Acarology: from taxonomy to biological control

NKFIH Research Proposal (108663)

Final report

Background

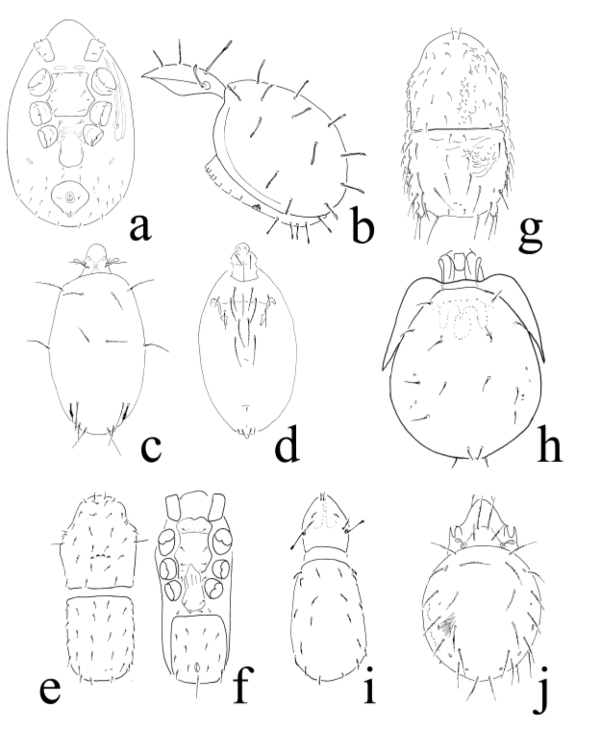
The mites are one of the most diverse groups of animals, they can be found in the soils, on plants, in all freshwater and marine habitats, and as external and internal parasites of plants and animals. Yet, due to their small size (usually less than 1 mm in length) people rarely see them. The mites are the most ancient fully terrestrial animals, with fossils known from the early Devonian, nearly 400 million years ago (Norton et al. 1988, Kethley et al. 1989). As a group, mites can do almost anything, be predators, parasites, herbivores, fungivores and detritivores. Regarding the latter, several groups have an important role in the decomposition of the leaf litter, thus forming soil (Krantz & Walter 2009). Nearly half the Acari species associate with plants and other animals. They can be found on plants, from the canopy level of the rainforests to the mosses on the soil surface, they can be pests of crops and tree crops. Therefore many mites have economic importance (Gerson & Smiley 1990) and are one of the most important pests (e.g., spider mites, false spider mites) in agricultural areas. Predatory mites are also useful biocontrol agents, especially the family Phytoseiidae (McMurtry & Croft 1997). Current acarological research usually focuses on the discovery and describing of new species (Xue & Zhang 2008), presenting results of taxonomic and systematic investigations. Groups of economic importance are mostly investigated from taxonomic importance pint of view. Taxonomic research of these groups can lead to the development of new biocontrol agents, and the improvement of diagnostics of pest species, which provides quarantine with the necessary tools to detect exotic species.
This project focused on three large study areas. Namely, (1) mite diversity of agricultural areas, (2) development of identification keys of agricultural mites and (3) mites as biological control.

<u>Mite diversity of agricultural areas</u>

Soil dwelling mites

Species composition of soil dwelling mites inhabiting agricultural areas are very poorly investigated in Hungary as well as in the neighbouring countries. The diversity and the role of the mesostigmatan mites are discussed in Karg (1968, 1978, 1986, 1993), Koehler (1997) and Wissuwa et al. (2012), but our knowledge on other soil dwelling mites of orchards, fields, private gardens is insufficient. In addition, several mite species have significant role as part of the soil animal community, particularly as biological control agent against nematodes, insect larvae and fungi. Furthermore, they are important in decomposing dead plant materials. Altogether 38 mite species were collected in different agroecosystems in Hungary. Among them, 23 species belong to the suborder Mesostigmata, 13 to Oribatida, one to Astigmata and one to Prostigmata. Nine species [*Alliphis halleri* (G. and R. Canestrini, 1881), *Antennoseius avius* Karg, 1976; *Antennoseius pannonicus* Willmann, 1951; *Arctoseius eremitus* (Berlese, 1918); *Cheiroseius bryophilus* Karg, 1969; *Leioseius insignis* (Hirschmann, 1963); *Oppiella loksai* (Schalk, 1966); *Punctodendrolaelaps fimetarius* (Karg, 1965); *Rhodacarellus perspicuus* Halaśkova, 1958] were found to be new to the Hungarian fauna. Seventeen species were collected in alfalfa plantations, ten in maize fields and nine in cereal fields. Four species

