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The impact of some inorganic substances on change in body mass of *Tenebrio molitor* (Coleoptera, Tenebrionidae) larvae in a laboratory experiment

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Abstract

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Addition of low concentrations of metal ions to the diet of saprophagous insects can impact on their metabolism over a short period of time, causing an increase or decrease in their body mass. This article presents a 14-day laboratory experiment evaluating the changes in the body mass of larval stage 3 of *Tenebrio molitor (*Linnaeus, 1758) induced by adding different inorganic substances (350 mg kg^{-1} of dry fodder) to the diet of the larvae. Following the addition of inorganic substances to the fodder, the most marked differences compared to the control were observed in the groups which consumed substrate with lead nitrate (the mass of the larvae increased on average by 102.6% compared to increase in mass in the control variant of the experiments), cobalt nitrate (by 96.9%), calcium chloride (by 89.1%) sodium triphosphate (by 86.0%), zinc chloride (by 83.5%). A nonsignificant effect (a tendency of increase in the body mass) on *T. molitor* larvae was caused by manganese sulfate (by 57.8%), aluminium nitrate (by 57.3%), iron oxide (by 51.5%), barium nitrate (by 47.9%), orthophosphoric acid (by 47.4%), manganese chloride (by 46.5%), calcium carbonate (by 27.7%), iron sulfate (by 24.2%) and ammonium heptamolybdate (by –7.5%). Therefore, 5 out of the 15 studied inorganic substances significantly stimulated the increase in the body weight of *T. molitor* larvae, and 7 manifested these capacities at the level of tendency (stimulated an increase in body weight averaging 43–58% over the 14-day experiment). The obtained data indicate a necessity for further study on the impact of inorganic pollutants on different stages of insects.

Keywords

body mass, heavy metal pollution, larvae, Tenebrionidae

Introduction

Environmental pollution is one of the most acute global ecological problems of today (Dallinger, 1993). Among a great variety of environmental factors affecting living organisms, the main role is taken by heavy metals, principally on account of human activity. The sources for contamination of the biosphere with heavy metals include the ferrous and non-ferrous metal industries, machine building industries, accumulator battery recycling plants, auto transport, and also volcanic eruptions and dissolution of minerals and rocks. Among chemical pollutants, heavy metals are considered a factor with significant ecological and biological consequences (Anderson et al., 1980; Bisthoven et al., 1992; Brygadyrenko and Reshetniak, 2014; Brygadyrenko and Ivanyshin, 2014, 2015; Shulman et al., 2017).

Inorganic substances (primarily, heavy metals) in spite

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of their migration ability, are capable of bioaccumulation and specific toxic effects; in particular through food products affected by levels of heavy metals which exceed the acceptable standards, are dangerous for human and animal health (Baker et al., 1998). The observed effects of metal ion contamination include carcinogenicity, immunotoxicity and neurotoxicity, which are considered to develop due to the formation of oxygen radicals, which cause oxidative stress and changes in physiological and biochemical characteristics of the tissues of organisms (Valko et al., 2005).

The physiological impact of inorganic substances on human and animal organisms varies and is related to their chemical activity, their natural form and also to their concentration (Buchwalter and Luoma, 2005). Many metals have pronounced capacities for forming complexes. In water, ions of these metals are hydro activated and they are able to form different hydroxi complexes, the composition of which is related to the acidity of the solution (Martinez et al., 2001). If a solution includes some anions and molecules of organic compounds, metal ions form complexes of different structures and stability, therefore their biological activity varies. Thus, the issue of objective evaluation of the ecological safety of the impact of chemical toxins on organisms in the conditions of natural and anthropogenic pollution is of great significance (Martynov and Brygadyrenko, 2017). An important role in this process is played by excessive pollution of the biosphere with inorganic pollutants, which is characterized by toxic effects which affect the main vital functions of organisms (Brygadyrenko and Ivanyshin, 2014, 2015). Metal salts and inorganic acids have a non-specific effect, which is realized by accumulation of changes in tissues and organs and manifests as fixation, blocking active centers of enzymes, which affect the condition of enzymic systems. Therefore, studying the effect of inorganic pollutants on living organisms is of great significance. There is a pressing need to develop methods for evaluating the pollutants´ negative effects and methods for their elimination.

This article aims to evaluate the impact on body weight of the third stage of *Tenebrio molitor* Linnaeus, 1758 larvae caused by adding different inorganic substances (highly toxic, mild and low toxic) in the conditions of a laboratory experiment.

