Biosystems
Diversity

ISSN 2519-8513 (Print)
ISSN 2520-2529 (Online)
Biosyst. Divers.

Survival of nematode larvae under exposure to explosion-derived contaminants in war-affected environments

O. O. Boyko*, V. V. Brygadyrenko**

** Dnipro State Agrarian and Economic University, Dnipro, Ukraine*
*** Oles Honchar Dnipro National University, Dnipro, Ukraine*

Article info

Received 14.03.2026
Received in revised form 10.04.2026
Accepted 21.05.2026

Dnipro State Agrarian and Economic University, Sergiy Efremov st., 25, Dnipro, 49000, Ukraine.
Tel.: +38-097-296-42-10.
E-mail: boikoalexandra1982@gmail.com

Oles Honchar Dnipro National University, Nauky av., 72, Dnipro, 49045, Ukraine.
Tel.: +38-050-93-90-788.
E-mail: brigad@ua.fm

Boyko, O. O., & Brygadyrenko, V. V. (2026). Survival of nematode larvae under exposure to explosion-derived contaminants in war-affected environments. Biosystems Diversity, 34(3), e2612. doi:10.15421/012612

Pollution of large areas as a result of military actions in Ukraine has been recorded at least since February 2022, when hazardous toxicants started to be released into environment en mass. Having the ability to bioaccumulate, they concentrate in environmental inanimate-nature objects (soil, natural water bodies). Therefore, the study of how those pollutants behave is of great ecological significance. To determine the effects of toxic releases of explosions on nematode larvae, we used 31 compounds at two concentrations (0.1% and 1.0%) and three nematodes (*Strongyloides papillosus*, *Haemonchus contortus*, and *Muellerius capillaris*). According to the results, a negative impact on the vitality of the nematode larvae was exerted by 15 toxicants. The greatest nematocidal effects were observed after 24 h exposure to 1% solutions of hydrazine hydrate, 4-nitro-phenol, p-nitroaniline, and 1-nitronaphthalene, which killed over 80% of the larvae of all three nematodes at different stages. The larvae of the nematodes were also sensitive to 3-nitrophthalic acid dimethyl ester, 1-methyl-2-nitro-benzene, o-nitroaniline, 2-hydroxy-5-nitro-benzaldehyde, 4,5-dibromo-2-nitroaniline, 2-methyl-5-nitro-benzenamine, trinitrotoluene (TNT), (2,4-dinitrophenyl)-hydrazine, fluorene, N-phenyl-1-naphthalenamine, and pentachloropyridine.

Keywords: *Strongyloides papillosus*; *Haemonchus contortus*; *Muellerius capillaris*; nematicidal activity; explosive compounds; pollution; armed conflicts.

Introduction

The use of different weapons in Ukraine during 2022–2026 has led to a large-scale environmental pollution that jeopardizes not only representatives of flora and fauna in Ukraine but in other countries as well (Dovhanenko et al., 2024a, 2024b). Toxicants accumulate in the soil, and from there spread to air, water bodies, and also living components of natural ecosystems (Almashat & McDiarmid, 2023; Kovalov et al., 2025). The large-scale invasion of Ukraine by the aggressor is leaving a legacy of organic pollutants, including petroleum waxes, naphthenes, aroma compounds (derivatives of benzol, toluol, xylol), polycyclic hydrocarbons (naphthalene, anthracene, phenanthrene, perylene), halogenated hydrocarbons, dichloroethane, chloroform, chlorobenzene, organic solvents, surfactants, synthetic phenols, dioxins, etc. (Parakhnenko et al., 2023; Rybalka & Brygadyrenko, 2026).

According to the results of our previous studies in Ukraine, the breach of the Kahovka Dam alone has polluted the soils of natural ecosystems with plethora of toxicants, the most dangerous of them being 1-methylpyrene, benzo[e]pyrene, dibenzo[def,mno]chrysene or benzo[ghi]perylene (polycyclic aromatic hydrocarbons); phthalicacidbutylundecylester (acidesters); dibenzothiophene, 3-(1,3,4-oxadiazol-2-yl)-1H-indole, 6H-chromeno[6,7-d]oxazol-6-one, 3-(chloromethyl)-5-[(E)-2-phenylethenyl]-1,2,4-oxadiazole (aromatic heterocycles); 1,6-dibenzyl-1,6-diphosphecane, and 4-nitro-N,N-dioctylaniline (miscellaneous) (Palchykov et al., 2026). Many of these compounds can accumulate in living organisms, are stable in the environment, and can be transported across large distances (Kang et al., 2025).

Therefore, the objective of our studies was to determine the effects of dangerous toxic releases from explosions, which have been recorded in environmental objects, on the vitality of larval stages of nematodes in soils of pastures and grazing sites in the conditions of military actions in Ukraine.

Materials and methods

Active agents for the experiment. To determine the effects of toxicants recorded in environmental objects after explosions on the pathogens of dangerous parasitic diseases of animals, those pollutants (31 in total, Table 1) were analyzed for their larvicidal properties.

