FUNCTIONAL AND ECOLOGICAL ADAPTATIONS OF SEVERAL ACARIDID MITE SPECIES (ACARIFORMES, ASTIGMATA) FOR FEEDING ON STORED PRODUCE

I. A. Akimov[1], Ya. R. Oksentyuk[2]

[1]*Schmalhausen Institute of Zoology, NAS of Ukraine,*
vul. B. Khmelnytskogo, 15, Kyiv, 01030 Ukraine
E-mail: akimov@izan.kiev.ua
[2]*Zhytomyr Ivan Franko State University,*
Pushkinska st., 42, Zhytomyr, 10008 Ukraine
E-mail: oksentyuk_ya@ukr.net

Functional and Ecological Adaptations of Several Acaridid Mite Species (Acariformes, Astigmata) for Feeding on Stored Produce. Akimov, I. A., Oksentyuk, Ya. R. —The ability of several acaridid species to colonize and feed in different nutritional substrates, such as grain crops, oil seeds, damaged vegetables, mixed fodder, hay and straw from the mangers and litter of livestock keeping places, litter, ambrosia and dead bees from beehive bottoms, is investigated. Species-specific differences in indices of domination and occurrence, and of Sørensen and Jaccard coefficients of similarity of species compositions on different substrates are related not only to the nutritional inequality of these substrates, but also to the mite ability to grind them and to absorb these substrates through intracellular, contact and cavitary digestion using certain hydrolytic enzymes.

K e y   w o r d s : Acariformes, Astigmata, feeding substrates, domination index, occurrence index, Sørensen and Jaccard similarity coefficients.

Introduction

The problem of acaridid mite species using specific feeding substrates is quite complicated. Mite-inhabited substrates are indicated in ecological studies (Zakhvatkin, 1941; Hughes, 1959, 1961), however, acaridids do not necessarily feed on all components of those substrates. Microscopic mites such as acaridids usually can choose the most suitable component. Acaridid mites are known to prefer grain embryos, the most nutritional part of the grain (Akimov, 1985). However, determining the feeding habits of mites in certain substrates is not always possible and presents an interesting problem. In this study, we address it using our data and considering results of previous morphofunctional and biochemical studies of mites (Erban, Hubert, 2012; Erban et al., 2015). Feeding habits of acaridid mites are also important from the economical standpoint. Acaridids not only partly destroy the stored produce; they pollute it with allergenic feces and exuviae.

Our study was aimed to:

– study the distribution and harmfulness of several common acaridid species as barn pests in Zhytomyr Polissia;

– analyze the feeding ability of several species according to consistency, nutritive and chemical properties of the feeding substratesbased on morphofunctional and physico-biochemical specifics of their digestive systems;

– identify possible synanthropic trends (including long-term harmfulness) of certain not synanthropicacaridid mites.

Material and methods

Samples were collected in 2014–2017 in beehives, mangers and litter from livestock keeping places, farm buildings and granaries, mills, fodder producing plants, and vegetable storages of Zhytomyr Polissia (Zhytomyr and Rivne Regions). Wheat, rye, barley, oats, corn and oilseed rape, flax, and sunflower stocks were also sampled, as well as litter, ambrosia and dead bees from beehive bottoms, hay and straw, mixed fodder, and (especially spoiled) vegetable crops. Mites were manually removed from the substrate under a dissecting microscope using a dissecting needle with a drop of Hoyer's liquid. For mass quantitative collection, the Berleze-Tullgren funnels were used. For species identification, acaridid mites were mounted on microslides in Hoyer's liquid (Giliarov, 1975). Altogether 2000 permanent slides were prepared, and more than 12,834 mite specimens were identified.

The data were statistically processed. Index of occurrence (Is, %) (Pesenko, 1982) and Paliy-Kovnatsky index of domination for individual species in samples (Di, %) were calculated. By domination index, mites ranged as follows: more than 10 % — eudominant species; 1 to 10 % — dominant species; 0.1 to 1 % — subdominant species; up to 0.1 % — secondary species (Shitikov et al., 2003, names of ranges are modified for convenience). Mite communities of nutritional substrates were compared using Sørensen (Qs) and Jaccard (Kj) coefficients of similarity (Pesenko, 1982) and using cluster analysis based on Ward's method in PAST software, version 1.65 (Hammeret al., 2001). Density of acaridid mites was determined in grain and fodder only, because volume of those substrates could be measured.