Materials and methods

The experiment used the third stage larvae of *T. molitor*. Before the experiment, the larvae were kept together for over a month in a single container and they were fed with the same fodder (dry oat flakes). The selection of animals for the experiment was random. The experiment was conducted in plastic cups (0.2 l), with 36.01 ± 0.27 g of dry oat flakes in each cup. The substrate was moistened from a pipette with solutions of the studied substances at a 3 ml dose, at a concentration of 4.2 g l^{-1} of chemically pure substances. Therefore, the concentration of the active substance in our experiment was 350 mg kg^{-1} of dry fodder.

The experiment was designed to compare the impacts of different (highly toxic, mild and low toxic) substances applied at the same concentrations and to determine the variability of reactions of *T. molitor* larvae: to assess both reduction and increase in the body weight in the particular variants of the experiment. According to Braeckman et al. (1999) LD_{50} cadmium chloride for *Aedes albopictus* (Skuse, 1895) is 2.08 mmol l^{-1} or 381.3 mg l^{-1}. In our experiments, the concentration of substances (350 mg kg^{-1}) corresponded to the average lethal dose of cadmium for *Ae. albopictus*. The toxicity of other compounds of metals used in the experiment was much lower (Table 1). Apart from heavy metals, the experiment analyzed additions of other comparatively safe chemical compounds to the diet (Table 2) in order to study their chronic impact at low concentrations (much lower than LD_{50}).

After moistening the substrate with chemical compounds, it was carefully mixed with a plastic stick for uniform distribution of the substance throughout the substrate. In the control group, we used distilled water to the same amount (3 ml). After the solutions were added, the substrate was dried for deleting excessive moisture in order to prevent mould and prevent fungi infestations of the *T. molitor* larvae. Then the substrate was mixed again to prevent development of large aggregates of oat flakes, which would bind together after addition of water solutions.

Each variant of the experiment included 8 cups, each with one *T. molitor* individual. All variants of the experiment used 128 individuals (120 – in 15 variants of the experiment and 8 in the control). The containers were placed randomly on tables in a laboratory with equal illumination and temperature, not exposed to direct sunlight. Temperature fluctuations over each day were not higher than 2 °C (+18…+20 °C), the duration of daylight between 09–23 August was 1,355–1,440 h and it was prolonged by artificial illumination to 16 h a day. Before the beginning and at the end of the 14-day experiment, all *T. molitor* individuals were weighed. The average initial body weight of the larvae equaled 46.8 ± 3.1 mg (x ± SD, n = 128), 14 days after the beginning of the experiment the mass of the animals had increased to 67.9 ± 11.2 mg. The mass of the larvae was determined to an accuracy of 0.1 mg on an analytic balance.

The results were statistically analyzed in Statistica 8.0 (Statsoft Inc., USA). The differences were considered significant at $P < 0.05$ (one-way ANOVA).

Results

Over the experiment, no deaths of larvae or cases of moulting were observed. The changes in the body weight of *T. molitor* larvae in the 14-day laboratory experiment concerning addition of different substances to the fodder

Table 1. Heavy metals used in experiment involving feeding *T. molitor* larvae

Name of the substance	Chemical formula	Capacities	LD_{50} (oral, Rat)*, mg kg^{-1}	TLV** (TWA), mg m^{-3}	Threat level to health***	Usage
Zinc chloride	$ZnCl_2$	White hygroscopic odorless crystals	350	1.00	3	Metallurgy, organic synthesis, textile and paper industry
Cobalt nitrate	$Co(NO_3)_2$	Red hygroscopic odorless crystals	691	0.02	2	Metallurgy, organic synthesis, production of pigments
Ammonium heptamolybdate	$(NH_4)_6Mo_7O_{24}$	White crystals well soluble in water	333	10.00	2	Metallurgy, analytical chemistry, production of ceramics and fertilizers
Cadmium chloride	$CdCl_2$	White hygroscopic odorless crystals	88	0.01	3	Organic synthesis, production of pigments, galvanization
Manganese sulfate	$MnSO_4$	White or red-pink crystals	4,000	10.00	1	Organic synthesis, food industry, agriculture
Manganese chloride	$MnCl_2$	Pink crystals well soluble in water	1,454	0.20	2	Chemical industry, battery production
Lead nitrate	$Pb(NO_3)_2$	White crystals well soluble in water	93	0.05	3	Chemical industry, production of pigments
Alluminium nitrate	$Al(NO_3)_3$	White hygroscopic crystals	3,632	2.00	2	Petrochemical industry, electronics
Barium nitrate	$Ba(NO_3)_2$	Colorless crystals well soluble in water	355	0.50	2	Manufacture of explosives

*according to data of Material Safety Data Sheet (MSDS) for every substance; **Threshold Limit Value (TLV) according to American Conference of Governmental Industrial Hygienists (ACGIH); ***according to Hazardous Materials Identification System.