Preparation of solutions of active agents. To prepare the solutions of active agents, we used 1.0% and 0.1% concentrations of each of the 31 compounds. As a solvent, we used 10% aqueous solution of polysorbate-80. For 1% solution, we weighed 0.1 mL of liquid and 0.1 g of a solid compound. Then, to each weighed compound, we added 10 mL of 10% solution of polysorbate-80. For the preparation of 0.1% solution of each of the tested compound, we took 1 mL of 1% solutions and added 9 mL of 10% solution of polysorbate-80. As the control, we used 10% aqueous solution of polysorbate-80.

Sampling of the biomaterial. The fecal samples were collected in Dnipropetrovsk Oblast (Ukraine). In the experiment, we used feces of caprine ruminants, naturally infected with the causative agents of haemonchosis, strongyloidiasis, and muelleriosis. The eggs of nematodes were detected using the MacMaster method and the larvae using the Baerman test with subsequent centrifugation at 1,500 rpm for two min. (Zajac, 2011).

The species composition of parasitic nematodes for the experiment. In the experiment, we used L_1 larvae of *Muellerius capillaris* (Muller, 1889), L_1 and L_2 of *Strongyloides papillosus* (Wedl, 1856), and L_3 of *Haemonchus contortus* (Rudolphi, 1803). The larvae were identified according to the morphological features (Van Wyk et al., 2004, 2013; Boyko et al., 2019; Gugosyan et al., 2019). At the same time, we took into account the presence of intestinal cells, their number, form, and also the shape of the esophagus and the tail end of the larvae.

Cultivation of nematode larvae. Larvae of the nematodes *S. papillosus* and *H. contortus* were cultivated in feces in a thermostat, starting from eggs, for 10 days at 20 °C in glass laboratory test tubes sealed with cotton balls. The feces were moistened with distilled water in a dose of 1 mL per test tube once a day.

Assessment of the effects of the compounds on the larvae' vitality. The sediment from the centrifuged test tubes with cultivated larvae in 0.1 mL of water (on average 15–50 larvae of each species) was placed in 1.5 mL test tubes, to which we added 1 mL of solutions of each of the studied compound. For each concentration (1.0% and 0.1%), five test tubes were used. The exposure to the compounds lasted for 24 h. Then, the supernatant was removed, and the 0.1 mL sediment with larvae from each test tube was analyzed under a microscope. We took into account the number of live and dead (immobile, with signs of destruction of the intestines) larvae. The parameters are provided in percents.

Table 1
Uses of toxicants recorded in environmental objects after explosions to determine the survivability of the nematodes in the laboratory experiment