Results and discussion

Altogether, representatives 30 acaridid species from five families were identified in the samples (table 1).

In **oil** seeds, 15 acaridid species were found (table 1). Of them, only *T. putrescentiae* and *A. siro* were eudominant in these substrates. *Tyrophagus molitor, A. farris*, *Gl. destructor*, *Gl. domesticus* and *T. perniciosus* were the dominant species there. The next group, subdominant species consisted of *T. humerosus, A. tyrophagoides*, and *T. longior*. Secondary (in those communities) species included *S. nesbiti, T. casei, T. formicetorum, N. sokolovi*, and *Gl. fustifer*. The highest value of occurrence index (Is) was observed for *Gl. domesticus*. As can be seen from table 1, *A. siro* and *T. putrescentiae* were most numerous, and *S. nesbiti, T. casei, T. formicetorum, N. sokolovi* were least common in those substrates.

Acaridid community of **grain** crops was the most diverse and included 17 species (table 1). *Glycyphagus destructor* and *Gl. domesticus* were eudominant, only *A. siro* was a dominant species. Subdominant species were absent, and there were 14 secondary species: *Gl. fustifer, A. farris, T. putrescentiae, T. casei, G. fusca, Ch. arcuatus, T. molitor, Gl. burchanensis, T. perniciosus, Gl. michaeli, A. tyrophagoides, T. mixtus, Gl. pilosus*, and *S. nova*. Highest occurrence values were also observed for *Gl. destructor* and *Gl. domesticus*. Of the 17 acaridid species of that community, highest density was found for *Gl. destructor* and *Gl. fustifer*, while *T. mixtus, S. nova* and *Gl. pilosus* were the least numerous.

The complex of acaridid species found in the studied **fodder** samples was the least diverse. That is rather surprizing because that substrate is rich in nutrients for livestock. A possible reason was the freshness of the stored produce. We found there only three species, *Gl. destructor, A. siro* and *Gl. domesticus*. Their occurrence (Is) was 100 % (table 1), however the mites were not numerous in samples.

Samples of **hay** and **straw** contained 12 acaridid species (table 1). Three of them were eudominant (*Gl. domesticus, A. siro* and *Gl. destructor*). There were no dominant species in that community; subdominant species included *A. farris, T. humerosus, A. tyrophagoides, T. molitor, G. fusca, Gl. burchanensis* and *M. fungivorus*. Secondary species there were

Table 1. Acaridid mites of studied feeding substrates

Family	Species	1 Di, %	1 Is, %	1 V	2 Di, %	2 Is, %	2 V	3 Di, %	3 Is, %	3 V	4 Di, %	4 Is, %	5 Di, %	5 Is, %	6 Di, %	6 Is, %
Suidasiidae	*Suidasia nesbiti* Hughes, 1948	0.027	20	0.002												
Acaridae	*Acarus siro* Linnaeus, 1758	19.6	60	0.16	3.35	38.8	0.041	36.8	100	0.014	26.5	62.5	0.027	26.7	0.12	20
	Acarus farris (Oudemans, 1905)	5.1	40	0.094	0.034	10.45	0.006				0.7	25				
	Acarus tyrophagoides Zachvatkin, 1941	0.37	40	0.007	0.0037	4.48	0.003				0.11	25				
	Mycetoglyphus fungivorus Oudemans, 1932										0.1	25			0.45	20
	Tyrolichus casei Oudemans, 1923	0.027	20	0.002	0.011	5.97	0.0055									
	Tyrophagus putrescentiae (Schrank, 1781)	13.11	60	0.107	0.049	16.42	0.0035				0.09	12.5	0.054	20		
	Tyrophagus molitor Zachvatkin, 1941	8.39	60	0.0069	0.021	10.45	0.0034				0.11	25	0.007	6.7	0.02	20
	Tyrophagus perniciosus Zachvatkin, 1941	1.54	60	0.013	0.0037	4.48	0.003						0.12	33.3	0.07	20
	Tyrophagus humerosus Oudemans, 1941	0.27	40	0.005							0.3	25				
	Tyrophagus longior (Gervias, 1844)	0.11	20	0.008									0.015	6.7		
	Tyrophagus formicetorum Volgin, 1948	0.027	20	0.002												
	Tyrophagus mixtus Volgin, 1948				0.0003	1.49	0.002									
	Schwiebea nova (Oudemans, 1906)				0.0003	1.49	0.002									
	Neoacotyledon sokolovi Zachvatkin, 1940	0.027	20	0.002											14.7	80
	Sancassania berlesei (Michael, 1903)														22.75	80
	Sancassania sphaerogaster (Zachvatkin, 1937)														15.5	80
	Sancassania rodionovi (Zachvatkin, 1935)														1.34	60
	Sancassania mycophagus (Megnin, 1874)														0.04	20
	Sancassania oudemansi (Zachvatkin, 1937)														0.02	20
	Rhizoglyphus echinopus (Fumouze & Robin, 1868)														0.21	40

Continued table 1.