Table 2. Inorganic substances used in the experiment involving feeding *T. molitor* larvae

Name of the substance	Chemical formula	Capacities	LD_{50} (oral, Rat)*, mg kg^{-1}	TLV** (TWA), mg m^{-3}	Threat level to health***	Usage
Calcium carbonate	$CaCO_3$	White crystals insoluble in water	6,450	10	2	Food industry, manufacture of paints, household chemistry industry
Calcium chloride	$CaCl_2$	White crystals well soluble in water	1,000	3	2	Metallurgy, production of construction materials, food industry
Iron sulfate	$FeSO_4$	White or green hygroscopic crystals	1,520	1	2	Textile industry, manufacture of paints, producing accumulators
Iron oxide	FeO	Black crystals insoluble in water	5,000	5	1	Food industry, cosmetics
Sodium triphosphate	$Na_5P_3O_{10}$	White hygroscopic crystals	3,900	10	2	Food industry, production of ceramics, detergents
Phosphoric acid	H_3PO_4	White crystals or colorless liquid soluble in water	1,895	10	3	Food industry, dentistry, rust removal, chemical industry

For key to abbreviations see Table 1.

substrate are presented in Figures 1 and 2. Following the addition of inorganic substances, the most clearly manifested differences compared to the control were observed in the groups which consumed the substrate containing lead nitrate (body mass increased by 102.6% compared to the control, $P < 0.01$) and calcium chloride (body weight increased by 89.1%, $P < 0.01$). A significant increase was observed after addition of cobalt nitrate (by 96.9%, $P < 0.05$), sodium triphosphate (by 86.0%, $P < 0.05$) and zinc chloride (by 83.5%, $P < 0.05$).

An insignificant impact on the body mass of *T. molitor* was observed following addition of manganese sulfate (by 57.8%, $P > 0.05$), aluminium nitrate (by 57.3%, $P > 0.05$), iron oxide (by 51.5%, $P > 0.05$), barium nitrate (by 47.9%, $P > 0.05$), orthophosphoric acid (by 47.4%, $P > 0.05$), manganese chloride (by 46.5%, $P > 0.05$), cadmium

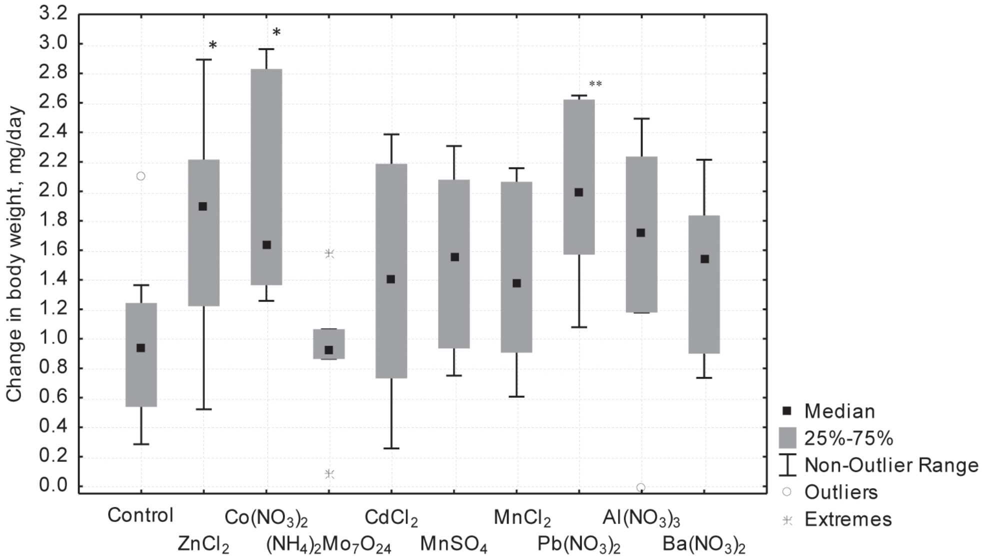

Fig. 1. Changes in the body weight of *T. molitor* over 14-day laboratory experiment with substrate including heavy metals at concentration of 350 mg kg^{-1} of fodder. $^*P < 0.05$, $^{**}P < 0.01$.