	IUPAC name	Molecular formula	CAS	Water solubility, mg/mL	Toxicity, LD_{50}
1.	Phenol, 4-nitro-	$C_6H_5NO_3$	100-02-7	11.6	202 mg/kg (oral, rat); 282 mg/kg (oral, mouse)
2.	Anthracene	$C_{14}H_{10}$	120-12-7	0.000044	1470–2440 mg/kg (oral, mouse); 430 mg/kg (intraperitoneal, mouse)
3.	Benzene, hexachloro-	C_6Cl_6	118-74-1	0.0000047	Rat oral 3500 mg/kg; Mouse oral 4000 mg/kg; Rabbit oral 2600 mg/kg
4.	Hydrazine hydrate	N_2H_6O	7803-57-8	completely miscible	129 mg/kg (oral, rat); 83 mg/kg (oral, mouse); 55 mg/kg (oral, rabbit)
5.	o-Nitroaniline	$C_6H_6N_2O_2$	88-74-4	1.00	–
6.	m-Nitroaniline	$C_6H_6N_2O_2$	99-09-2	1.50	308 mg/kg (oral, mouse); 535 mg/kg (oral, rat)
7.	p-Nitroaniline	$C_6H_6N_2O_2$	100-01-6	1.70	1400 mg/kg (oral,rat); 810 mg/kg (oral, mouse)
8.	Benzene, 1-methyl-2-nitro-	$C_7H_7NO_2$	88-72-2	0.10	–
9.	Benzene, 1-methyl-2,4-dinitro-	$C_7H_6N_2O_4$	121-14-2	0.05	790 mg/kg (oral, mouse); 268 mg/kg (oral, rat)
10.	Hydrazine, (2,4-dinitrophenyl)-	$C_6H_6N_4O_4$	119-26-6	0.01	450 mg/kg (intraperitoneal, mouse)
11.	Pyridine, pentachloro-	C_5Cl_5N	2176-62-7	0.005	235 mg/kg (intraperitoneal, mouse); 435 mg/kg (oral, rat)
12.	Benzene, 2-bromo-1,3,5-trinitro-	$C_6H_2BrN_3O_6$	4185-53-9	0.002	–
13.	Benzenamine, 2-bromo-4-nitro-	$C_6H_5BrN_2O_2$	13296-94-1	0.80	–
14.	Trinitrotoluene	$C_7H_5N_3O_6$	118-96-7	0.013	660 mg/kg (oral, mouse); 607 mg/kg (oral, rat)
15.	Benzene, 1-chloro-2,4-dinitro-	$C_6H_3ClN_2O_4$	97-00-7	0.01	640 mg/kg (oral, rat); 130 mg/kg (skin, rabbit)
16.	Benzaldehyde, 2-hydroxy-5-nitro-	$C_7H_5NO_4$	97-51-8	0.50	880 mg/kg (intraperitoneal, mouse); 1960 mg/kg (oral, rat)
17.	Benzenamine, 2-methoxy-5-nitro-	$C_7H_8N_2O_3$	99-59-2	0.90	997 mg/kg (oral, rat)
18.	4-Ethoxy-2-nitroaniline	$C_8H_{10}N_2O_3$	616-86-4	0.70	–
19.	4,5-Dibromo-2-nitroaniline	$C_6H_4Br_2N_2O_2$	75293-97-9	0.03	–
20.	4-Methoxy-2-nitroaniline	$C_7H_8N_2O_3$	96-96-8	0.85	997 mg/kg (oral, rat)
21.	Benzenamine, 2,4-dinitro-	$C_6H_5N_3O_4$	97-02-9	0.06	285 mg/kg (oral, rat); 370 mg/kg (oral, mouse)
22.	Benzene, 1-chloro-4-nitro-	$C_6H_4ClNO_2$	100-00-5	0.02	294 or 694 mg/kg (oral in male rats); 565 or 664 mg/kg (in female rats)
23.	4,5-Dimethyl-2-nitroaniline	$C_8H_{10}N_2O_2$	6972-71-0	0.90	–
24.	3-Nitrophthalic acid dimethyl ester	$C_{10}H_9NO_6$	13365-26-9	0.05	–
25.	Naphthalene	$C_{10}H_8$	91-20-3	0.031	100 mg/kg (intravenous, mouse); 3 gm/kg (oral, rabbit)
26.	1-Naphthalenamine, N-phenyl-	$C_{16}H_{13}N$	90-30-2	0.002	1450 mg/kg (oral, mouse); 8730 mg/kg (oral, rat)
27.	2-Naphthalenol, 1-nitroso-	$C_{10}H_7NO_2$	131-91-9	0.10	3400 mg/kg (oral, mouse); 86 mg/kg (intraperitoneal, rat)
28.	Naphthalene, 1-nitro-	$C_{10}H_7NO_2$	86-57-7	0.004	3400 mg/kg (oral, mouse); 86 mg/kg (intraperitoneal, rat)
29.	Benzenamine, 2-methyl-5-nitro-	$C_7H_8N_2O_2$	99-55-8	0.95	–
30.	Fluorene	$C_{13}H_{10}$	86-73-7	0.0019	–
31.	Phenanthrene	$C_{14}H_{10}$	85-01-8	0.0012	–

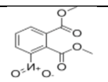
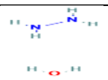
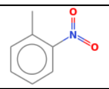
Note: information on the toxicity of substances was analyzed using the Pubchem database: National Technical Information Service, PB214-270; National Technical Information Service, OTS0536503; Aerospace Medical Research Laboratory Report, TR-72-62(1972); The National Institute for Occupational Safety and Health (NIOSH); Office of Toxic Substances Report, OTS.

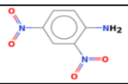
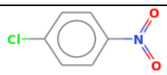
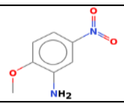
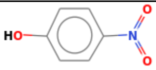
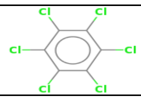
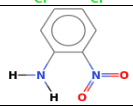
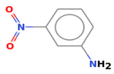
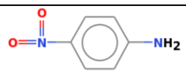
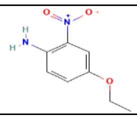
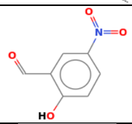
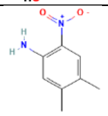
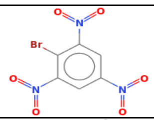
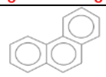
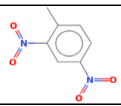
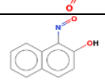
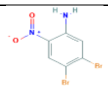
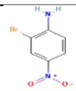
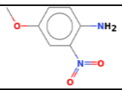
Statistical analysis. During the statistical analysis of the results, we calculated mean value (x) ± standard deviation (SD). To determine the differences between the samples within one line in Table 2, we used the analysis of variance (ANOVA) with Bonferroni correction ($P < 0.05$).

