological industries
Carnitine $C_7H_{15}NO_3$		197.0	no data	solid	it is present in meat and dairy products; the organism produces it from other amino acids; is used for food supplements for support of cardiac health and promotion of fat metabolism	as active agent in drugs and dietary supplements for improvement of heart functions and promotion of weight loss	in chemical and biotechnological industry
L-Cysteine $C_3H_7NO_2S$		240.0	no data	solid	has antioxidant properties; is used in bakery for improvement of structure and taste of bread; food supplement E920	can be used in pharmaceutics as a component of drugs for treatment of poisonings with acetaminophen (paracetomol)	in production of cosmetics, food supplements, and drugs
6-Aminohexanoic acid $C_6H_{13}NO_2$		205.0	no data	solid	it is not an amino acid, is not used as a food supplement	Is used in the treatment of acute bleeding due to elevated fibrinolytic activity; used in anticoagulation therapy and invasive dental procedures	it is used for production of polymers, nylon-6; can be used for production of other chemical compounds
Phosphoric acid H_3O_4P		42.3	212.0	solid	it is used for regulation of pH, as a preservative and stabilizer of gased beverages; used in process of phosphatation of meat for improvement of quality and food preservation; food supplement E338	used in dentistry and orthodontics as an etching solution, cleaning agent	for production of fertilizers, detergents, alluminium alloys
Boric acid BH_3O_3		170.9	300.0	sodium	acidity regulator and food preservative; food supplement E284	antiseptic and means of treatment of some dermatological diseases	production of fertilizers, fire-resistant materials; ceramics; is used to protect plants against pests

The mites displayed the highest locomotor activity only when exposed to asparagine (over half of specimens travelled 13.5 mm distance for 10 s), L-ornithine (13.0 mm), propionic acid (12.6 mm), tridecanoic acid (12.1 mm), boric acid (12.2 mm), and L-arginine (12.0 mm) (Table 2). In the control group (with no exposure to any organic acid), over half of the mites travelled 9.2 mm distance. The mites' locomotor activity was slowed down by pivalic acid (6.7 mm), thioacetic acid (6.4 mm), succinic acid (6.2 mm), maleic acid (6.2 mm), 3,3-dimethylbutanoic acid (6.0 mm), and 6-aminohexanoic acid (5.7 mm).

The highest percentage of specimens that did not demonstrate locomotor activity was observed in experiments (Table 2) with 3,3-dimethylbutanoic acid (64.2%), thioacetic acid (58.7%), pivalic acid (58.1%), maleic acid (55.3%), formic acid (54.4%), succinic acid (52.8%), 2-methylbutanoic acid (52.0%), isovaleric acid (51.6%), 6-aminohexanoic acid (51.0%), and 2-oxoglutaric acid (50.9%). In the control variant of the experiment (without influence of organic acids), 39.7% of the mites did not leave their shelter. Minimum percentage of mite individuals (Table 2) stayed in the shelter (i.e. no increase in the locomotor activity was observed) during exposure to L-ornithine (16.6%), tartaric acid (23.5%), asparagine (23.7%), oleic acid (26.8%), carnitine (29.1%), and tridecanoic acid (29.4%).

