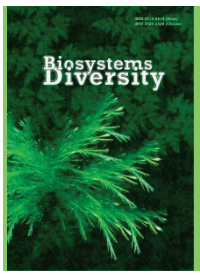

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Effects of biphenyl on *Blaberus craniifer* (Blattodea, Blaberidae) cockroaches and their parasites – gregarines and nematodes

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In natural ecosystems, parasites and their hosts are subject to xenobiotics, which overall weaken either a host or its parasites. There has been no laboratory study of this process on the example of cockroaches and their parasites. In accurately controlled conditions, we examined the influence of a food supplement – biphenyl – on cockroaches and their three parasites. In the conditions of our experiment, *Blaberus cranifer* (Blattodea, Blaberidae) cockroaches significantly reduced the rates of anabolism even while consuming the lowest biphenyl concentration in their diet. While the control group was observed to have a 59.4 mg/day increase in body mass, the mass of the cockroaches given biphenyl in the dose of 0.5% of diet mass decreased by 3.4 mg/day on average. Subject to high dosages of biphenyl (0.5–16.0% of fodder mass), body mass of the cockroaches decreased on average by 1.1–9.4 mg/day. The insects consumed their diet at the same rate, no matter the biphenyl concentration given. The number of gregarines *Blabericola cubensis* (Eugregarinorida, Blabericolidae) and *Protomagalhaensia granulosae* did not change even at the highest concentration (16.0% of fodder mass) added to the *B. craniifer* cockroaches' diet. We observed no significant changes in the amount of larvae of the *Cranifera cranifera* (Oxyurida, Thelastomatidae) nematodes, while the adult nematodes tended to decline in number when subject to increased concentration of the food supplement in the cockroaches' food. The number of *P. granulosae* gregarines did not significantly increase with body-mass gains of their hosts – cockroaches, that is despite increase in volume of their living environment (the midgut of cockroaches) and extension of the period during which the cockroaches consumed gregarine oocysts from the environment with food. Similarly, the number of *B. cubensis* gregarines also did not significantly change with increased food consumption by the cockroaches. However, we observed a tendency towards greater numbers of this gregarine in the cockroach larvae that were losing mass during the experiment. The greatest mass loss during the experiment was observed in the cockroaches that consumed biphenyl in the diet and had the largest number of *C. cranifera* nematodes in the hindgut. We observed no significant negative correlation between the numbers of *B. cubensis* and *P. granulosae* gregarines. A cockroach that was found to have 70 specimens of *B. cubensis* in the midgut, had no *P. granulosae* gregarines. In contrast, when the intestines of a cockroach contained over 10–15 specimens of *P. granulosae*, some *B. cubensis* were always present. The number of *C. cranifera* nematodes in the cockroaches' hindgut did not depend on the number of *B. cubensis* or *P. granulosae* gregarines in their hosts' midgut. Perhaps, this was related to absence of competition for the intestinal section among them. The regularities we found are different from what we expected to see in the parasitic system prior to the experiment. Gregarines did not compete with nematodes. Neither of them died from biphenyl, though the cockroaches ceased to normally gain weigh when eating biphenyl. That is, the host suffered from biphenyl more than the parasites, even when consuming the lowest concentration of the xenobiotic we tested.

Keywords: Blattodea; Thelastomatidae; Eugregarinorida; food supplements; gregarines; xenobiotics; biphenyl; parasitic system; insect parasites.

Introduction

Xenobiotics can drastically reduce the immunity of a host that is continuously struggling with several species of parasites. Coming with fodder, they are easily adsorbed, passing between or through epithelial cells. Moreover, they metabolize into simple or complex chemical compounds after interacting with enzymes (Yanovych & Yanovych, 2011). In this situation, the parasites-host system can be ruined because (1) the host will be less efficient in opposing its parasites, which will then suppress it much more, or (2) the xenobiotic will have a stronger impact on the parasites, resulting in their death and thus improving the health of the host, or (3) both parasites and host die.

Of the greatest practical interest is the variant when the host remains alive, while one or several species of parasites decline in number. Also, xenobiotics have effects also on a number of microorganisms (bacteria, fungi), which are in the intestines and interact both with parasites and host, as well as with xenobiotics, subjecting the latter to biotransformation (Koppel et al., 2017). In one way or the other, such a situation can be observed in thousands of vertebrate and invertebrate hosts in xenobiotic-contaminated territories. However, monitoring the parasitic system in natural conditions is a challenge due to dozens of biotic and abiotic factors that are hard to control. Therefore, it is best to model the basics of interaction between parasites and their host subject to xenobiotics in the laboratory conditions (Tanada & Kaya, 1993).

Cockroaches *Blaberus craniifer* Burmeister, 1838 (Blattodea, Blaberidae) are a common laboratory culture of insects, originating from the Central America. These insects are often used to carry out various experiments related to influence of xenobiotics on their vitality (Goudey-Perrière et al., 2003, 2007; Lambiase et al., 2004; Parhomenko et al., 2022). This insect is parasitized by several nematodes and gregarines (Smith & Cook, 2008; Clopton, 2012b). It is easy to keep this insect in laboratory conditions and evaluate the effects of various xenobiotics on it and its parasites

(Kulma et al., 2020). The objective of our study was evaluating the influence of biphenyl on parasites and growth rates of *B. craniifer* larvae, accounting for age of larvae (their body mass), intensity of parasite infestation, and interaction between them.

Materials and methods

To conduct the experiment, we selected 175 larvae of the cockroaches *Blaberus craniifer* Burmeister, 1838, varying in age and mass. We placed them in plastic cups with fodder containing biphenyl in different concentrations. Humidity was maintained with water-soaked cotton disks. Also, in each cup, we put a piece of cardboard egg carton, so that the insects could hide from daylight. The temperature in the room was maintained at the level of +22…+25 ºC. Light was natural, and the cups were out of direct sunlight.

Biphenyl is a white solid compound. It crystallizes into glossy plates or monoclinic prisms. It is poorly soluble in water (7.2 mg/L in normal conditions), but is easily soluble in ethyl alcohol, fats, ethers, and other organic solvents. Therefore, to carry out the experiment, we dissolved this compound in ethyl alcohol (96%). This alcohol solution of biphenyl was evenly mixed with dry meat-and-bone meal (1 g), and dried until evaporation of ethyl alcohol and the required concentrations of this preservative in food for the cockroaches (0.0%, 0.5%, 1.0%, 2.0%, 4.0%, 8.0%, 16.0%). Then, the diet with different biphenyl concentrations was transferred to 500 mL plastic cups, each containing one cockroach. Each concentration was tested on 25 cockroaches. The control group contained 25 cockroaches as well. In total, we used 175 cockroaches. The cockroach larvae were weighed prior to the experiment and then at the end. The experiment lasted for 3 days. To study the parasites (gregarines and nematodes), the intestines of cockroaches were dissected according to the generally accepted methods (Adamson & Van Waerebeke, 1992; Clopton, 2011; Morffe et al., 2022; Parhomenko et al., 2023), and temporary preparations were made from the midgut and hindgut, and the parasites were counted under a microscope.