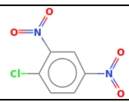
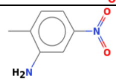
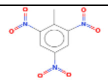
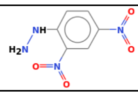
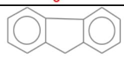
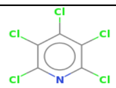
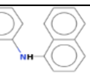
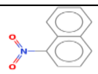
Results

According to the results, the larvae of the nematodes were most sensitive to 3-nitrophthalic acid dimethyl ester, hydrazine hydrate, 1-methyl-2-nitro-benzene, 4-nitro-phenol, o-nitroaniline, 2-hydroxy-5-nitro-benzaldehyde, 4,5-dibromo-2-nitroaniline, 2-methyl-5-nitro-benzenamine, trinitrotoluene (TNT), (2,4-dinitrophenyl)-hydrazine, fluorene, pentachloropyridine, N-phenyl-1-naphthalenamine, p-nitroaniline, and 1-nitronaphthalene (Table 2). At the same time, the larvae of all studied nematodes were affected by the following toxicants: 3-nitrophthalic acid dimethyl ester, hydrazine hydrate, 1-methyl-2-nitrobenzene, 4-nitro-phenol, o-nitroaniline, pentachloropyridine, p-nitroaniline, and 1-nitronaphthalene. The greatest toxic effect among these pollutants was produced by hydrazine hydrate, 4-nitro-phenol, p-nitroaniline, and 1-nitronaphthalene: Over 80% of the larvae of all the studied nematodes died during 24 h exposure to their 1% concentrations.

Table 2
Mortality of the larvae of *S. papillosus*, *M. capillaris*, and *H. contortus* (%) during 24 h laboratory experiment under the influence of toxicants recorded in environmental objects after explosions against the background of military actions (x ± SD, n = 5)

Compound	Structural formula	Nematode species	Mortality of nematode larvae in 0.1% solution, %	Mortality of nematode larvae in 1.0% solution, %
3-Nitrophthalic acid dimethyl ester		$L_{1–2}$ of *S. papillosus*	82.8 ± 7.1 ***	89.0 ± 2.7 ***
		L_1 of *M. capillaris*	7.8 ± 7.2	31.2 ± 6.5 ***
CAS 13365-26-9		L_3 of *H. contortus*	18.6 ± 1.7 ***	73.1 ± 6.5 ***
Hydrazine hydrate		$L_{1–2}$ of *S. papillosus*	8.3 ± 1.7 *	100.0 ± 0.0 ***
		L_1 of *M. capillaris*	0.0 ± 0.0	100.0 ± 0.0 ***
CAS 7803-57-8		L_3 of *H. contortus*	0.0 ± 0.0	91.1 ± 8.4 ***
Benzene, 1-methyl-2-nitro-		$L_{1–2}$ of *S. papillosus*	23.7 ± 1.0 ***	92.6 ± 6.9 ***
		L_1 of *M. capillaris*	6.1 ± 10.5	31.1 ± 1.0 ***
CAS 88-72-2		L_3 of *H. contortus*	6.7 ± 6.3	70.8 ± 10.1 ***