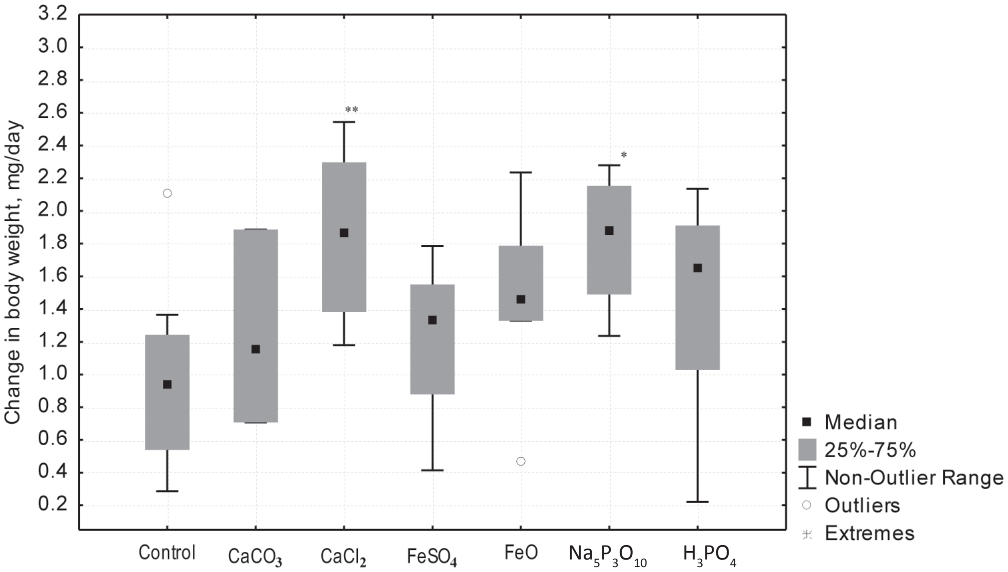

Fig. 2. Changes in the body weight of *T. molitor* over a 14-day laboratory experiment with substrate containing inorganic substances in concentration of 350 mg kg^{-1} of fodder. $^*P < 0.05$, $^{**}P < 0.01$.

chloride (by 43.9%, P > 0.05), calcium carbonate (by 27.7%, P > 0.05), iron sulfate (by 24.2%, P > 0.05) and ammonium heptamolybdate (by –7.5%, P > 0.05).

Discussion

The results obtained indicate that the studied concentrations of inorganic substances in the diet of *T. molitor* caused an increase in the body weight of the larvae rather than a decrease. Such effect is probably related to excessive consumption of fodder and metabolic disorders in the animals' organism, which could be caused by accumulations of heavy metals in the organism (Brygadyrenko and Ivanyshin, 2014, 2015). Considering the low concentration of substances in the experiment, the observed changes, i.e. gain in weight by *T. molitor*, indicate a chronic toxic effect during the primary stages intoxication of the organism.

Similar results, which indicate an increase in the body weight of *Eisenia foetida* (Savigny, 1826) (Annelida, Lumbricidae) were presented by Van Gestel et al. (1993) for chrome and zinc. Also, disorders in reproductive activity, in cocoon formation and reduction in the number of offspring were observed. Nevertheless, many researchers have reported an opposite impact of heavy metals on body weight. Decrease in body weight was found for impact of cadmium (Van Gestel et al., 1993; Santana et al., 2005), lead (Wang et al., 2015), copper (Baker et al., 1998), aluminium (Gomez et al., 1991) and other heavy metals.

The main source of heavy metals for the organism of terrestrial arthropods is food, and the main organ of accumulation is the walls of the digestive tract (Maroni and Watson, 1985; Lindqvist et al., 1995; Hensbergen et al., 2000). One of the ways of detoxication of accumulated trace amounts of metals in arthropods is fixation of metallothioneins in cell cytosols (Korsloot et al., 2004). Lauverjat et al. (1989) demonstrated apical extrusion of cadmium from the cells of the epithelium of *Drosophila melanogaster* (Meigen, 1830), and Posthuma et al., (1992) discovered that up to 35% of cadmium obtained by the organism of *Orchesella cincta* (Linnaeus, 1758) is removed every moult through removal of intestinal epithelium. Cadmium-binding proteins were discovered in some species of arthropods, such as *Locusta migratoria* (Linnaeus, 1758), *Pteronarcys californica* Newport, 1848 and others (Clubb et al., 1975; Martoja et al., 1983; Dallinger, 1993). Pedersen et al. (2007) reported the extraction of a cadmium-binding protein, different from metallothioneins, in *T. molitor* larvae, exposed to the impact of cadmium.