The study materials were statistically analyzed using the standard methods of variance statistics, regression and correlation analysis, and also a cluster analysis in a Statistica 8.0 (StatSoft Inc., USA) software pack. We used ANOVA to compare the samplings, and employed the Tukey test in the case of discovering significant differences. The differences were considered significant at $P < 0.05$ with Bonferroni's Correction.

Results

The correlation analysis (Table 1) revealed the extent of interaction between the examined parameters. The most significant correlation coefficients were found between the number of larvae, males, and females of nematodes, as expected prior to the study.

The *Blaberus craniifer* cockroaches had significantly reduced rates of anabolism (Fig. 1) even subject to the lowest concentration of the food supplement we studied. The median of body-mass gain in the control group of cockroaches was 59.4 mg/day, while the body mass of the cockroaches consuming biphenyl in the amount of 0.5% of the fodder mass not only did not increase, but, on the contrary, started to decrease, by 3.4 mg/day. Addition of various doses of biphenyl (0.5–16.0% of fodder mass) had no significant effect on the median of body-mass changes, which maintained in the range of –9.4…–1.1 mg/day.

Table 1

Correlation between the studied characteristics of the *Blaberus craniifer* cockroaches and their parasites – gregarines and nematodes (n = 175)

Characteristic	Concentration of biphenyl in the diet, %	Initial body mass of cockroach, mg	Changes in body mass, mg/day	Changes in mass of fodder, mg/day	*Blabericola cubensis*	*Protomagalhaensia granulosae*	*Cranifera cranifera*, females	*C. cranifera*, males	*C. cranifera*, larvae
Initial body mass of cockroach	–0.103 ± 0.076	1	–	–	–	–	–	–	–
Changes in body mass	–0.259 ± 0.073*** (Fig. 1)	–0.033 ± 0.076	1	–	–	–	–	–	–
Changes in diet mass	0.108 ± 0.076 (Fig. 2)	–0.009 ± 0.076	0.180 ± 0.075*	1	–	–	–	–	–
Blabericola cubensis	–0.092 ± 0.076 (Fig. 3)	0.056 ± 0.076	–0.160 ± 0.075* (Fig. 10)	–0.026 ± 0.076	1	–	–	–	–
Protomagalhaensia granulosae	0.033 ± 0.076 (Fig. 4)	0.214 ± 0.074** (Fig. 9)	–0.005 ± 0.076	0.028 ± 0.076	– 0.26±0.07*** (Fig. 13)	1	–	–	–
Cranifera cranifera, females	–0.194 ± 0.075** (Fig. 5)	0.079 ± 0.076	–0.168 ± 0.075*	–0.191 ± 0.075*	0.231 ± 0.074**	–0.159 ± 0.075*	1	–	–
C. cranifera, males	–0.132 ± 0.075 (Fig. 6)	0.051 ± 0.076	–0.124 ± 0.075	–0.236 ± 0.074**	0.151 ± 0.075*	–0.136 ± 0.075	0.46±0.07*** (Fig. 16)	1	–
C. cranifera, larvae	–0.141 ± 0.075 (Fig. 7)	0.138 ±0.075	–0.212 ± 0.074**	–0.194 ± 0.075**	0.109 ± 0.076	–0.091 ± 0.076	0.44±0.07*** (Fig. 17)	0.28±0.07*** (Fig. 18)	1
C. cranifera (females, larvae)	–0.207 ± 0.074** (Fig. 8)	0.116 ± 0.076	–0.217 ± 0.074** (Fig. 11)	–0.243 ± 0.074*** (Fig. 12)	0.222 ± 0.074** (Fig. 14)	–0.164 ± 0.075* (Fig. 15)	0.917 ± 0.030***	0.579 ± 0.062***	0.737 ± 0.051***

Note: for the most significant correlation coefficients, we calculated the significance of changes of dependable variable of independent (the table cells contain references to the figures).

Consumption of feed by the cockroaches (Fig. 2) did not significantly change in the most periods of the studied range of concentrations.

The number of the *Blabericola cubensis* (Fig. 3) and *Protomagalhaensia granulosae* (Fig. 4) gregarines did not change when subject to addition of biphenyl to diet of the *Blaberus craniifer* cockroaches, even in the highest concentration (16.0% of the fodder mass). No significant changes occurred in number of the larvae of *Cranifera cranifera* (Fig. 7), whereas the adult nematodes (Fig. 5 and 6) were observed to have a tendency towards decrease following increase in concentration of the supplement added to the diet. The overall number of this nematode did not significantly change when subject to various concentrations of biphenyl in the feed (Fig. 8). The population of *P. granulosae* gregarines (Fig. 9) did not significantly increase with growing body mass of their hosts – cockroaches, that is despite increase in the volume of their living environment (the midgut of the cockroaches) and longer consumption of gregarine oocysts by the cockroaches from the environment with the feed. The population of *B. cubensis* gregarines (Fig. 10) significantly did not change with increase in the rates of feed intake by the cockroaches. However, the number of this gregarine tended to be higher in the cockroach larvae whose body mass had been decreasing during the experiment (Fig. 10).

The greatest mass decrease in the experiment was observed in the cockroaches that consumed biphenyl in the diet and had the highest number of *Cranifera cranifera* nematodes in the hindgut (Fig. 11). Naturally, a similar tendency was seen for the rates of changes in mass of feed offered to the cockroaches (Fig. 12).

Interestingly, we found no significant negative correlation between the numbers of gregarines *B. cubensis* (abscissa axis in Fig. 13) and *P. granulosae* (ordinate axis in Fig. 13). While over 70 specimens of *B. cubensis* were found in the midgut of the cockroaches, we did not find a single *P. granulosae* gregarine in those cockroaches. In contrast, a cockroach having over 10–15 specimens of *P. granulosae* in the intestines almost always had some individuals of *B. cubensis* (Fig. 13).

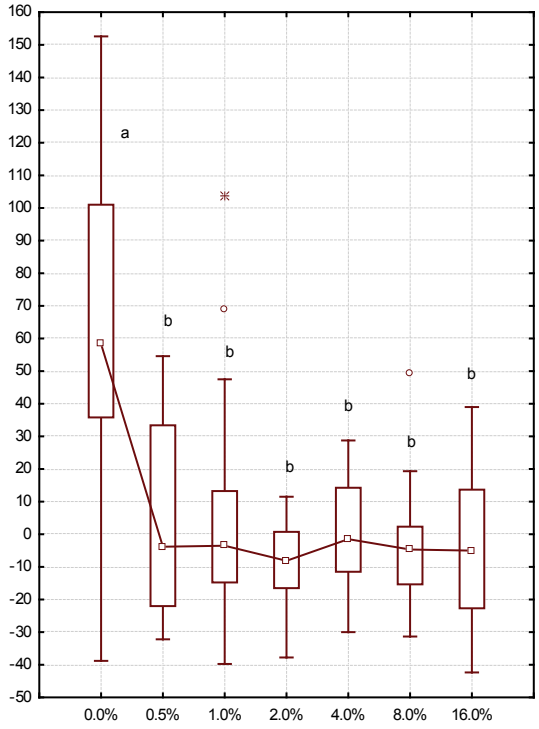

Fig. 1. Changes in body mass ($P = 3.9*10^{-15}$; $F = 16.83$, $F_{0.05} = 2.15$) of *Blaberus craniifer* cockroaches (ordinate axis, mg of live body mass per day) depending on biphenyl concentration in their food (abscissa axis, %): the small square in the center is the median, upper and lower border of the rectangle correspond to the first and third quartiles, upper and lower borders of the vertical lines indicate minimum and maximum values of the samplings, respectively; different letters above the boxes indicate samplings significantly different one from another according to the Tukey test, accounting for Bonferroni's Correction; n = 25