Family	Species	Feeding substrate																
		1			2			3			4		5		6		
		Di, %	Is, %	V	Di, %	Is, %	V	Di, %	Is, %	V	Di, %	Is, %	Di, %	Is, %	Di, %	Is, %	
Glycyphagidae	*Glycyphagus domesticus* (De Geer, 1778)	4.88	80	0.023	19.98	68.66	0.079	21.1	100	0.008	36.4	100	18.7	93.3	3.07	80	
	Glycyphagus destructor Schrank, 1781	4.07	60	0.03	44.49	74.63	0.15	42.1	100	0.016	12	87.5	72.6	93.3	0.5	40	
	Glycyphagus fustifer (Oudemans, 1903)	0.05	20	0.004	0.041	5.97	0.21						0.013	13.3			
	Glycyphagus burchanensis Oudemans, 1903				0.0037	4.48	0.003				0.1	25					
	Glycyphagus michaeli Oudemans, 1903				0.0017	1.49	0.014				0.04	12.5					
	Glycyphagus pilosus (Oudemans, 1906)				0.0003	1.49	0.002										
	Gohieria fusca Oudemans, 1902				0.017	4.48	0.015				0.11	12.5					
Chortoglyphidae	*Chortoglyphus arcuatus* (Troupeau, 1879)				0.003	1.49	0.022										
Aeroglyphidae	*Aeroglyphus peregrinans* (Berlese, 1892)												0,57	60			
Total		15			17			3			12		9		13		

N o t e . Is — index of occurrence; Di — Paliy-Kovnatsky index of domination; V — density.* 1 — oilseed crops; 2 — grain; 3 — fodder; 4 — hay and straw; 5 — litter, dead bees and ambrosia from beehive bottoms; 6 — spoiled vegetable crops (root and tuberous crops).

T. putrescentiae and *Gl. michaeli*. As for occurrence, only *Gl. domesticus* was was present in all samples of that substrate.

Acaridid community of **beehives** is comprized of nine species (table 1). Two species, *Gl. destructor* and *Gl. domesticus* were eudominant in the studied samples of ambrosia, litter and dead bees. No dominant species were observed in those samples. Two species, *A. peregrinans* and *T. perniciosus* were subdominant. This is the first find of *A. peregrinans* in beehives in Ukraine. Previously it was recorded as a pest in nests of *Xylocopa* bees in rotten wood (Khaustov, 2012). The species *T. putrescentiae, T. longior, Gl. fustifer, T. molitor* and *A. siro* were secondary in that community. Most samples contained representatives of *Gl. destructor* and *Gl. domesticus*.

On spoiled **root** crops we found representatives of 13 acaridid species. *Sancassania berlesei, S. sphaerogaster,* and *N. sokolovi* were eudominant in that community. Dominant species included *Gl. domesticus* and *S. rodionovi*, while *Gl. destructor, M. fungivorus, Rh. echinopus* and *A. siro* were subdominant. *Sancassania mycophagus, S. oudemansi, T. perniciosus*, and *T. molitor* were secondary there. High occurrence values were observed for *Gl. domesticus, S. berlesei, S. sphaerogaster,* and *N. sokolovi*.