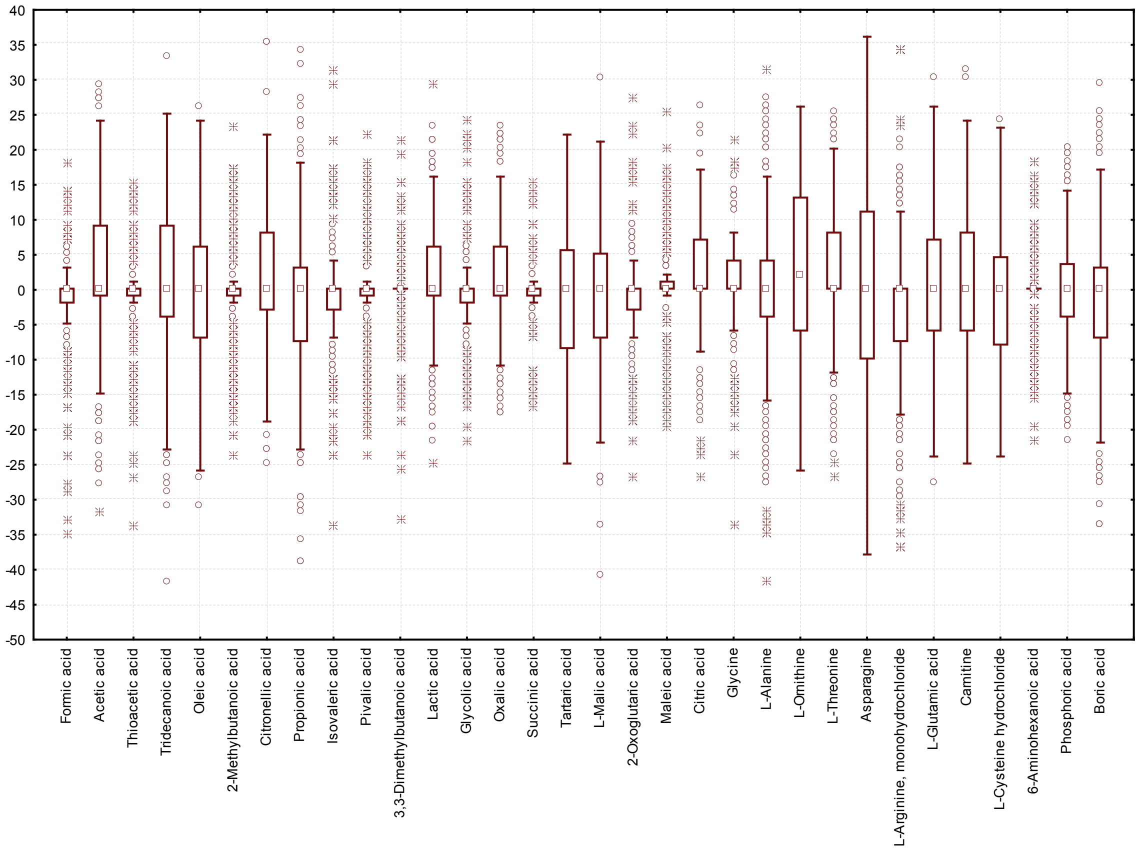


Fig. 1. Effects of organic acids on the locomotor activity of *Stratiolaelaps scimitus*: the ordinate axis represents distance (mm) that the mites travelled in 10 s

Table 2
Effects of organic acids on the locomotor activity of the *Stratiolaelaps scimitus* mites