Compound	Structural formula	Nematode species	Mortality of nematode larvae in 0.1% solution, %	Mortality of nematode larvae in 1.0% solution, %
Anthracene		L_{1-2} of *S. papillosus*	3.3 ± 5.8	28.2 ± 2.7 ***
		L_1 of *M. capillaris*	2.0 ± 3.4	0.0 ± 0.0
CAS 120-12-7		L_3 of *H. contortus*	0.0 ± 0.0	0.0 ± 0.0
Benzenamine, 2,4-dinitro-		L_{1-2} of *S. papillosus*	3.7 ± 6.4	20.7 ± 3.7 ***
		L_1 of *M. capillaris*	2.8 ± 4.8	0.0 ± 0.0
CAS 97-02-9		L_3 of *H. contortus*	0.0 ± 0.0	0.0 ± 0.0
Naphthalene		L_{1-2} of *S. papillosus*	2.2 ± 3.8	18.5 ± 7.1 **
		L_1 of *M. capillaris*	0.0 ± 0.0	0.0 ± 0.0
CAS 91-20-3		L_3 of *H. contortus*	0.0 ± 0.0	0.0 ± 0.0
Benzene, 1-chloro-4-nitro-		L_{1-2} of *S. papillosus*	0.0 ± 0.0	18.6 ± 6.1 **
		L_1 of *M. capillaris*	0.0 ± 0.0	0.0 ± 0.0
CAS 100-00-5		L_3 of *H. contortus*	0.0 ± 0.0	0.0 ± 0.0
Benzenamine, 2-methoxy-5-nitro-		L_{1-2} of *S. papillosus*	2.1 ± 3.6	14.1 ± 2.6 **
		L_1 of *M. capillaris*	0.0 ± 0.0	0.0 ± 0.0
CAS 99-59-2		L_3 of *H. contortus*	0.0 ± 0.0	0.0 ± 0.0
Phenol, 4-nitro-		L_{1-2} of *S. papillosus*	60.7 ± 16.4 ***	98.6 ± 2.4 ***
		L_1 of *M. capillaris*	0.0 ± 0.0	100.0 ± 0.0 ***
CAS 100-02-7		L_3 of *H. contortus*	5.6 ± 9.6	89.2 ± 9.6 ***
Benzene, hexachloro-		L_{1-2} of *S. papillosus*	2.0 ± 3.4	0.0 ± 0.0
		L_1 of *M. capillaris*	0.0 ± 0.0	0.0 ± 0.0
CAS 118-74-1		L_3 of *H. contortus*	1.5 ± 2.6	0.0 ± 0.0
o-Nitroaniline		L_{1-2} of *S. papillosus*	14.7 ± 6.1 *	100.0 ± 0.0 ***
		L_1 of *M. capillaris*	3.4 ± 3.0	42.8 ± 6.2 ***
CAS 88-74-4		L_3 of *H. contortus*	5.4 ± 4.8	50.7 ± 16.2 ***
m-Nitroaniline		L_{1-2} of *S. papillosus*	8.1 ± 8.3	15.0 ± 1.7 **
		L_1 of *M. capillaris*	0.0 ± 0.0	0.0 ± 0.0
CAS 99-09-2		L_3 of *H. contortus*	0.0 ± 0.0	0.0 ± 0.0
p-Nitroaniline		L_{1-2} of *S. papillosus*	27.7 ± 5.1 ***	85.0 ± 4.6 ***
		L_1 of *M. capillaris*	6.1 ± 10.5	79.8 ± 17.8 ***
CAS 100-01-6		L_3 of *H. contortus*	16.3 ± 14.3 *	84.1 ± 16.7 ***
4-Ethoxy-2-nitroaniline		L_{1-2} of *S. papillosus*	2.0 ± 3.4	20.7 ± 3.9 **
		L_1 of *M. capillaris*	0.0 ± 0.0	0.0 ± 0.0
CAS 616-86-4		L_3 of *H. contortus*	0.0 ± 0.0	0.0 ± 0.0
Benzaldehyde, 2-hydroxy-5-nitro-		L_{1-2} of *S. papillosus*	15.0 ± 9.0 *	100.0 ± 0.0 ***
		L_1 of *M. capillaris*	0.0 ± 0.0	0.0 ± 0.0
CAS 97-51-8		L_3 of *H. contortus*	0.0 ± 0.0	0.0 ± 0.0
4,5-Dimethyl-2-nitroaniline		L_{1-2} of *S. papillosus*	2.2 ± 3.8	9.3 ± 0.9 *
		L_1 of *M. capillaris*	0.0 ± 0.0	0.0 ± 0.0
CAS 6972-71-0		L_3 of *H. contortus*	0.0 ± 0.0	0.0 ± 0.0
Benzene, 2-bromo-1,3,5-trinitro-		L_{1-2} of *S. papillosus*	0.0 ± 0.0	0.0 ± 0.0
		L_1 of *M. capillaris*	2.4 ± 4.1	0.0 ± 0.0
CAS 4185-53-9		L_3 of *H. contortus*	0.0 ± 0.0	0.0 ± 0.0
Phenanthrene		L_{1-2} of *S. papillosus*	2.2 ± 3.8	5.3 ± 1.1 *
		L_1 of *M. capillaris*	0.0 ± 0.0	0.0 ± 0.0
CAS 85-01-8		L_3 of *H. contortus*	1.5 ± 2.6	1.4 ± 2.4
Benzene, 1-methyl-2,4-dinitro-		L_{1-2} of *S. papillosus*	1.8 ± 3.0	18.5 ± 6.3 *
		L_1 of *M. capillaris*	0.0 ± 0.0	0.0 ± 0.0
CAS 121-14-2		L_3 of *H. contortus*	0.0 ± 0.0	1.7 ± 2.9
2-Naphthalenol, 1-nitroso-		L_{1-2} of *S. papillosus*	1.7 ± 2.9	19.9 ± 9.8 *
		L_1 of *M. capillaris*	0.0 ± 0.0	0.0 ± 0.0
CAS 131-91-9		L_3 of *H. contortus*	0.0 ± 0.0	0.0 ± 0.0
4,5-Dibromo-2-nitroaniline		L_{1-2} of *S. papillosus*	9.4 ± 2.4 *	74.8 ± 5.0 ***
		L_1 of *M. capillaris*	0.0 ± 0.0	0.0 ± 0.0
CAS 75293-97-9		L_3 of *H. contortus*	1.9 ± 3.2	6.9 ± 6.4
Benzenamine, 2-bromo-4-nitro-		L_{1-2} of *S. papillosus*	8.5 ± 2.4 *	21.9 ± 3.9 **
		L_1 of *M. capillaris*	0.0 ± 0.0	0.0 ± 0.0
CAS 13296-94-1		L_3 of *H. contortus*	0.0 ± 0.0	0.0 ± 0.0
4-Methoxy-2-nitroaniline		L_{1-2} of *S. papillosus*	5.1 ± 5.0	11.7 ± 2.9 *
		L_1 of *M. capillaris*	0.0 ± 0.0	0.0 ± 0.0
CAS 96-96-8		L_3 of *H. contortus*	1.8 ± 3.0	4.2 ± 7.2