A lot of acaridid species were found in several nutritive substrates (table 1). *Acarus siro, Gl. destructor* and *Gl. domesticus* were observed in samples from all substrates. The species *T. molitor* was common in all substrates except fodder. Those species are polyphagous and differ in dominance and occurrence rates in various substrates. According to our data, only four to five acaridid species are common pests of produce in Zhytomyr Polissia (table 1). The species are possibly ecologically and physiologically preadapted to the best storing conditions for the produce. They can be considered synanthropic because their harmfullness and colonization of new portions of produce are aided by human agricultural activity. Several of those species were found only in one substrate type. For example, *S. nesbiti* and *T. formicetorum* were found in oilseeds. *Tyrophagus mixtus, S. nova, Gl. pilosus* and *Ch. arcuatus* were obtained only from grain crops of long-term storage (table 1). Acaridid community of beehives was the only one with *A. peregrinans*. Acaridid species composition of spoiled vegetables included six otherwise not found species: *S. berlesei, S. oudemansi, S. rodionovi, S. sphaerogaster, S. mycophagus* and *Rh. echinopus* (all from the subfamily Rhizoglyphinae). Samples of fodder, hay and straw were not characterized by substrate-specific acaridid mites. As for the pest density in the studied substrates, it was highest in nutrition-rich substrates such as grain crops (17) and oilseeds (15), and on spoiled vegetables (13) due to acaridids' mycophagy on microscopic fungi.

Acaridid communities of different substrates were also compared using Sørensen and Jaccard coefficients (table 2). Maximum similarity values were observed for acaridid complexes of grain crops and their derivatives, hay and straw (Qs = 0.69; Kj = 0.53), and for oilseeds and beehive substrate (Qs = 0.67; Kj = 0.5). Species composition of acaridid mites

T a b l e　2. Similarity of studied acaridid comminities (Sørensen and Jaccard coefficients)

Sørensen coefficient of similarity

	1	2	3	4	5	6
1		0.63	0.33	0.59	0.67	0.43
2	0.45		0.3	0.69	0.54	0.33
3	0.2	0.18		0.4	0.5	0.38
4	0.42	0.53	0.25		0.48	0.4
5	0.5	0.37	0.33	0.31		0.45
6	0.27	0.2	0.23	0.25	0.3	

Jaccard coefficient of similarity

N o t e . Hereafter: 1 — oilseed crops; 2 — grain crops; 3 — fodder; 4 — hay and straw; 5 — litter, dead bees and ambrosia from beehive bottoms; 6 — spoiled vegetables.* Number of acaridid species found in the substrate is given in tinted cells.

in spoiled vegetables is most similar to that of beehive substrates (Qs = 0.45; Kj = 0.3). Fodder acaridid community is also most similar to that of beehives (Qs = 0.5; Kj = 0.33).

Species composition of mite communities in substrates was then compared using cluster analysis. The dendrogram is given on fig. 1. There are two well-supported clusters indicating higher similarity of species compositions: in hay, straw and grain crops, and in other substrates. Interestingly, communities of grain crops and derivative substrates also diverge with rather high boot-strap support (61 %).

The species compositions of acaridid communities in various substrates may differ due to many factors. Those include nutritional value, hardness and state of aggregation of studied substrates, morpho-functional specifics of acaridid mouth parts, pre-treatment of food particles in the digestive system and the digestion itself, presence of certain hydrolases and conditions that regulate their activity. There are also the effects of interspecific competition. Certain species usually remain after the most active synanthropic pests leave the substrate. At that time, the substrate is poor in nutrients so that the remaining species do not become the most influential pests. For example, *Ch. arcuatus* and *G. fusca* are known to inhabit long-term stored produce and are not considered common pests here or in other studies.

According to data on structure and function of mouthparts in several acaridid species (Akimov, 1985), certain morphofunctional types of mouthparts can be assigned based on adaptations to pre-treatment and adsorption of food particles. For example, acaroid type of mouth parts is adapted to active mechanical grinding of substrate with chelicerae and acute prostomal teeth. In that case, the cheliceral claws have rather acute teeth that can damage whole grain, which is only typical of mites with that type of mouthparts.

A modification of the acaroid mouthparts type is rhisoglyphoid type, characterized by the presence of comb-like processes on the ventral surface of the epipharynx which have, in our opinion, a filtration function (Akimov, 1985). Rhisoglyphoid mouth type, typical for representatives of the subfamily Rhisoglyphinae, is adapted to a humidified, sometimes almost liquid substrate. The mouth parts grind and bite off food pieces just as the acaroid mouth parts with cheliceral claws.
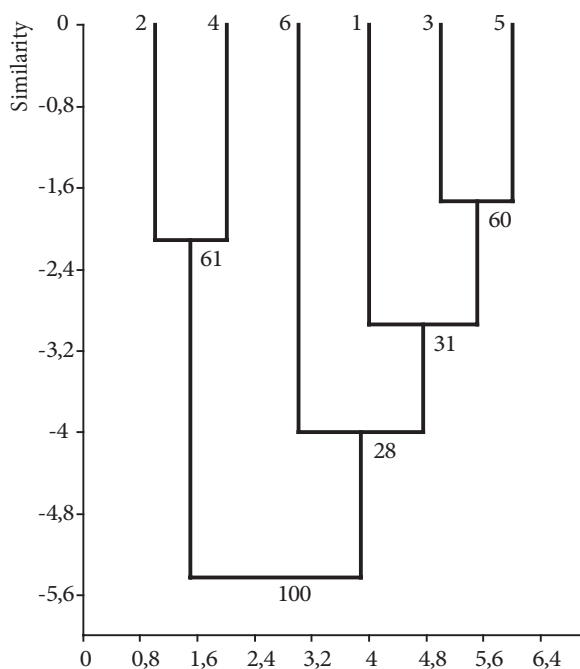