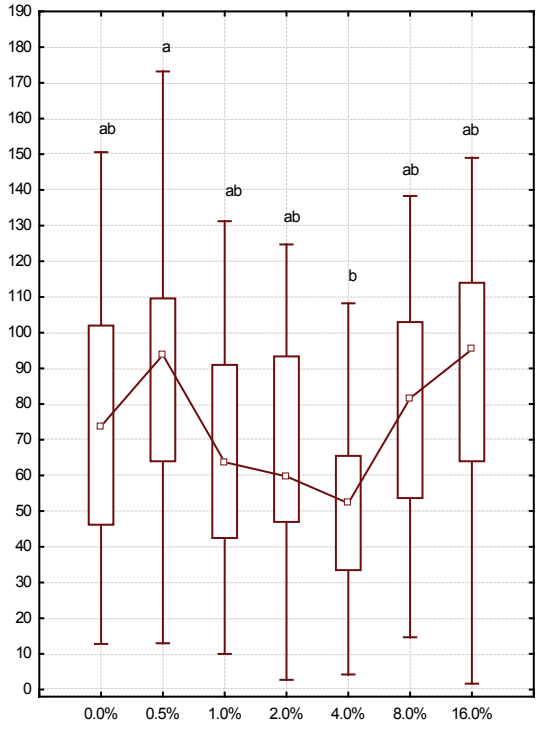

Fig. 2. Changes in mean daily diet consumption ($P = 1.5*10^{-3}$; $F = 3.78$, $F_{0.05} = 2.15$) by the *Blaberus craniifer* cockroaches (ordinate axis, mg per day) depending on biphenyl concentration in their fodder (abscissa axis, %): see Fig. 1

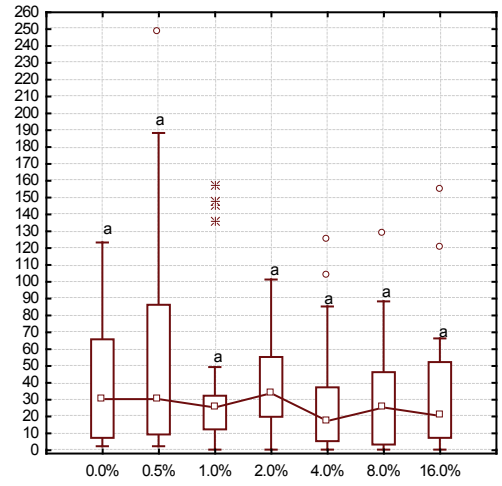

Fig. 3. Number of the *Blabericola cubensis* greagarines in the intestines of the *Blaberus craniifer* cockroaches depending on biphenyl concentration in the diet (abscissa axis, %): no significant differences between the samplings were found ($P = 0.321$; $F = 1.18$, $F_{0.05} = 2.15$); see Fig. 1

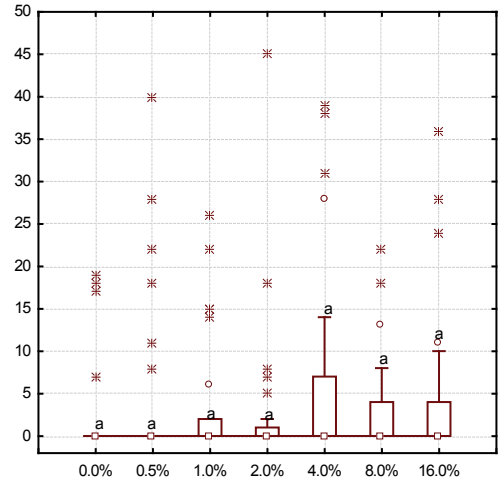

Fig. 4. Number of the *Protomagalhaensia granulosae* gregarines in the intestines of the *Blaberus craniifer* cockroaches depending on biphenyl concentration in the diet (abscissa axis, %): no significant differences between the samplings were found ($P = 0.646$; $F = 0.705$, $F_{0.05} = 2.15$): see Fig. 1

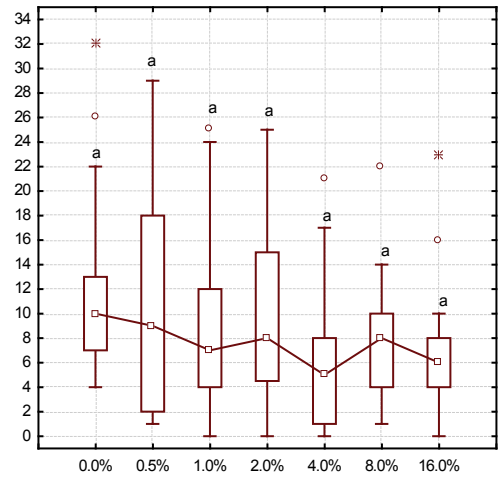

Fig. 5. Number of female *Cranifera cranifera* nematodes ($P = 0.040$; $F = 2.26$, $F_{0.05} = 2.15$) depending on biphenyl concentration in the diet of *Blaberus craniifer* cockroaches (abscissa axis, %): see Fig. 1

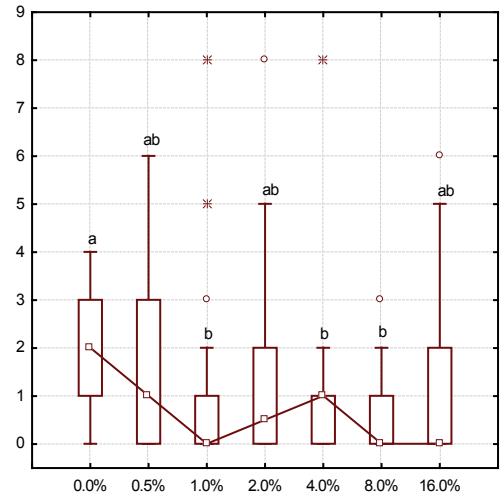

Fig. 6. Number of male *Cranifera cranifera* nematodes (P = 0.112; F = 1.75, $F_{0.05}$ = 2.15) depending on biphenyl concentration in diet of *Blaberus craniifer* cockroaches (abscissa axis, %): see Fig. 1