Compound	Structural formula	Nematode species	Mortality of nematode larvae in 0.1% solution, %	Mortality of nematode larvae in 1.0% solution, %
Benzene, 1-chloro-2,4-dinitro-		L_{1-2} of *S. papillosus*	3.8 ± 3.3	7.0 ± 2.6 *
		L_1 of *M. capillaris*	0.0 ± 0.0	0.0 ± 0.0
CAS 97-00-7		L_3 of *H. contortus*	0.0 ± 0.0	0.0 ± 0.0
Benzenamine, 2-methyl-5-nitro-		L_{1-2} of *S. papillosus*	17.3 ± 6.2 *	76.6 ± 5.8 ***
		L_1 of *M. capillaris*	0.0 ± 0.0	91.7 ± 14.4 ***
CAS 99-55-8		L_3 of *H. contortus*	0.0 ± 0.0	0.0 ± 0.0
Trinitrotoluene		L_{1-2} of *S. papillosus*	19.7 ± 8.6 *	76.3 ± 7.8 ***
		L_1 of *M. capillaris*	13.1 ± 5.3 *	76.7 ± 25.2 ***
CAS 118-96-7		L_3 of *H. contortus*	0.0 ± 0.0	0.0 ± 0.0
Hydrazine, (2,4-dinitrophenyl)-		L_{1-2} of *S. papillosus*	17.4 ± 4.5 **	71.5 ± 4.2 ***
		L_1 of *M. capillaris*	16.1 ± 4.1 **	81.7 ± 16.3 ***
CAS 119-26-6		L_3 of *H. contortus*	0.0 ± 0.0	0.0 ± 0.0
Fluorene		L_{1-2} of *S. papillosus*	6.0 ± 6.3	73.1 ± 3.0 ***
		L_1 of *M. capillaris*	0.0 ± 0.0	0.0 ± 0.0
CAS 86-73-7		L_3 of *H. contortus*	0.0 ± 0.0	0.0 ± 0.0
Pyridine, pentachloro-		L_{1-2} of *S. papillosus*	18.4 ± 6.6 **	93.9 ± 2.8 ***
		L_1 of *M. capillaris*	20.3 ± 10.8 **	91.7 ± 14.4 ***
CAS 2176-62-7		L_3 of *H. contortus*	8.6 ± 5.8 *	44.0 ± 12.1 ***
1-Naphthalenamine, N-phenyl-		L_{1-2} of *S. papillosus*	23.8 ± 8.3 **	87.2 ± 5.5 ***
		L_1 of *M. capillaris*	0.0 ± 0.0	1.7 ± 2.9
CAS 90-30-2		L_3 of *H. contortus*	0.0 ± 0.0	12.7 ± 5.0 *
Naphthalene, 1-nitro-		L_{1-2} of *S. papillosus*	94.7 ± 9.1 ***	100.0 ± 0.0 ***
		L_1 of *M. capillaris*	40.3 ± 20.0 **	100.0 ± 0.0 ***
CAS 86-57-7		L_3 of *H. contortus*	12.2 ± 11.3 *	100.0 ± 0.0 ***

Note: mortality of nematode larvae was compared with that of the untreated control (without the addition of the test compounds) using ANOVA. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$; mortality of larvae of all three nematode species in the control group (without exposure to the test compounds) was 0.0 ± 0.0%.

Discussion

The use of weapons, whether on military test grounds or in combat, is accompanied by contamination of large areas with explosive compounds, inflicting irreversible harm to the environment (Temple et al., 2018; Palchykov et al., 2025). Therefore, in the experiments, different authors investigated the distribution and transport of 2,4-dinitroanisole, 1-nitroguanidine, and 3-nitro-1,2,4-triazole-5-one in two types of soil in the United Kingdom. The results revealed that these three explosive compounds did not interact with one another in the soils. Such studies focus on the behavior of components of highly explosive compounds for the prognosis of environmental pollution, and particularly the states of soil and water following military drills. Nitroaromatic compounds are released in large amounts not only during dyes and plastic, but also explosives (Hill et al., 2012). Their infiltration in waste water and natural sources of water raises concerns among researchers around the globe with regards to their effects on the environment (Higson, 1992). Therefore, our studies were focused on the behavior of toxicants released as products of explosions during military actions, in particular their interactions with living organisms.

Polycyclic aromatic hydrocarbons are released into the environment during the use of missile detonations and drone strikes, and are dangerous toxicants and carcinogens. Some of them cause complex mutations in cells. Those organic pollutants end up in the environment due to both natural and anthropogenic activities, including oil spills and explosions (Iniaghe & Kpomah, 2023). When assessing the long-term impact of an explosion at an oil pipeline in Qingdao (2013), sixteen different polycyclic aromatic hydrocarbons were found three years after the accident. Spatiotemporal changes in the concentrations of these toxicants indicated that their minimal effect is present even three years after the disaster (Ding et al., 2022). All of this creates high risks to health of people and safety of natural ecosystems and agroecosystems. Polycyclic aromatic hydrocarbons can reach human body via different pathways, including food products (Ma & Wu, 2024).