Fig. 1. Cluster analysis of similarity of acaridid complexes in studied substrates (Ward's method, correlation coefficient 0.5844).

The organs of glycyphagoid mouth parts type, characteristic of Glycyphagidae mites, are not adapted to biting off pieces of food. Prostomal teeth here are membranized and do not play a role in food grinding. However, they have powerful clawed chelicerae with blunt teeth that mechanically grind food particles by crushing them. Glycyphagidae can damage only a variety of already crushed grains and grain-based produce (cereals). These mites mostly eat the small grain parts and pieces (Akimov, 1985). Thus, moist spoiled vegetables are mostly damaged by species with glycyphagoid mouth parts. The following digestion of food particles occurs in the mite gut (Akimov, 1985). Unlike many Chelicerata, especially ticks with intracellular digestion (Balashov, 1982), acaridid mites can also digest relatively large food particles covered by peritrophic membrane in their gut (Hughes, 1959; Brody, 1972; Akimov, 1971) and are capable of parietal digestion (Akimov, 1985). Thus they also may significantly damage the stored produce.

It should be noted that acaridid mites can chemically pre-treat food with enzymes excreted with their feces. This is easily seen in live mite cultures which moisten their substrates.

There are a lot of hydrolytic enzymes (amylase, cellulase, invertase, chitinase etc.) in acaridid mites (Akimov, 1985; Erban, Hubert, 2012, etc.). Amylase is one of the most active enzymes, especially so in *A. siro* mites. This is the possible link between their polyphagy and dominance in the acaridid community. Carbohydrases (including amylase and invertase) are significantly more active compared to other enzymes of that species (Akimov, 1965). Thus this species should be considered one of the most specialized granivorous species, which prefers carbohydrates. Rather high activity is also found in chitinases of *S. berlesei* and *Rh. echinopus* (Akimov, 1985), which may be connected to their feeding on yeast and other microscopic fungi.

Hence, analysis of the compiled data on acaridid pests allows us to understand the acaridid species-level specifics of substrate colonization. Most of studied mite species are polyphagous. That polyphagy, however, is based on various and unequally active functional and structural specifics of their digestive systems. Moreover, in our opinion that allows several relatively different species to co-habitat one relatively wide trophic niche. It is clearly demonstrated by the successions of acaridid species in the course of depletion and aging of nutritional substrates. In time those substrates are colonized by species able to digest cell-wall polysaccharides and substrates, vastly poor in nutrients (Akimov, 1985; Erban, Hubert, 2012).

Also, the synanthropic species such as *A. siro*, *Gl. destructor* and *Gl. domesticus* are relatively plastic because they were found in all studied substrates.

Analysis of acaridid communities in natural and anthropogenic stored substrate resulted in two equal groups of species. As previously noted, four to five species (*A. siro, Gl. destructor, Gl. domesticus,T. putrescentiae, T. molitor*) are known as barn pests. Other species prefer naturally stored nutritional substances. Thus it is unsurprizing that species that prefer conditions resembling those of barns, storages and other concentrated mite substrates are common pests, easily infecting new portions of substrates. These species are usually considered synanthropic. There also are mites that colonize antropogenic stored substrate but are naturally concentrated elsewhere. This group includes *A. peregrinans, A. farris, M. fungivorus,* etc. They are the reserve of barn pests.

The constant access to stored produce induces the development of synanthropy. This is especially possible in unstable environmental conditions (global climatic changes, oscillating humidity, etc.).