Apart from this, Pedersen et al. (2008) in a 16-day experiment with content of cadmium at 50 mg 100 g^{-1} of fodder found that 70% of cadmium obtained by the organism of *T. molitor* was accumulated in the wall of the intestine and in its content. In other parts of the body, including the malpighian tubule system, the fat body, muscles and cuticle, the accumulation of cadmium was 11%. Most of the accumulated metal was found in the digestive tract after the 16-day experiment. Transferring the larvae to non-contaminated food resulted in decrease in content of cadmium by 80%, which is explained by its removal with feces.

In their study of the absorption of cadmium and zinc, Buchwalter and Luoma (2005) found that *Drunella grandis* (Eaton, 1884) and *D. flavilinea* (McDunnough, 1926) accumulated these metals faster than the other species. The indicators of Cd absorption varied 250 times between *Siphlonuris* sp. and *D. flavilinea*. Similarly, the levels of Zn absorption varied 35 times between *Ameletus* sp. and *D. grandis*. The differences in consumption of metals were calculated through number of channels, for it was found that *D. flavilinea* has 266 times more transporters of cadmium than *Siphlonuris* sp. Coefficients of absorption of Cd and Zn from the solution vary for different species of aquatic insects by dozens of times. This variability is directly related to morphological characteristics, and finally – to osmoregulation function.

Lagisz (2008) studied the impact on ground beetles *Pterostichus oblongopunctatus* (Fabricius, 1787) of cadmium at environmental concentration of 50 mg kg^{-1} and of zinc of 500 mg kg^{-1}, over 70 days. The beetles with higher initial mass had higher probability of surviving longer. Over the experiment, the average body weight decreased with both diets, though the effect was most clearly manifested among males.

A study on the impact of zinc and food containing cadmium on *Poecilus cupreus* (Linnaeus, 1758) was conducted by Maryanski et al. (2002). They found that the beetles were able to regulate efficiently the concentration of zinc. To some extent, the insects were capable of regulating the concentration of Cd, though not so efficiently. Despite significant differences between the results for both sexes, decrease in body weight under the impact of the studied metals was observed. Mircic et al. (2010, 2013) and Vlahovic et al. (2008, 2012) studied the impact of cadmium on the larvae of *Lymantria dispar* (Linnaeus, 1758), using a concentration of Cd at 50 mg kg^{-1} of fodder. When the larvae were given food containing this dose of Cd, the chronic effect on their body weight was found significant. The results of the study showed a significant impact of the diet containing cadmium. The duration of development of larvae was extended and the body weight reduced under the impact of Cd. This coincided with data from the literature on other species (Schmidt et al., 1991; McChaton and Pascoe, 1991; Niu et al., 2002; Cervera et al., 2004; Mircic et al., 2010).

In the study on the impact of heavy metals on *Aiolopus thalassinus* (Fabricius, 1781) conducted by Schmidt et al. (1992), the fodder contained 10, 30 and 70 mg kg^{-1} of $HgCl_2$, 25, 75 and 100 mg kg^{-1} of $CdCl_2$ and 75, 200 and 500 mg kg^{-1} of $PbCl_2$ of dry mass. At the highest concentrations of these substances, mature individuals died very early before laying eggs. At all concentrations of cadmium and mercury, extension of the duration of nymph stage was observed, which was not found with fodder containing lead. Heavy metals affected the weight of mature individuals, though this effect varied in relation to the metal. Mercury caused significant loss of weight among both females and males. A similar effect was observed for males which consumed cadmium. Females and males fed with the highest lead concentration were observed to decrease in body weight. On the other hand, at lower concentrations of lead, the body weight was similar to the control.