Polycyclic organic hydrocarbons negatively affect growth and development of plants. Concentrations of phenanthrene and fluorene, some of the most hazardous toxicants, can increase over time in treated plants. Their bioavailability depends not only on time but also on the plant species. Previous studies revealed that the rates of intake and translocation of phenanthrene were higher than those of fluorene. At the same time, fluorene mostly accumulates in roots, while phenanthrene migrates to the aboveground parts of plants (Salehi-Lisar et al., 2015). High concentrations of these pollutants inhibit growth of plants and reduce their survival (Li et al., 2024). Since these toxicants are released during combustion, we included polycyclic aromatic hydrocarbons such as phenanthrene and fluorene in our study. Although they are considered some of the most dangerous for living organisms, we recorded no negative action toward the nematode larvae. Only noninvasive stages of *S. papillosus* died in over 70% cases of 24 h exposure to 1% fluorene solution. Invasive stages of ruminant nematodes turned out to be more resistant to those pollutants. Perhaps, the negative impact on the vitality and functioning of the nematodes can be observed after long-term exposure to those compounds.

One of the proposed methods of cleansing soil contaminated with polycyclic aromatic hydrocarbons, particularly phenanthrene and fluorene, is arbuscular mycorrhiza phytoremediation. Microbiota in a mycorrhiza association is responsible for the degradation of those hydrocarbons (Gao et al., 2011). Remediation based on biocoal is used for cleansing of water and soil, particularly from phenanthrene and pentachlorophenol (Rao et al., 2017). Similar experiments with addition of biocoal were conducted by Xue et al. (2024), Shi et al. (2023), and Guo et al. (2023) in order to improve the anaerobic biodegrading of polycyclic aromatic hydrocarbons (including phenanthrene) in polluted soils of wetlands. Since many polluted areas are located in anaerobic environments, such as deep soils and flooded soils, cleansing of soils polluted with polycyclic aromatic hydrocarbons has garnered considerable attention worldwide (Chen et al., 2023, 2024; Zhou et al., 2024; Chen & Ma, 2025; Wang et al., 2025). An individual direction of biodegradation of polycyclic aromatic hydrocarbons (in particular phenanthrene) is studying the effects of sulfate-reducing bacteria on the degradation of those toxicants (Dhar et al., 2023, 2024; Zhang et al., 2023; Heker et al., 2025).

Hexachlorobenzene is a bioaccumulative compound, and a dangerous environmental toxin. It is ubiquitous, present in air, water, soil, and also living organisms. Due to its insecticidal and other properties, it is significant in different industries. However, its production and use can cause ecological problems. Not only does this pollutant raise concerns regarding its deleterious impacts on natural ecosystems, but is regarded as a probable carcinogen and is a serious health concern (Reed et al., 2007; Chawla, 2025). Nonetheless, we observed no nematocidal effect during 24 h when using 1% solution of this pollutant.

Hydrazine and its derivatives are associated with carcinogenic and neurotoxic effects on animals. Those compounds are present in some fungi and plants used as food. Also, they are present in products used in different industries, including aerospace manufacturing. Those compounds are able to damage DNA and lead to neurologic disorders (Spencer & Kisby, 2021). Hydrazine hydrate has been tested against root nematodes, agricultural pests of crops Meloidogyne javanica and Rotylenchulus reniformis. The studies revealed that treatment of seed with hydrazine hydrate significantly reduced the populations of nematodes in the soil, and thus the damages to the roots (Ahmad et al., 2012). It displayed a powerful nematocidal effect toward the larvae of ruminant nematodes in our experiment as well. Over 90% of invasive and noninvasive nematode larvae died subject to 1% solution of hydrazine hydrate during 24 h exposure. When assessing the effect of (2,4-dinitrophenyl)-hydrazine, we also observed the death of a large number of the noninvasive stages of *S. papillosus* and *M. capillaris*.

Territories of enterprises that are producing or had been producing munitions, and also sites of their disposal (soils, groundwater, lakes, oceans), are polluted with 2,4,6-trinitrotoluene. This poses a potential threat to humans and the environment (Neuwoehner et al., 2007). Assessments of the danger of six explosive agents (including the main explosive compound – trinitrotoluene) according to their acute toxicity revealed that for two crustaceans (Daphnia magna and Nitocra spinipes), the EC/LC_{50} values of aqueous phase ranged from 5 to 20 mg/L (Dave, 2000). Also, a significant toxic impact was exerted by trinitrotoluene and products of its breakdown (1,3,5-trinitrobenzene [TNB] and 2,4-diamino-6-nitrotoluene) for the midge *Chironomus tentans* and the amphipod crustacean *Hyalella azteca* (Steevens et al., 2002). In the industrial zone of Sweden, a study took a look at the negative impact of water from one of the ponds polluted with 2,4,6-trinitrotoluene on Salmonidae fishes. Thus, the studied water mixed with tap water led to an increase in the mortality frequency of their fries, up to fivefold dilution (0.4 mg of trinitrotoluene per L) (Leffler et al., 2014). The studies of the impacts of this explosive agent on rats revealed that over time it can affect the development of ovary follicles (Lin et al., 2023). In our experiment, trinitrotoluene exhibited a significant negative impact on all noninvasive stages of the ruminant nematodes. Over 76% of the individuals died during 24 h exposure to its 1% solution.