Conclusions

1. In Zhytomyr Polyssia, 30 species of saprophagous acaridid mites were observed, including both synantropic barn pests (*Acarus siro, Tyrophagus putrescentiae, Glycyphagus*

domesticus, Gl. destructor), and species usually found inhabiting naturally accumulated organic matter or facultatively spoiling stored produce.

2. Most of those acaridid mites are polyphagous. In various substrates, their communities are highly similar by species composition yet not by species-specific dominance and density.

3. The recorded species exhibited certain substrate preferences. For example, all acaridid mites prefer nutritional substrates and damage grain embryos before they damage endosperm. Several species such as *T. putrescentiae* leave the nutritional substrate immediately upon depletion. Acaridids living in depleted, usually decaying substrates (vegetables, etc.), such as species of the subfamily Rhizoglyphinae, feed on the hyphae and sporangia of more nutritious fungi, yeast and mold.

4. Communities of acaridid mites in naturally and artificially accumulated organic matter undergo certain successions. Only the species capable of feeding on the unused poor nutritional substances remain in aged substrates. That was demonstrated in several studies (including those by one of the co-authors) of digestive physiology of mites. In those, several polyphagous acaridid species were observed to digest cell-wall polysaccharides (cellulose, chitin, etc.).

5. Natural accumulation of nutritional substrates with characteristic acaridid species are a prerequisite for several of those species to becoming synanthropic barn pests in suitable environmental conditions. There are a few species which demonstrate that already, for example, *A. peregrinans*, *T. molitor*, etc.

References

Akimov, I. A. 1971. Morphological and physiological peculiarities of alimentary canal of bulb mite *Rizoglyphusechinopus* (Ful. et Rob.). *In*: Abstract 3d Intern. Congress of Acarology. Prague, 31 August 1971. Academia, Prague, 5 [In Russian].

Akimov, I. A. 1985. *The biological aspects of harmfulness of acaroid mites*. NaukovaDumka, Kiev, 1–157 [In Russian].

Balashov, Y. V. 1982. *Parasite-host relations of arthropods and terrestrial vertebrates*. Nauka, Leningrad, 1–318 [In Russian].

Brody, A. R., McGrath, J. C., Wharton, G. W. 1972. Dermatophagoides farinae: The digestive system. J*ournal of the New York Entomological Society*, 3, 152–177.

Erban, T., Hubert, J. 2012. Digestive physiology of synanthropic mites (Acari: Acaridida). *Entomological Studies*, 1, 1–32.

Erban, T., Rybanska, D., Hubert, J. 2015. Population Growth of the Generalist Mite *Tyrophagus putrescentiae* (Acari: Acaridida) Following Adaptation to High- or Low-Fat and High- or Low-Protein Diets and the Effect of Dietary Switch. *Environ. Entomol.,* 44,1599–1604. DOI 10.1093/ee/nvv129

Giliarov, M. S. 1975. *Key of soil Sarcoptiformes*. Nauka, Moscow, 416–476 [In Russian].

Hammer, Ø., Harper, D. A. T., Ryan, P. D. 2001. PAST: Paleontological statistics software package for education anddata analysis. *Palaeontologia Electronica,* **4** (1), 1–9 (https://palaeo-electronica.org/2001_1/past/past.pdf).

Hughes, T. E. 1959. *Mites or the Acari*. Athlon press, London, 1–227.

Hughes, A. M. 1961. The mites of stored food. Ministry of Agriculture. *Fisheries and Food. Technical Bulletin.* London, 9, 1–287.

Khaustov, A. A. 2012. Mites of the families Chaetodactylidae and Aeroglyphidae (Acari: Astigmata), phoresing on bees of the genera *Xylocopa* (Hymenoptera: Apidae: Xylocopinae*)* and *Osmia* (Hymenoptera: Megachilidae) in the Nature Reserve "Mys Martian". *Nauchnye zapiski prirodnogo zapovednika "Mys Martian"*, 3, 177–179 [In Russian.]

Pesenko, Yu. A. 1982. *Principles and methods of quantitative analysis in faunistic studies*. Nauka, Moscow, 1–281 [In Russian].

Shitikov, V. K., Rosenberg, G. S., Zinchenko, T. D. 2003. *Quantitative hydroecology: methods of system identification*. IEVB RAN, Tolyatti, 1–463 [In Russian].

Zakhvatkin, A. A. 1941. *Arachnoidea*. U.S.S.R. Academy of Sciences, Moscow, Leningrad, **4** (1), 1–474 [In Russian.]