Toxicity of lead, especially if its concentration in the organism exceeds physiological thresholds, was observed for some species of insects. Disorders in the functions of organism of insects, which inhabited an environment contaminated with zinc, such as *Pterostichus oblongopunctatus*, *Poecilus cupreus*, were observed by Bisthoven et al. (1992), Martinez et al. (2001, 2002, 2004), Maryanski et al. (2002), Lagisz (2008). Consumption of zinc-contaminated food by insects caused delays in their development, for example, among larvae of *Aglais urticae* (Linnaeus, 1758) (Lindqvist, 1994), *Trichoplusia ni* (Hubner, 1800–1803) (Larsen et al., 1994), *P. oblongopunctatus* (Zygmunt et al., 2006) and *Issoria lathonia* (Linnaeus, 1758) (Noret et al., 2007). High concentrations of Zn led to a low survival rate of *Priosotoma minuta* (Nursita et al., 2005). The effect of Zn on breeding insects was studied for *P. minuta* (Nursita et al., 2005) and for the grasshopper *Chorthippus brunneus* (Thunberg, 1815) (Augustyniak et al., 2008).

The study of the impact of lead nitrate on the survival rate in aquatic insects *Pteronarcys dorsata* (Say, 1823), *Hydropsyche betteni* (H.H. Ross, 1938), *Brachycentrus* sp. and *Phemerella* sp. Spehar et al. (1978) revealed that a maximum dose of lead nitrate at 0.565 mg l^{-1} had no effect. Anderson et al. (1980) studied the impact of lead nitrate on *Tanytarsus dissimilis* (Johannsen, 1905) over 10 days, beginning from the egg stage: average LC_{50} equaled 0.258 mg l^{-1}. No significant impact on the growth of the surviving larvae was observed until the concentration was raised. A study of the impact of iron and lead on mayflies *Leptophlebia marginata* Linnaeus, 1767 was conducted by Gerhardt (1994): the toxicity of both metals was higher at low levels of pH. Over 96 h exposure, LC_{50} for Fe equaled 106.3 mg l^{-1} at pH 7.0 and 89.5 mg l^{-1} at pH 4.5. The values of Pb equaled >5 mg l^{-1} and 1.09 mg l^{-1}, respectively.

A study of accumulations of aluminium in insects, carried out by Hall et al. (1988) showed that an increase in pH of water induced a decrease in concentration of aluminium in black flies and mayflies. Similar results were observed for chironomids (Young and Harvey, 1988). Guerold et al. (1995) studied the accumulation of aluminium in chloride epithelium cells of *Perla marginata* Panzer, 1799. Frick and Herrmann (1990) studied the accumulation of aluminium (Al) in nymphs of the mayfly *Heptagenia sulphurea* (Muller, 1776). The nymphs were affected by two concentrations of Al (0.2 and 2.0 mg l^{-1}) and two periods of impact (2 and 4 weeks); the longer time period also included the moult stage. The group of nymphs, which survived moulting, was observed to have an increase in the aluminium content almost twice (2.34 mg g^{-1} of dry mass) as high as the group with the two-week exposure (1.24 mg g^{-1}). This indicated that Al also accumulates inside nymphs, though most of the metal was deposited on the external part of the insects. Therefore, the insects accumulate aluminium in their cuticle and in the content of their intestine. Tabak and Gibbs (1991) evaluated the impact of aluminium and calcium on laying eggs and nymphs in *Cloeon triangulifer* (McDunnough, 1931). The eggs were incubated in acidic waters (pH 4.0 and 5.5) with admixed calcium (10 and 100 mg g^{-1}) and aluminium (100 and 500 μg g^{-1}): the admixture significantly reduced the percentage of successful moulting. Also, calcium increases the percentage of both successful and partly successful moulting. Havens (1993) studied the impact of aluminium (200 μg g^{-1}) on aquatic invertebrates: it was found that aluminium significantly decreased the survival rate of *Gyraulus*, *Hyalella* and Chironomida, at the same time, the survival rate of *Enallagma* and *Caenis* at low pH (4–5) improved due to Al.

Kijak et al. (2014) studied the toxic impact of aluminium on *Drosophila melanogaster* (Meigen, 1830). The flies were exposed to aluminium at concentrations from 40 to 280 mg kg^{-1} in the food substrate. The study measured the life expectancy of insects exposed to the impact of aluminium (40, 120 or 240 mg kg^{-1} of Al in the fodder) at different stages of their life cycle. The results showed that aluminium is toxic in concentrations higher than 160 mg kg^{-1} in the feed. The life expectancy of the flies was reduced in relation to concentration of Al and the duration of exposure. Average concentrations (120 mg kg^{-1}) of Al had a stimulating effect on the males, improving their life expectancy and locomotion activity.