As of now, this toxicant has been poorly studied regarding its behavior (degradation) in the environment against the background of military conflicts. In addition, there is a necessity to develop effective technologies of cleansing ecosystems from this compound. Yang et al. (2023) suggest a strategy of microbial remediation of the soil plagued with munitions. Twelve of the isolated bacterial strains proved to be highly effective in degrading this pollutant and its intermediate toxic products of breakdown. Researchers note a great significance of such studies for recovery of the soil productivity after armed conflicts.

An amino-nitro-benzene derivative 2-methyl-5-nitroaniline is a key intermediate product in the synthesis of azo dye. Recent studies involving adults and children revealed that this toxicant can be absorbed by the skin, penetrate perorally or inhaled via lungs. Furthermore, clinical data suggest it has a potential hepatotoxic effect (Liu et al., 2024). Other studies confirmed the ability of aniline (in the form of hydrochloride) to cause tumors in the spleen of rats (Bomhard & Herbold, 2005). During our trials of o-nitroaniline, around 50% of the invasive nematode larvae died. Also, a high mortality was observed among the noninvasive larvae of *S. papillosus*. A similar nematocidal effect was displayed by 1% solution of p-nitroaniline. Over 79% of the larvae of all studied nematodes died during 24 h exposure.

Naphthalene is a dangerous carcinogen for humans and animals. Nevertheless, it is used in olive orchards as a repellent of the olive fruit fly *Bactrocera oleae* (Bempelou et al., 2019). Naphthalene can be removed from the environment, in particular soils, by pea *Pisum sativum* L. It is recommended for phytoremediation of naphthalene-contaminated soil (Agoun-Bahar et al., 2018). Our studies revealed varying effects of naphthalene and 1-nitronaphthalene. Thus, naphthalene alone had no effect on the survival of the nematode larvae. However, with nitro group (1-nitronaphthalene), it had a notable negative impact on the nematodes. All the larvae of three species died in 24 h.

Numerous experiments have been focused on the effects of those toxicants on living organisms. An assessment of the effects of an interaction of oxidation, temperature increase, and toxicity of polyaromatic hydrocarbons on meiobenthos communities revealed that pollution with acenaphthene and benzo(a)pyrene led to an increase in the density of some genera of Nematoda, in particular *Pseudochromadora* (Portugal et al., 2025). By contrast, in combating *Plasmodium falciparum*, the preclinical trials of novel 3-hydroxypropanamides (HPAs) with modified phenanthrene and the 4-fluorobenzamidine moieties indicated an *in vitro* inhibition of *P. falciparum* (Klein et al., 2025). A notable antiplasmodial activity of 3-hydroxypropanamide in in vitro conditions against drug-sensitive and drug-resistant strains of *P. falciparum* was confirmed by Knaab et al. (2025). When designing drugs against leishmaniasis, Pal et al. (2024) discussed an approach based on synthetic products using furan, pyrrole, thiazole, imidazole, pyrazole, triazole, quinazoline, quinoline, pyrimidine, coumarin, indole, acridine, oxadiazole, purine, chalcone, carboline, and phenanthrene. Some other hazardous toxicants that can be released as a result of weapon use into the environment were analyzed for their interactions with a parasitic protozoan *Trypanosoma cruzi*, detecting its metabolism of o-nitroanilines, the main products of metabolism of 5-phenylethenylbenzofuroxans (Boiani et al., 2009).

Currently, another relevant issue worldwide is the selection of alternative methods of combating infectious diseases (including parasites) due to their resistance to antiparasitic drugs (Boyko & Brygadyrenko, 2019, 2021, 2022). Therefore, further studies of how those toxicants affect mammal nematodes at different development stages not only can reveal potential negative effects, but aid in discovering new, alternative methods of managing nematodoses of animals and humans.

Conclusion

A negative impact on the vitality of larvae of ruminant nematodes was exerted by 15 toxicants, released into the environment by explosions during military actions. However, the most notable nematocidal effects were observed for the pollutants hydrazine hydrate, 4-nitrophenol, p-nitroaniline, and 1-nitronaphthalene. In the experiment that lasted 24 h, over 80% of larvae of the nematodes *S. papillosus*, *M. capillaris*, and *H. contortus* at different development stages died subject to 1% aqueous solution of these explosion-associated contaminants.

The authors declare no conflict of interest.

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