Name	Formula	Total number of mites in the experiment	Positive chemotaxis, % of the total number of specimens	Did not leave the shelter (absence of migration activity), % of the total number of specimens	Negative chemotaxis, % of the total number of specimens	Average distance and mean-square deviation which the mites travelled in 10 s (x ± SD), mm	Attractiveness coefficient (% of specimens with positive chemotaxis, divided by % with negative chemotaxis)	Coefficient of exploratory activity (% of specimens that left the shelter, divided by % of specimens that did not leave the shelter)
Formic acid	CH_2O_2	204	17.6	54.4	28.0	–1.7 ± 7.6	0.63	0.84
Acetic acid	$C_2H_4O_2$	304	41.4	31.6	27.0	2.4 ± 11.3	1.53	2.16
Thioacetic acid	C_2H_4OS	283	15.5	58.7	25.8	–1.1 ± 6.4	0.60	0.70
Tridecanoic acid	$C_{13}H_{26}O_2$	190	39.5	29.4	31.1	0.5 ± 12.1	1.27	2.40
Oleic acid	$C_{18}H_{34}O_2$	179	41.9	26.8	31.3	–0.1 ± 11.2	1.34	2.73
2-Methylbutanoic acid	$C_5H_{10}O_2$	348	20.7	52.0	27.3	–0.7 ± 7.6	0.76	0.92
Citronellic acid	$C_{10}H_{18}O_2$	106	40.6	31.1	28.3	1.0 ± 11.4	1.43	2.22
Propionic acid	$C_3H_6O_2$	176	28.4	35.2	36.4	–1.5 ± 12.6	0.78	1.84
Isovaleric acid	$C_5H_{10}O_2$	275	16.4	51.6	32.0	–1.3 ± 8.0	0.51	0.94
Pivalic acid	$C_5H_{10}O_2$	315	16.5	58.1	25.4	–1.1 ± 6.7	0.65	0.72
3,3-Dimethylbutanoic acid	$C_6H_{12}O_2$	246	15.5	64.2	20.3	–0.6 ± 6.0	0.76	0.56
Lactic acid	$C_3H_6O_3$	218	35.3	38.1	26.6	1.2 ± 9.5	1.33	1.62
Glycolic acid	$C_2H_4O_3$	255	23.5	47.9	28.6	–0.5 ± 7.3	0.82	1.09
Oxalic acid	$C_2H_2O_4$	215	39.1	34.9	26.0	1.2 ± 8.7	1.50	1.87
Succinic acid	$C_4H_6O_4$	125	19.2	52.8	28.0	–1.0 ± 6.2	0.69	0.89
Tartaric acid	$C_4H_6O_6$	204	34.8	23.5	41.7	–1.3 ± 10.1	0.83	3.26
L-Malic acid	$C_4H_6O_5$	133	31.6	36.8	31.6	–1.1 ± 10.9	1.00	1.72
2-Oxoglutaric acid	$C_5H_6O_5$	169	18.3	50.9	30.8	–1.1 ± 7.7	0.59	0.96
Maleic acid	$C_4H_4O_4$	257	28.7	55.3	16.0	0.5 ± 6.2	1.79	0.81
Citric acid	$C_6H_8O_7$	124	39.5	38.7	21.8	1.4 ± 9.8	1.81	1.58
Glycine	$C_2H_5NO_2$	166	30.1	46.4	23.5	0.0 ± 8.3	1.28	1.16
L-Alanine	$C_3H_7NO_2$	450	28.9	43.6	27.5	–1.1 ± 11.4	1.05	1.29
L-Ornithine	$C_5H_{12}N_2O_2$	193	52.3	16.6	31.1	2.4 ± 13.0	1.68	5.02
L-Threonine	$C_4H_9NO_3$	232	43.5	31.9	24.6	1.4 ± 10.7	1.77	2.13
Asparagine	$C_4H_8N_2O_3$	333	40.5	23.7	35.8	0.1 ± 13.5	1.13	3.22
L-Arginine	$C_6H_{14}N_4O_2$	352	23.5	43.8	32.7	–2.9 ± 12.0	0.72	1.28
L-Glutamic acid	$C_5H_9NO_4$	230	34.3	36.1	29.6	0.4 ± 11.0	1.16	1.77
Carnitine	$C_7H_{15}NO_3$	199	38.7	29.1	32.2	0.6 ± 10.2	1.20	2.44
L-Cysteine	$C_3H_7NO_2S$	176	29.5	33.0	37.5	–1.0 ± 9.7	0.79	2.03

Name	Formula	Total number of mites in the experi-ment	Positive che-motaxis, % of the total num-ber of speci-mens	Did not leave the shelter (absence of migration activity), % of the total number of specimens	Negative chemotaxis, % of the total number of specimens	Average distance and mean-square devia-tion which the mites travelled in 10 s (x ± SD), mm	Attractiveness coefficient (% of specimens with positive chemotaxis, di-vided by % with negative chemotaxis)	Coefficient of exploratory activity (% of specimens that left the shelter, divided by % of specimens that did not leave the shelter)
6-Aminohexanoic acid	$C_6H_{13}NO_2$	306	24.5	51.0	24.5	0.0 ± 5.7	1.00	0.96
Phosphoric acid	H_3O_4P	212	29.2	36.8	34.0	–0.4 ± 8.6	0.86	1.72
Boric acid	BH_3O_3	185	30.8	30.3	38.9	–1.8 ± 12.2	0.79	2.30
Control	–	2442	29.2	39.7	31.1	–0.6 ± 9.2	0.94	1.52

Note: ratio of coefficients of exploration activity and attractiveness allow us to assume the dominant model of the mites' behaviour in relation to an aroma compound; high attractiveness and migration-activity coefficients mean signal of attack on a victim; low coefficients indicate motionless; high migration activity and low attractiveness coefficient mean an "escape" reaction.