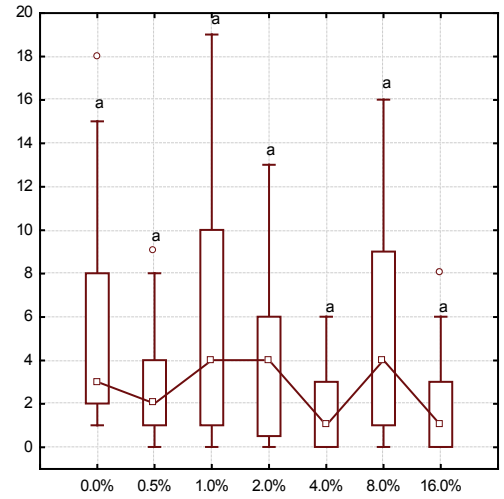

Fig. 7. Number of larvae of *Cranifera cranifera* nematodes (P = 1.1*10^{-3}; F = 3.90, $F_{0.05}$ = 2.15) depending on biphenyl concentration in the diet of *Blaberus craniifer* cockroaches (abscissa axis, %): see Fig. 1

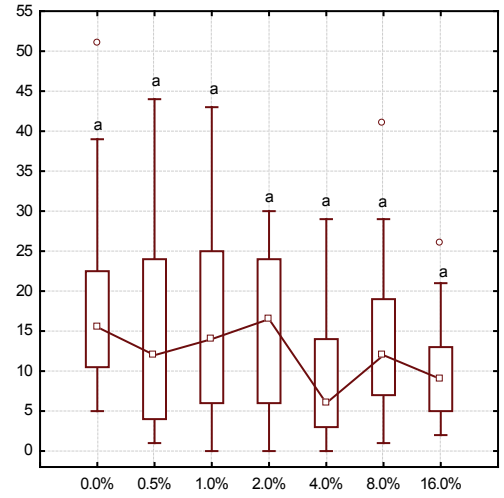

Fig. 8. Overall number of larvae, females, and males of *Cranifera cranifera* (P = 0.012; F = 2.82, $F_{0.05}$ = 2.15) depending on biphenyl concentration in the feed of the *Blaberus craniifer* cockroaches (abscissa axis, %): see Fig. 1

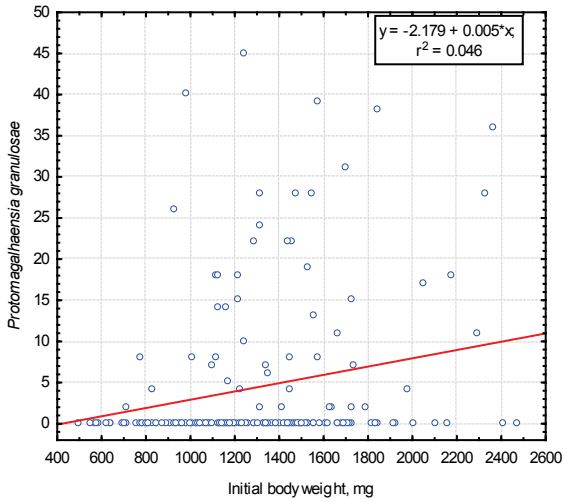

Fig. 9. Regression analysis of the number of *Protomagalhaensia granulosae* gregarines (the ordinate axis shows number of gregarine specimens in the intestines of one cockroach) in *Blaberus craniifer* cockroaches depending on their body mass

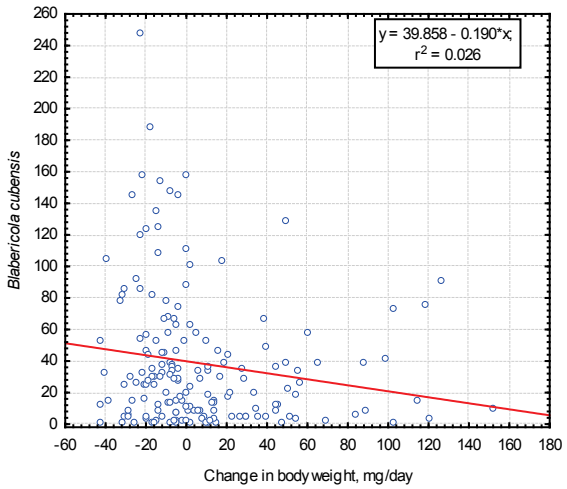

Fig. 10. Correlation between number of *B. cubensis* gregarines (ordinate axis represents number of gregarine specimens in the intestines of one cockroach) and rates of changes in body mass of their hosts – the *Blaberus craniifer* cockroaches (abscissa axis, mean-daily changes in body mass of the cockroaches, mg/day)

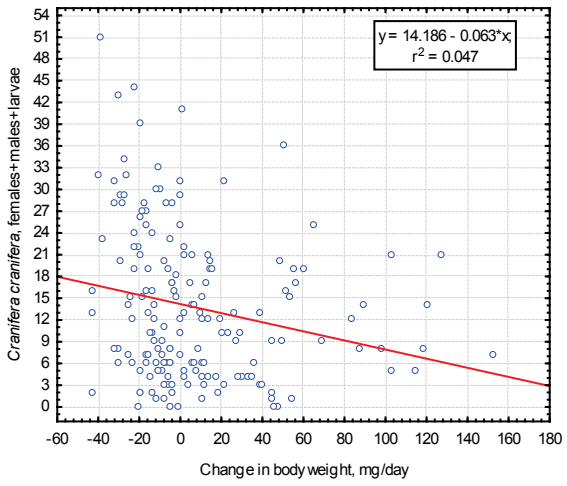

Fig. 11. Correlation between number of all groups of nematodes (larvae, males, and females) of *Cranifera cranifera* (the ordinate axis, number of nematode specimens in one host) and changes in body mass of the *Blaberus craniifer* during the experiment

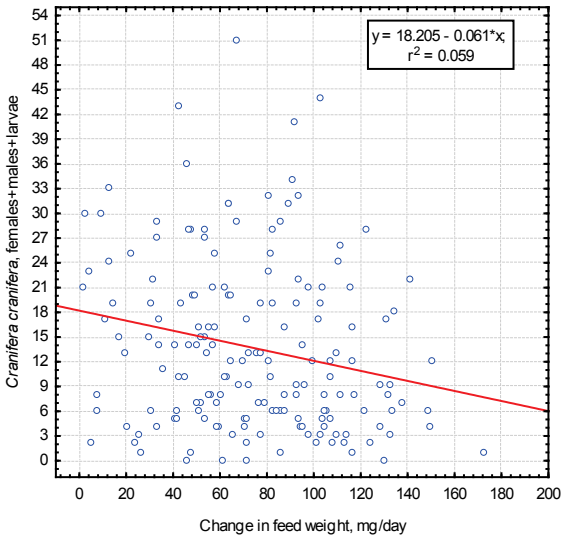

Fig. 12. Correlation between number of parasitic nematodes in the hindgut and rates at which the cockroaches consumed fodder