The reactions of broad-nosed weevil *Phyllobius arborator* (Herbst, 1797) to enhanced concentration of manganese in the diet were studied by Martinek et al. (2017). The broad-nosed weevils were fed with birch (*Betula pendula* Roth) leaves soaked in solutions of $MnCl_2$ with graduated concentrations of manganese. Even significantly high consumption of manganese did not cause changes in reactions of the *P. arborator* imagoes compared to the control. The study did not find significant differences in food consumption, body weight of the imagoes and duration of their feeding period. It was found that *P. arborator* avoided manganese intoxication through food by releasing manganese into the feces or by neutralizing manganese in relatively high concentrations. Kula et al. (2014) studied the reaction of *Lymantria dispar* (Linnaeus, 1758) to the content of manganese in food during laboratory breeding of the caterpillars. The caterpillars were fed with leaves of birch soaked in solutions of $MnCl_2$ at concentrations of 0, 0.5, 5 and 10 mg kg^{-1}, the content of manganese equaled 307, 632, 4,087 and 8,124 mg kg^{-1}. High concentration of manganese in the food affected the process of development. The death rate of the caterpillars of the first stage was 8% and 62% at the highest content of manganese. The study observed an increase in the periods of development and in consumption of food. The main strategy of caterpillars' defense is accumulating metal in their cover. With imagoes the content of manganese decreased to 0.5% of the consumption even under maximum concentrations.

Sorensen et al. (2009) studied the survival rate of a cosmopolitan insect *Megaselia scalaris* (Loew, 1866), exposed to a Mn concentration of 2,600 mg kg^{-1} of dry mass. The insects with a diet Mn 260–2,600 mg kg^{-1} showed a significant decrease in the duration of their larval development, total duration of imago formation and breeding. Also an increase in the width of the females' wings was observed. The timing of hatching, the number of females and the wing length of the males did not differ from the control.

Gongalsky (2006) studied the accumulation of molybdenum in soil insects around the areas of uranium mining. The author found that the concentration of molybdenum in the insects equaled 1.4–8.5 mg kg^{-1}, which is 2–12 times higher compared to the insects in the control area. High concentrations were found in *Poecilus gebleri* (Dejean, 1828), *P. fortipes* (Chaudoir, 1850), *Nicrophorus investigator* (Zetterstedt, 1824), *Blaps rugosa* (Gebler, 1825), *Angaracris barabensis* (Pallas, 1773). The insects most susceptible to accumulating metal were found to be saprophagous darkling beetles.

The toxicity of barium carbonate for *Sarcophaga ruficornis* (Fabricius, 1794) was studied by Singh et al. (2017). They found a significant death rate in the pupae, despite the absence of changes at the larval stage. A maximum concentration of 10,000 ppm caused death of 26.6% of the pupae and 73.3% of the imagoes. The observed mortality of the pupae was directly related to the concentration.

Despite the significant amount of studies on the impact of heavy metals on insects, it should be mentioned that there is insufficient information on particular compounds of salts and metals, and also on the impact of these substances on particular species. According to our research, *T. molitor* is a good model for studying the impact of heavy metals and other, substances delivered to insects with food.

Conclusions

A significant gain in the body weight in *T. molitor* larvae was caused by adding 350 mg 1 kg^{-1} of lead nitrate, cobalt nitrate, calcium chloride, sodium triphosphate and zinc chloride to the larvae's fodder. We observed a tendency towards increase in the body weight in larvae of *T. molitor* after adding manganese sulfate, aluminium nitrate, iron oxide, barium nitrate, orthophosphoric acid, manganese chloride, cadmium chloride, calcium carbonate and iron sulfate in the same concentrations.

Therefore, 5 out of the 15 studied inorganic substances reliably stimulated the gain in body weight of the third stage *T. molitor* larvae, and 7 manifested properties at the level of tendency (stimulated an increase in mass on average by 43–58% over the 14-day experiment). These data contradict a significant amount of data from the literature which states that pollutants reduce the body weight in the model insect species. The study of the impact of heavy metals on insect organisms is significant for protecting rare species in the conditions of industrial and agricultural pollution. The conservation of these species requires development of methods for evaluating the hazard of negative impacts on the organisms of invertebrates and development of measures for eliminating such negative impacts.

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