Discussion

When we planned the research, we thought that various organic acids would exert notable attractive or repellent properties during the experiment. Those reactions can be genetically determined by inherent schemes of behavior- taste reaction of *S. scimitus* mites. The body of arachnids has chemosensitive receptors, when moving, mites orientate using sense organs, and also mechanical and thermo-hygroreceptors (Foelix, 1970). However, during the experiments with aroma compounds, the migratory activity and movement direction of the mites did not point to distinct attractive and repellent effects. The mites exerted the same movement direction both to and from the tested compounds. This was in cases of *a-priori* toxic compounds (for example, formic acid and boric acid), as well as for relatively safe – amino acids (alanine, ornithine, threonine, glycine), which comprise the structure of proteins in the body of mites.

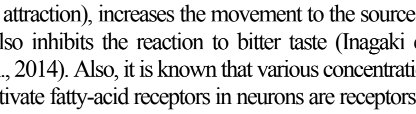
A large proportion of the mites began moving from the circle in the first seconds of the experiment, and the movement direction was conditioned by location of the mite body on the migration circle. A large number of mites ran on the margins of the circle. It has to be noted that the length of the inner margin of the 9 cm-diameter circle was 28.3 cm, and the length of the outer 11 cm-diameter circle was only 34.6 cm, i.e. 22% greater. Therefore, the attractiveness coefficient in the control equaled 0.94 (Table 1). This may be attributed to the fact that at the beginning of the experiment, the number of mites in the inner circle of the migration circle was always lower; structure of the migration circle did not affect the migration-activity coefficient in relation to certain compounds.

The mites moved along a straight trajectory, systematically changing direction. The body length of *S. scimitus* is around 0.5 mm, and the distance a mite travelled while moving straight was 20–40 mm. That is, having travelled its 40–80 body lengths and having found no trophic object, the mite changed the movement direction and started winding. Movement trajectory of the mites on the experimental field was reminiscent of the Brownian motion of gas molecules with some differences. Gas molecules change movement direction at a sharp angle after colliding with another molecule. At the same time, mites, by contrast, can move along curved trajectories without colliding with any evident irritants from the surrounding (the experiment field for running was each time covered with a clean polyethylene sheet) (Moshkin & Brygadyrenko, 2022). Mites have good abilities to move on various surfaces, having relatively small sizes and light body weight (Spagna & Peattie, 2012). For adhesion to the surface, the mites' limbs have various parts that on one hand fixate them, and on the other hand allow them to move fast. Some species can even jump. Also, the limbs perform functions of grabbing and sense organs (Mizutani et al., 2006). Having 1 mm body size, Archegozetes longisetosus Aoki, 1965 (Sarcoptiformes, Trhypochthoniidae) exerted holding force that 1,180-fold exceeded its own weight (Heethoff & Koerner, 2007). Predatory teneriffiid mites were recorded to have the relative speed of 10.6 ± 0.91 cm/s at 40 and 50 °C. Currently, this is the highest relative speed in relation to body sizes (Wu et al., 2010). Therefore, on the 10th second of the experiment, arrangement of the mites on the experimental field reliably reflected their attitude to an aroma compound. Thus, we can quickly and relatively easily identify whether the body of mites bears the required receptors, able to sense an aroma compound. For convenience of the data analysis, we propose using coefficients of attractiveness and migration activity (Table 1). Those coefficients better demonstrate the influence of aroma compounds on mites than average distance they travelled per unit of time. Relationship between the coefficients allows us to assume a dominant model of behaviour of mites in relation to an aroma compound. This model is attack, motionless state, and escape. High attractiveness and migration-activity coefficients mean attack, low coefficients mean motionless state, and high migration-activity and low attractiveness coefficients mean escape.