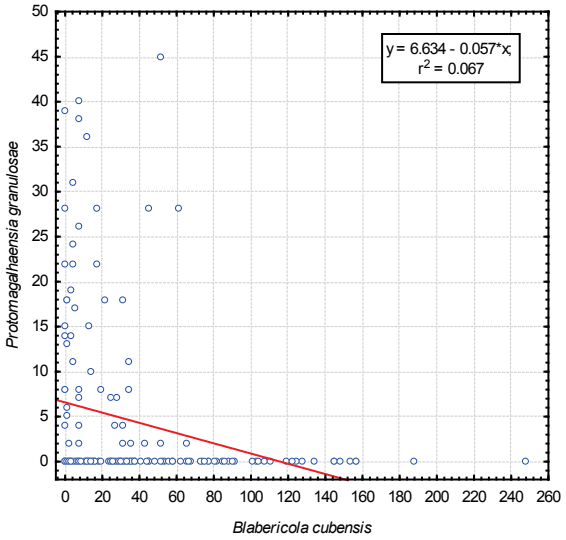

Fig. 13. Correlation between numbers of *B. cubensis* (abscissa axis) and *P. granulosae* (ordinate axis) in one *Blaberus craniifer* cockroach (n = 175)

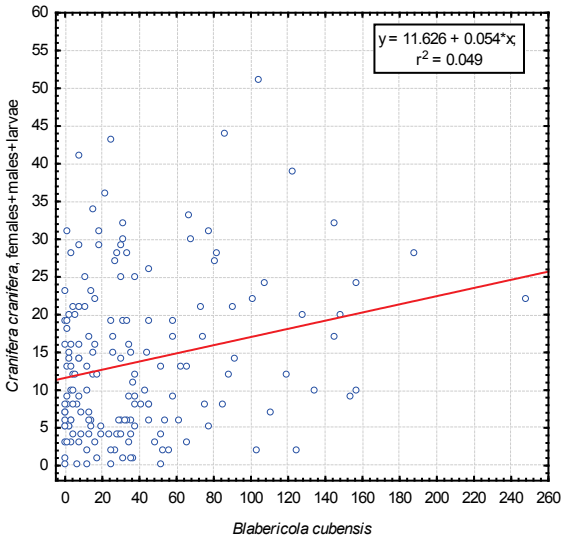

Fig. 14. Number of *Cranifera cranifera* nematodes (ordinate axis) depending on number of *B. cubensis* (abscissa axis) (n = 175)

The number of *C. cranifera* nematodes in the hindgut of the cockroaches did not depend on numbers of *B. cubensis* (Fig. 14) or *P. granulosae* (Fig. 15) gregarines in the midgut of *Blaberus craniifer*. Perhaps, this was related to absence of competition among them for a certain gut section.

Various stages of development of nematodes that lived in the cockroaches' hindgut correlated with each other by number (Table 1, Fig. 16–18): as the number of males and females increased, the number of larvae also increased.

The closest correlation, as expected before the experiment, was found between different development stages of the nematodes *Cranifera cranifera* (Fig. 19). The second cluster comprised the initial body mass (closely correlated with age of the cockroaches, and therefore with likelihood of their infection with gregarines) and degree of their infestation with gregarines. The third cluster (Fig. 19) comprised biphenyl concentration in the insects' diet, change in their body mass and feed mass.

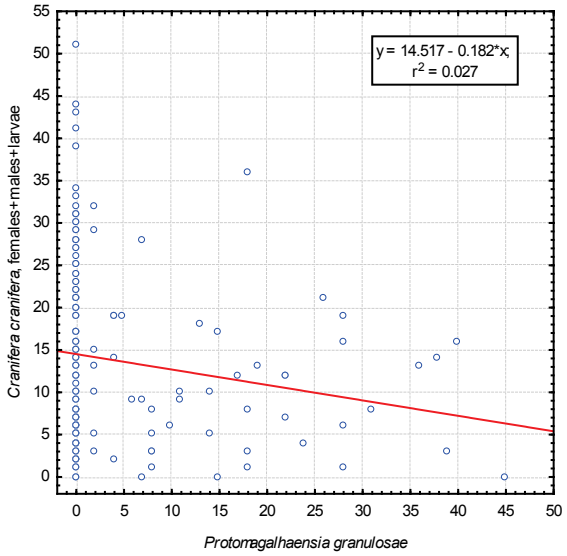

Fig. 15. Number of *Cranifera cranifera* nematodes (ordinate axis) depending on number of *P. granulosae* (abscissa axis) (n = 175)

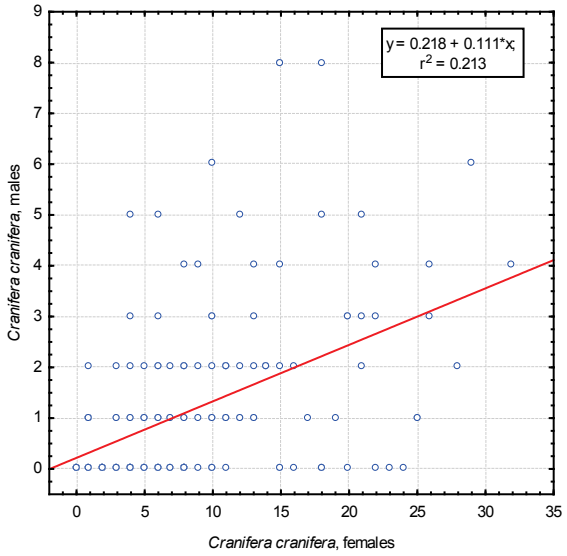

Fig. 16. Correlation between number of male and female *Cranifera cranifera* nematodes

Discussion

Food supplements have negative impacts on vertebrates (Lieshchova et al., 2018, 2020, 2023; Bilan et al., 2019) and invertebrates (Martynov & Brygadyrenko, 2017, 2018; Kozak et al., 2020), and also nematodes –

their parasites (Boyko & Brygadyrenko, 2017, 2019a, 2019b, 2022). Biphenyl (or phenyl benzene, diphenyl, biphenyl), which we tested, is used as a preservative (additive E_{230}) for better shelf life of the products, preventing reproduction of bacteria and fungi on them. The main source of biphenyl for humans is food products (Schecter, 2010; Feinberg et al., 2011). It is used as a sterilizing supplement for stopping aging of wine, and also as a disinfectant. It has no color and no odor. Most often, biphenyl is applied onto the surface of citrus fruits (for example, oranges, lemons, mandarins), apples, and other fruits. Washing fruits usually does not remove the antifungal and antibacterial coatings. Biphenyl is a strong allergenic agent that often causes an allergic reaction in people, inhibits the activity of the nervous system, stimulates skin diseases, and can lead to malfunctions of the gastrointestinal tract (Griesbaum et al., 2012; Grimm et al., 2015).