Intrinsic behaviour reactions are conditioned by activation of neurons, but those reactions modulate depending on the internal condition of the organism and its need in existing conditions. Temperature or food can cause adaptive changes in behaviour: increase or decrease the locomotor activity, improvement of the olfactory or taste senses for certain compounds (Pool & Scott, 2014; Yang et al., 2015). Absence of clear attractive or repellent differences in the behaviour could be related to absence of certain sensory neurons in mites or to a phenomenon when one compound can activate various classes of sensory neurons that are responsible for opposite behavior scenarios (Chandrashekar et al., 2010; Oka et al., 2013; Zhang et al., 2013; Ahn et al., 2017; Jaeger et al., 2018). Studies of effects of acetic acid on *Drosophila melanogaster* Meigen, 1830 (Diptera, Drosophilidae) revealed that opposite behaviour reactions were conditioned by two different classes of taste neurons: neurons that recognize delicious and sour taste, but a certain trophic reaction depends on the insect's satiety or hunger (Devineni et al., 2019). Hunger alters the behaviour reaction (from repulsion to attraction), increases the movement to the source of delicious taste, and also inhibits the reaction to bitter taste (Inagaki et al., 2012; Inagaki et al., 2014). Also, it is known that various concentrations of hexanoic acid activate fatty-acid receptors in neurons are receptors of delicious taste, while high concentrations activate the bitter-taste receptor (Ahn et al., 2017).

Acetic acid is a product of fruit fermentation, signalizes to insects and mites about presence of food, and encourages them to lay eggs on the surface of fruits that had started decaying (Joseph et al., 2009; Chen & Amrein, 2017). Fallen fruits, together with leaves and terrestrial vegetation, make up the food base and a favourable environment for the development of various groups of mites, larvae of flies and beetles. Some of those saprophages (in particular organisms feeding on fruits of plants) are included in the diet of *S. scimitus*. We may assume that this is why acetic acid made 68.4% of the mites to leave the migration circle; 41.4% of them moved towards the compound, and 27.0% away from it; the attractiveness coefficient equaled 1.53 and the migration-activity coefficient was 2.16 (Table 1).

Thioacetic acid is obtained by reaction of acetic anhydride with hydrogen sulfide (Phillips, 2001). Thioacetic acid is different from acetic acid by replacement of one oxygen atom by sulfur (Fig. 2). This replacement causes a significant change in reaction of mites to the compound: attractiveness coefficient decreased to 0.60 and coefficient of migration activity was 0.70 (Table 1). As we see, acetic acid activated and attracted mites, whereas thioacetic acid inhibited and repelled them.



acetic acid *thioacetic acid*

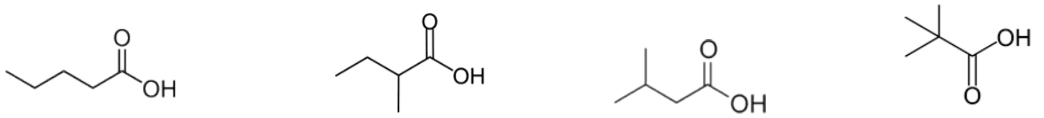
Fig. 2. Acetic acid and thioacetic acid

Acetic acid is used in the food industry, medicine, and chemical industry. In the 19th century it was used as an injection to tumorus for cancer treatment (Barclay, 1866). In many countries, it is used as a part of screening for cervical cancer (Fokom-Domgue et al., 2015); this compound is an effective antiseptic against streptococci, staphylococci, pseudomonas, and enterococci (Ryssel et al., 2009; Madhusudhan, 2015); acetic acid is used for treatment of skin diseases caused by antibiotic-resistand pseudomonas (Nagoba et al., 2013). In the human metabolism, acetic acid performs a general function, specifically symporter activity, catalizes fast transport of many monocarboxylates, obtained from leucine through the plasmatic membrane (Tamai et al., 1999). It is a proton-coupled monocarboxylate transporter that catalyzes the transport of monocarboxylates across the plasma membrane. Those monocarboxylates include lactate, pyruvate, branched-chain oxo acids that derive from leucin. It also mediates Na^+-independent transport of organic anions, including taurocholate, the prostaglandins PGD2, PGE1, PGE2, leukotriene C4, thromboxane B2, and iloprost). Salts of thioacetic acid are used for transformationof nitroarene into arilacetamid in one step in production of paracetomol (Bhattacharya et al., 2006).