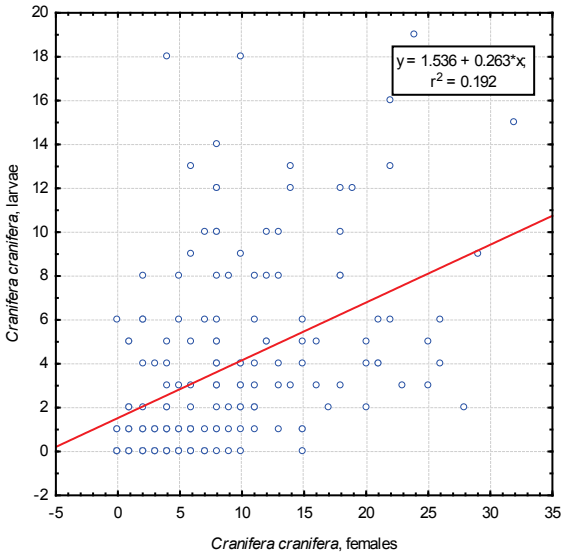

Fig. 17. Correlation between number of larvae and female *Cranifera cranifera* nematodes

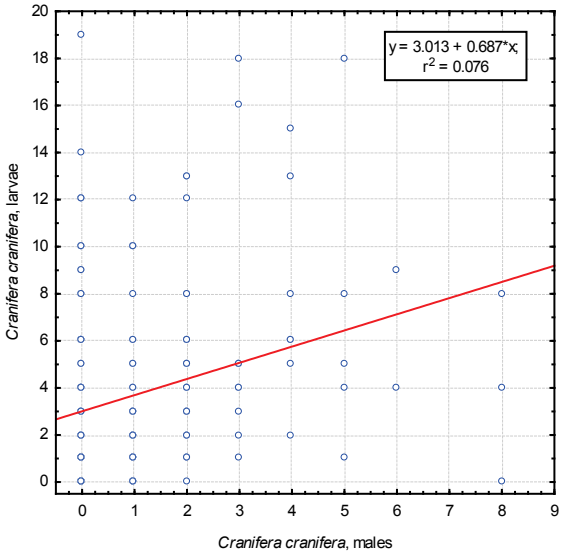

Fig. 18. Correlation between number of larvae and male *Cranifera cranifera* nematodes

According to the results of some studies, biphenyl has a carcinogenic activity. This compound is present in coal tar, oil, and oil products, and in natural gas. Biphenyl is broadly used in non-combustible transformer oils as a high-temperature heat carrier, and also in production of numerous colorings – polychlorobiphenyls and polybrominated biphenyls. Polysaccharide diphenyls are widely known carcinogenic compounds, internationally restricted by the 2001 Stockholm Convention on Persistent Organic Pollutants (according to this convention, PSDs are confirmed carcinogens for people and animals). The most likely contact with it is when working with electric transformers or their components (for example, with transformer wiring) in household conditions.

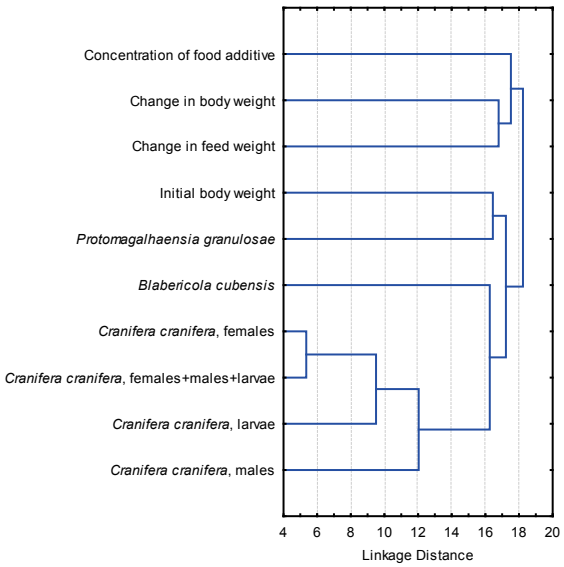

Fig. 19. Cluster analysis (Single linkage, Euclidean distances) of correlations of physiological specifics and number of parasites in the intestines

Maximum allowable intake of biphenyl with food for humans is 0.5 mg/kg of body mass a day. Having a body mass of 70 kg, this is equivalent to 35 mg/day. Since a human consumes on average 1.75 kg of food a day, it corresponds to 20 mg of biphenyl per 1 kg of food. On the one hand, the concentrations we used were very high compared with those used in human nutrition (for example, 1.0% of food mass is 10,000 mg per 1 kg of food). On the other hand, because biphenyl is applied onto the surface of fruits in quite high concentrations, cockroaches and other insects consuming household wastes can encounter biphenyl in approximately those concentrations we used in the experiment. Once inside an organism, they affect symbiotic microorganisms and its parasitic fauna (Lange & Lord, 2012). Effects of this xenobiotic are conditioned by its toxic action, its accumulation in a living organism, and its involvement in trophic food chains of ecosystems. In the organism, xenobiotics are subject to biotransformation, with formation of intermediate and end products that can be toxic and affect the gut microbiota (Halkin & Filipova, 2020). Passing through the intestines, they are modified by food enzymes and are absorbed by the tissues, and also affect the parasite fauna in the intestines.

The rates of metabolism and body mass of the larvae decreased when consuming even the lowest concentration we tested (0.5% biphenyl of fodder mass), while the body mass of the cockroaches decreased by 3.4 mg/day. Subject to high doses of biphenyl (0.5–16.0% of feed mass), body mass of the cockroaches stopped increasing, being in the range of –9.4…–1.1 mg/day. At the same time, feed consumption by the cockroaches remained the same with all the studied biphenyl concentrations in their fodder.

In *Blaberus craniifer* Burmeister, 1838 (Blattodea, Blaberidae) cockroaches, we found three species of parasites (two gregarines and one nematode).

Gregarines in the intestines of their phytophage hosts are subject to changes in the host's diet (Desportes & Schrével, 2013; Brygadyrenko & Svyrydchenko, 2015; Brygadyrenko & Reshetniak, 2016). Furthermore, parasites, bacteria, and fungi that live in various sections of the intestines, are adapted to a particular living environment, since different regions of the gastrointestinal tract are characterized by various physiology of epithelial cells, pH, level of oxygen and nutrients. This creates the different conditions and influences the types of metabolic processes occurring inside those sections (Aron-Wisnewsky et al., 2012; Sender et al., 2016). Fauna of cockroach gregarines is diverse, because the number of gregarines increases in the insects that (1) are quite large, (2) live for a quite long

period, (3) that live on the soil surface and litter, and not only in grass and trees, (4) that live in shaded microbiotopes that prevent the solar UV rays from killing gametocytes and oocysts of gregarines. Cockroaches meet all those criteria (Clopton & Hays, 2006; Clopton, 2002, 2010, 2012a, 2012b).

The numbers of the gregarines *Blabericola cubensis* (Peregrine, 1970) Clopton, 2009 (Eugregarinorida, Blabericolidae) and *Protomagalhaensia granulosae* Peregrine, 1970 did not change after adding biphenyl to the diet of the *B. craniifer* cockroaches, even in the highest concentration (16.0% of diet mass). We observed no changes in the number of larvae of the nematodes *Cranifera cranifera* (Chitwood, 1932) Kloss, 1960 (Oxyurida, Thelastomatidae), while the adult nematodes had a decreasing tendency after increase of concentration of this food supplement. The gregarines of *P. granulosae* did not reliably increase in number with growth of body mass of their hosts – cockroaches. This occurred despite increase in their living space (the midgut of cockroaches) and the longer period of consumption of gregarine oocysts from the environment with feed. No significant changes occurred in the number of gregarines *B. cubensis* with increase of the cockroaches' rates of feed consumption. However, there was a tendency towards higher numbers of this gregarine in the cockroach larvae whose body mass had been decreasing during the experiment. The greatest decrease in body mass during the experiment was in the cockroaches consuming biphenyl in the diet and that had the highest number of *C. cranifera* nematodes in the hindgut. No significant negative relationship was observed between the number of *B. cubensis* and *P. granulosae* gregarines. The cockroaches that had over 70 specimens of *B. cubensis* in the midgut, had no *P. granulosae* gregarines. In contrast, while the intestines of cockroaches were found to have 10–15 specimens of *P. granulosae*, some *B. cubensis* were almost always present. The number of nematodes of *C. cranifera* in the hindgut of the cockroaches did not correlate with the numbers of gregarines *B. cubensis* or *P. granulosae* in the hosts' midgut.

Gregarines did not compete with nematodes; neither died due to biphenyl, but the cockroaches ceased to normally accumulate mass subject to even low concentrations of this xenobiotic. That is, biphenyl did more harm to the host than its parasites, even in the lowest concentration of this xenobiotic we studied.

Conclusions

Xenobiotics affect populations of many insects, as well as their intestinal parasites. Parasites are simultaneously subject to the inhibiting action of their hosts' immune system and to toxic compounds entering the insects' intestines with food. In some hosts, ingress of xenobiotics helps the insects to get rid of their parasites, while in others the effects of xenobiotics benefit the parasites, which hence parasitize their hosts more effectively and inhibit their population. Unfortunately, there are very few in-depth studies of effects of xenobiotics on the host-parasites system. We hope that the experiment presented in this article would draw attention to this issue.

Analysis of the parasite-host system as an integral formation at the population level, in the gradient of influence of external factors, allows one to study the processes that will develop in artificial ecosystems – open agrocenoses and greenhouses, in laboratory cultures of insects. Supporting a balance in the parasitic systems is an issue that would probably be more relevant in the conditions of creating cultures of plants and insects outside the Earth's atmosphere: when creating artificial circulations of biogenic elements on the Moon, Mars, interplanetary space stations. Therefore, study of effects of xenobiotics on parasites and their hosts is of practical importance.

The authors declare no conflict of interests.

References

Adamson, M. L., & Van Waerebeke, D. (1992). Revision of the Thelastomatoidea, Oxyurida of invertebrate hosts I. Thelastomatidae. Systematic Parasitology, 21, 21–63.

Aron-Wisnewsky, J., Doré, J., & Clement, K. (2012). The importance of the gut microbiota after bariatric surgery. Nature Reviews Gastroenterology and Hepatology, 9(10), 590–598.

Bilan, M. V., Lieshchova, M. A., Tishkina, N. M., & Brygadyrenko, V. V. (2019). Combined effect of glyphosate, saccharin and sodium benzoate on the gut microbiota of rats. Regulatory Mechanisms in Biosystems, 10(2), 228–232.

Boyko, A. A., & Brygadyrenko, V. V. (2017). Changes in the viability of the eggs of *Ascaris suum* under the influence of flavourings and source materials approved for use in and on foods. Biosystems Diversity, 25(2), 162–166.

Boyko, O. O., & Brygadyrenko, V. V. (2019a). The impact of acids approved for use in foods on the vitality of *Haemonchus contortus* and *Strongyloides papillosus* (Nematoda) larvae. Helminthologia, 56(3), 202–210.

Boyko, O. O., & Brygadyrenko, V. V. (2019b). The viability of *Haemonchus contortus* (Nematoda, Strongylida) and *Strongyloides papillosus* (Nematoda, Rhabditida) larvae exposed to various flavourings and source materials used in food production. Vestnik Zoologii, 53(6), 433–442.

Boyko, O., & Brygadyrenko, V. (2022). Nematicidal activity of organic food additives. Diversity, 14, 615.

Brygadyrenko, V. V., & Reshetniak, D. Y. (2016). Morphometric variability of *Clitellocephalus ophoni* (Eugregarinida, Gregarinidae) in the intestines of *Harpalus rufipes* (Coleoptera, Carabidae). Archives of Biological Sciences, 68(3), 587–601.

Brygadyrenko, V. V., & Svyrydchenko, A. O. (2015). Influence of the gregarine *Stenophora julipusilli* (Eugregarinorida, Stenophoridae) on the trophic activity of *Rossiulus kessleri* (Diplopoda, Julidae). Folia Oecologica, 42(1), 10–20.

Clopton, R. E. (2002). Phylum Apicomplexa Levine, 1970: Order Eugregarinorida Leger, 1900. In: Lee, J. J., Leedale, G., Patterson, D., & Bradbury, P. C. (eds.). Illustrated guide to the Protozoa. 2nd ed. Society of Protozoologists, Lawrence, Kansas. Pages 205–288.

Clopton, R. E. (2010). *Protomagalhaensia cerastes* n. sp. (Apicomplexa: Eugregarinida: Blabericolidae) parasitizing the pallid cockroach, *Phoetalia pallida* (Dictyoptera: Blaberidae). Comparative Parasitology, 77, 117–124.

Clopton, R. E. (2011). Redescription of *Protomagalhaensia granulosae* Peregrine, 1970 (Apicomplexa: Eugregarinida: Blabericolidae) parasitizing the discoid cockroach, *Blaberus discoidalis* (Dictyoptera: Blaberidae). Comparative Parasitology, 78(1), 63–72.

Clopton, R. E. (2012a). Redescription of *Protomagalhaensia blaberae* Peregrine, 1970 (Apicomplexa: Eugregarinida: Blabericolidae) parasitizing the Bolivian cockroach, *Blaberus boliviensis* (Dictyoptera: Blaberidae). Comparative Parasitology, 79(2), 182–191.

Clopton, R. E. (2012b). Synoptic revision of *Blabericola* (Apicomplexa: Eugregarinida: Blabericolidae) parasitizing blaberid cockroaches (Dictyoptera: Blaberidae), with comments on delineating gregarine species boundaries. Journal of Parasitology, 98(3), 572–583.

Clopton, R. E., & Hays, J. J. (2006). Revision of the genus *Protomagalhaensia* and description of *Protomagalhaensia wolfi* n. comb. (Apicomplexa: Eugregarinida: Hirmocystidae) and *Leidyana haasi* n. comb. (Apicomplexa: Eugregarinida: Leidyanidae) parasitizing the lobster cockroach, *Nauphoeta cinerea* (Dictyoptera: Blaberidae). Comparative Parasitology, 73, 137–156.