Formic acid is used as a preservative and antibacterial agent in hay maintenance for promotion of fermentization of lactic acid and inhibition of formation of butyric acid; fermentation of silage occurs fast and at lower temperature, and its food value is better preserved (Reutemann & Kieczka, 2000). It is also good for improving maintanence of potatoes (Ajingi et al., 2020). In poultry farming, formic acid is added to fodder for elimination of *Escherichia coli* (Griggs & Jacob, 2005; Garcia et al., 2007). Also, formic acid is an effective means of treatment of warts (Bhat et al., 2001). Furthermore, it is used as a coagulant in production of rubber, and also means of removing limescale and in the content of agents for cleaning toilets (Reutemann & Kieczka, 2000).

The word oleic derives from Latin oleum, meaning oil. Oleic acid is the commonest fatty asid in nature. Oleic acid and its ethers are used as plastifiers to obtain paint and varnish materials (Thomas, 2000). Oleic acid reduced artherial pressure in rats (Terés et al., 2006) and was observed to cause necrotic reaction in ants (Wilson et al., 1958). Over the process of breakdown of fats and proteins in corpses of insects, fatty acids (in particular oleic) gradually accumulate. They are the most chemically stable and least volatile, compared with short-chained molecules (Diez et al., 2013). However, in ants, fatty acids caused not only a necrotic reaction but also stimulated food search; the reaction depended on the current activity of ants in nests (Choe et al., 2009). Perhaps, that is why under influence of tridecanoic acid and oleic acid, more mites than in the control left the migration circle – fatty acids activated the locomotor activity of *S. scimitus*.

Interestingly, *S. scimitus* had almost the same reation to three isomers of valeric acid (2-methylbutanoic acid, 3-methylbutanoic acid, 2,2-dimethylpropanoic acid) (Fig. 2): most mites did not leave the migration circle, and those specimens that started migration mostly had negative chemostasis (Table 2).



1-butanecarboxylic acid *2-methylbutanoic acid* *3-methylbutanoic acid* *2,2-dimethylpropanoic acid*

Fig. 3. Valeric acid and three of its isomers

Around several million kilograms of pivalic acid (2,2-dimethylpropanoic acid) (Riemenschneider, 2000) are produced annually worldwide. 2-methylbutanoic acid is a component of the medicinal plant *Valeriana officinalis* L., 1753 (Dipsacales, Caprifoliaceae), dry roots of which people have been using in medicine as a sedative for thousands of years (Eadie, 2004). 2-methylbutanoic acid is also present in fruits of many plants, including apples and apricots (Rettinger et al., 1991). It is a volatile, colourless fluid with a strong cheesy scent, used as an aroma compound and food supplement (Mariaca et al., 2001). 3-Methylbutanoic acid, or isovaleric acid, is a natural component of many food products, intermediate product of amino-acid metabolism with a ramified chain (Wilson et al., 2013). Its chemical identity was for the first time studied in the 21st century (Pedler, 1868). Isovaleric acid is produced by skin bacteria that metabolize leucine: therefore its odour is unpleasant to humans, and it is the main component of the pungent smell of unwashed feet (or, as often said, smell of dirty feet) (Ara et al., 2006).

Lactic acid had no effect on the behaviour of the mites (Table 2). Lactic-acid fermentation occurs because of lactic-acid bacteria. Subject to their influence, glucose and sacharose transform into lactic acid. Those bacteria are able to breed in the oral cavity of humans and cause development of tooth decay (Caufield et al., 2006; Badet & Thebaud, 2008; Nascimento et al., 2009). Lactic acid is an important chemical in construction, used for roduction of biodegradable polymers (PLLA, PDLA, etc), and also a basic polymer for the pharmaceutical industry (Shuklov et al., 2016).

Succinic acid is involved in many metabolic processes in the body (De Castro Fonseca et al., 2006; Pell et al., 2016), but the mites exerted no migration activity, "calmly" reacting to this compound (most stayed on the circle). Succinic acid and its derivatives are used for synthesis of colourings, insecticides, plastic, aroma compounds, and drugs.