Desportes, I., & Schrével, J. (2013). Treatise on zoology – anatomy, taxonomy, biology. The gregarines. In 2 vols. The early branching Apicomplexa. Brill.

Feinberg, M., Soler, L., Contenot, S., & Verger, P. (2011). Assessment of seasonality in exposure to dioxins, furans and dioxin-like PCBs by using long-term food-consumption data. Food Additives and Contaminants: Part A, 28(4), 502–512.

Goudey-Perrière, F., Lemonnier, F., Bergougnoux, V., & Perrière, C. (2007). Low doses of the pesticide lindane induce protein release by the fat body of female cockroach *Blaberus craniifer* (Dictyoptera). Comparative Biochemistry and Physiology Part C: Toxicology and Pharmacology, 146(4), 492–501.

Goudey-Perrière, F., Lemonnier, F., Perrière, C., Dahmani, F.-Z., & Wimmer, Z. (2003). Is the carbamate juvenoid W-328 an insect growth regulator for the cockroach *Blaberus craniifer* Br. (Insecta, Dictyoptera)? Pesticide Biochemistry and Physiology, 75, 47–59.

Griesbaum, K., Behr, A., Biedenkapp, D., Voges, H., Garbe, D., Paetz, C., Collin, G., Mayer, D., & Höke, H. (2012). Hydrocarbons. In: Ullmann's encyclopedia of industrial chemistry. Wiley-VCH, Weinheim. Pp. 168–171.

Grimm, F. A., Hu, D., Kania-Korwel, I., Lehmler, H. J., Ludewig, G., Hornbuckle, K. C., Duffel, M. W., Bergman, Å., & Robertson, L. W. (2015). Metabolism and metabolites of polychlorinated biphenyls. Critical Reviews in Toxicology, 45(3), 245–272.

Halkin, B. M., & Filipova, T. O. (2020). Biotransformacija ksenobiotikov mikrobiotoj zheludochno-kishechnogo trakta i ejo posledstvija dlia cheloveka [Biotransformation of the xenobiotics by microbiota of the gastrointestinal tract and its consequences for humans]. Microbiology and Biotechnology, 49, 6–23 (in Russian).

Koppel, N., Maini Rekdal, V., & Balskus, E. P. (2017). Chemical transformation of xenobiotics by the human gut microbiota. Science, 356(6344), eaag2770.

Kozak, V. M., Romanenko, E. R., & Brygadyrenko, V. V. (2020). Influence of herbicides, insecticides and fungicides on food consumption and body weight of *Rossiulus kessleri* (Diplopoda, Julidae). Biosystems Diversity, 28(3), 272–280.

Kulma, M., Kouřimská, L., Homolková, D., Božik, M., Plachý, V., & Vrabec, V. (2020). Effect of developmental stage on the nutritional value of edible insects. A case study with *Blaberus craniifer* and *Zophobas morio*. Journal of Food Composition and Analysis, 92, 103570.

Lambiase, S., Rasola, M., & Grigolo, A. (2004). Daily rhythm, ATP concentration and oxidative activity in an aposymbiotic strain of *Blaberus craniifer* Burmeister (Blattaria, Blaberidae). Italian Journal of Zoology, 71(4), 305–308.

Lange, C. E., & Lord, J. C. (2012). Chapter. 10. Protistan entomopathogens. In: Vega, F. E., & Kaya, H. K. (Eds.). Insect pathology. Second edition. Academic Press, Amsterdam. Pp. 367–394.

Lieshchova, M. A., Bilan, M. V., Bohomaz, A. A., Tishkina, N. M., & Brygadyrenko, V. V. (2020). Effect of succinic acid on the organism of mice and their intestinal microbiota against the background of excessive fat consumption. Regulatory Mechanisms in Biosystems, 11(2), 153–161.

Lieshchova, M. A., Tishkina, N. M., Bohomaz, A. A., Gavrilin, P. M., & Brygadyrenko, V. V. (2018). Combined effect of glyphosphate, saccharin and sodium benzoate on rats. Regulatory Mechanisms in Biosystems, 9(4), 591–597.

Lieshchova, M., Logvinova, V., Bilan, M., Bohomaz, A., & Brygadyrenko, V. (2023). Effect of azodicarbonamide on rats with a high-fat hypercaloric diet. Acta Fytotechnica et Zootechnica, 26(1), 15–27.

Martynov, V. O., & Brygadyrenko, V. V. (2017). The influence of synthetic food additives and surfactants on the body weight of larvae of *Tenebrio molitor* (Coleoptera, Tenebrionidae). Biosystems Diversity, 25(3), 236–242.

Martynov, V. O., & Brygadyrenko, V. V. (2018). The influence of the synthetic food colourings tartrazine, allura red and indigo carmine on the body weight of *Tenebrio molitor* (Coleoptera, Tenebrionidae) larvae. Regulatory Mechanisms in Biosystems, 9(4), 479–484.

Morffe, J., García, N., Véliz, L., Hasegawa, K., & Carreno, R. A. (2022). Morphological and molecular characterization of two species of nematodes (Oxyuridomorpha: Thelastomatoidea: Protrelloididae, Thelastomatidae) parasitic in the cockroach *Blaberus discoidalis* Serville (Blattaria: Blaberidae) from Cuba. Zootaxa, 5194(1), 92–108.

Parhomenko, O. V., Kolomiichuk, S. V., Omelianov, D. D., & Brygadyrenko, V. V. (2022). Potential use of synthetic and natural aromatic mixtures in prevention from *Shelfordella lateralis* cockroaches. Regulatory Mechanisms in Biosystems, 13(2), 174–179.

Parhomenko, O. V., Lagutenko, O. T., Lebedynets, N. V., & Brygadyrenko, V. V. (2023). Body-weight gains in *Blaberus craniifer* cockroaches and the intensity of their infection with gregarines and nematodes. Biosystems Diversity, 31(3), 368–375.

Schecter, A., Colacino, J., Haffner, D., Patel, K., Opel, M., Päpke, O., & Birnbaum, L. (2010). Perfluorinated compounds, polychlorinated biphenyls, and organochlorine pesticide contamination in composite food samples from Dallas, Texas, USA. Environmental Health Perspectives, 118(6), 796–802.

Sender, R., Fuchs, S., & Milo, R. (2016). Revised estimates for the number of human and bacteria cells in the body. PLoS Biology, 14(8), e1002533.

Smith, A. J., & Cook, T. J. (2008). Host specificity of five species of Eugregarinida among six species of cockroaches (Insecta: Blattodea). Comparative Parasitology, 75(2), 288–291.

Tanada, Y., & Kaya, H. K. (1993). Insect pathology. Academic Press, San Diego.

Yanovych, D. O., & Yanovych, N. E. (2011). Biotransformatsija ksenobiotykiv i mekhanizmy yiyi rehulyatsiyi [Biotransformation of xenobiotics and mechanisms of its regulation]. Scientific Bulletin of the LNUVMBT named after S. Z. Gzhitskyi, 48(2), 305–311 (in Ukrainian).