Tartaric acid is a common natural compound, formed during fermentation of grape juice (Duarte et al., 2012). Similarly to acetic acid, it is a product of fruit fermentation, which signals the presence of food to insects and mites (Chen & Amrein, 2017). The mites had an active reaction to tartaric acid: on the 10th second, around 76.5% of the mites left the migration circle; the attractiveness coefficient was lower than average, 0.83, and the coefficient of migration activity was high – 3.26. It turns out that tartaric acid made the mites escape.

2-Oxoglutaric acid is a common compound that plays an important role in microbial pathways of catabolism; it is used in manufacture of fuel or chemical reagents (Ledwidge & Blanchard, 1999; Richard & Hilditch, 2009). 2-oxoglutaric acid produced 0.59 attractiveness coefficient and 0.96 migration-activity coefficient: both parameters were lower than in the control. This acid caused the mites to freeze.

L-Ornithine is not an amino acid coded by DNA, i.e. not a proteinogenic amino acid. However, in non-hepatic tissues of mammals, the urea cycle is mainly used for arginin biosynthesis. Because ornithine is a quite important intermediate product in metabolic processes, it is able to abnormally accumulate in the body against the background of deficit of ornithine transcarbamylase (Weber & Miller, 1981; Sivashanmugam et al., 2017; Butterworth & McPhail, 2019); l-ornithine promotes discharge of ammonia and increases the effectiveness of energy consumption, creating a fatigue-prohylaxis effect (Sugino et al., 2008; Demura et al., 2010). Perhaps, l-ornithine activated the mites and produced the highest migration activity (5.02) and high attractiveness coefficient (1.68).

L-Cysteine is present in products with high protein content. There is a high amount of cysteine in poultry, eggs, beef, and whole grains. In high-protein diets, cysteine can be partially responsible for decrease in arterial pressure and risk of stroke (Larsson et al., 2015). Cysteine activated the mites and simultaneously repelled them: coefficient of migration activity was heightened (2.03) and the attractiveness coefficient was low (0.79).

The most informative parameters were coefficient of exploration activity and coefficient of attractiveness (Table 1): they pointed to compounds affecting the behaviour of mites. A high coefficient of the exploration activity indicates effect of a compound on the mite group, high attractiveness coefficient points to luring and low means repelling. Those were the key indicators in identifying attractive and repelling properties of the compounds. Because mites are small, they moved quickly, and therefore those characteristics are of great importance for identifying effects of various compounds on their behaviour. The examined mites were relatively small, and this should be accounted for during analysis of their reactions to various compounds. Miniature sizes and fast movement make mites vulnerable to effects of various volatile chemical compounds that people use at home, in industry, and agriculture. Differences in behaviour of the mites were less notable to people than differences in large organisms. However, research on effects of volatiles on those important components of natural fauna should be continued.

Conclusion

In this study, we researched the effects of organic acids such as acetic acid, thioacetic acid, and others, on behaviour of mites *Stratiolaelaps scimitus*. We found that various acids provoke certain reactions in those organisms. For example, acetic acid caused activity in the mites and attracted them, while thioacetic acid had an opposite effect, inhibiting or repelling those zoophages.

Fatty acids such as tridecylic acid and oleic acid exerted an activating effect on the locomotor activity of *S. scimitus*, pointing to an important role of those compounds in the regulation of behaviour reactions of those organisms.

Mites of *S. scimitus* had almost the same reaction to three isomers of valeric acid, and most did not leave the migration circle, but those that started to migrate demonstrated a negative chemostasis.

Those results indicate complexity of mites' behaviour reactions, which, despite their small sizes were sensitive to volatile chemical compounds in the environment. The mites had different reactions to different acids, indicating the large potential of those compounds to attract those zoophages for pest control in greenhouse agrocenoses.

The attractiveness and migration-activity coefficients we proposed reflect the effects of aroma compounds on mites. Those coefficients help in identifying a behaviour model of mites in relation to aroma compounds: attack, motionless state, and escape. Those coefficients can be used in further studies of the ecology of mites.

Our research helps understand the effects of organic acids on behaviour of *S. scimitus*. The results can be used for development of effective strategies of controlling the number of thrips, Sciaridae, and other agricultural pests.

The authors declare no conflict of interests.

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