were found in oilseed rape fields and five in apple orchard. Two species occurred in garden soil, three in compost hill and sunflower plantation, and two in the studied pasture. The most frequent mesostigmatan species was the *Alliphis halleri* species which occurred in maize, cereal, alfalfa plantations and garden soils. *Rhysotritia ardua* was the most frequently collected oribatid mite in the studied agroecosystems. Further common species in soils of agricultural fields were *Arctoseius cetratus*, *Arctoseius venustulus* and *Bakerdania exigua*. The mesostigmatan *Alliphis halleri*, was the most common in the studied agroecosystems; this species was found in nine different plantations in Hungary. Koehler (1997) and Wissuwa et al. (2012) presented another *Alliphis* species (*A. siculus* Oudemans, 1905) from the agricultural soils, which may be a misidentification of the *A. halleri* (see Halliday, 2010). Two *Arctoseius* species (*A. venustulus* and *A. cetratus*) were collected in several different fields and plantations in the investigated agroecosystems.
These species are very common in the disturbed habitats, such as agricultural soils (Koehler 1997; Wissuwa et al., 2012). Most mesostigmatans feed on nematodes and small insect larvae in the soil, which can be very frequent in the agricultural soils. The oribatid mites have important role in the decomposition of dead plants and in the soil formation. They usually can feed on decaying plant material and organic matters in the agricultural soils. Agricultural soils usually are poor in the organic material; therefore the species number and the frequency of the oribatid species are lower than mesostigmatans. The species *Rhysotritia ardua* was collected in higher number in the studied agroecosystems, this species usually occurs in other unstable habitats and other plantations (Kontschán et al., 2015) as well. The pygmephorid, *Bakerdania exigua* species are discovered and described from Hungary by Mahunka (1969), therefore it was a surprise that this rare species occurred very often in the agricultural soils. The most species rich plantation was the alfalfa fields with 17 collected species. The alfalfa plantation elevates the nitrogen content in the soils; this effect can have an important role in the mite diversity of agricultural soils.



Some soil dwelling mites from Hungarian agroecosystems: a: *Alliphis halleri* (R. & G. Canestrini, 1881), b: *Rhysotritia ardua* (C. L. Koch, 1841), c-d: *Bakerdania exigua* (Mahunka, 1969), e-f: *Rhodacarellus perspicuous* Halaśkova, 1958, g: *Asca bicornis* (Canestrini & Fanzago, 1887) dorsal view, h: *Peloptulus phaenotus* (C.L. Koch, 1844), i: *Epilohmannia stiriaca* Schuster, 1960, j: *Tyrophagus longior* (Gervais, 1844).

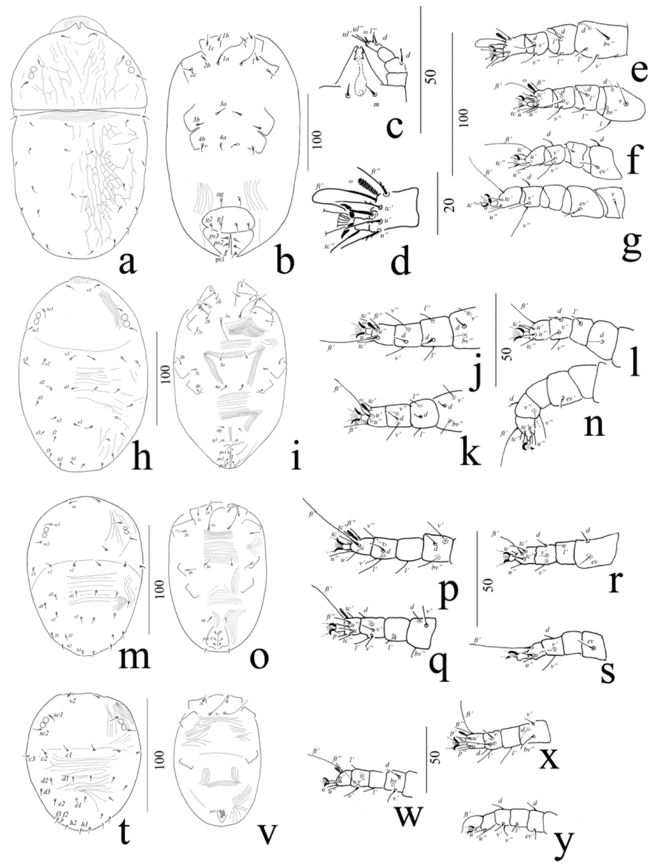
Numerous new and poorly known species can live in tropical agricultural soils. I described new species and I reported poorly known species from *Cryptomera japonica*, Monterey pine, cocoa, banana, bamboo, coffee plantations from Asia and from South-America. The known species found were listed earlier only from natural habitats of the these realms. These are usually common species, but there is very few information about their habitat preferences. It might be true also for soil dwelling mites that some tropical agricultural areas are good refuges for these species. Thus, these areas contribute significantly to their biodiversity (Gobbi 2000, Perfecto *et al.* 1996, Schrot & Harvay 2007).

The exotic and introduced mite species, *Holaspina alstoni* (Evans, 1956), from the family Parholaspididae Evans, 1956 was collected in soils of three different Hungarian greenhouses. This was the first record of this family, genus and species in Hungary. This species was collected in natural habitats only in East- and South-Asia and in the Middle-East. In Europe, it was found only in greenhouses of botanical gardens; therefore the parholaspidid mites in Central Europe are certainly introduced by human soil transport. The colonization of the natural habitats by the parholaspidid mites in Central Europe seems to be implausible, because the climate is probably not acceptable for these species; therefore they find suitable habitats only in the warm and wet greenhouses. Similarly to the other parholaspidid mites, *H. alstoni* is also a fast moving predatory mite, similar to native macrochelid, veigaiaid or parasitid mesostigmatan mites, which can feed on other mites and springtails in the soil of greenhouses.

Mites inhabiting plants

Spider mites and flat mites

The Hungarian mite fauna seems to be relatively well-known (Horváth et al., 2010), but numerous groups are found in our knowledge, for example some groups of the order Trombidiformes. During this project years several poorly known, but large and easily recognizable phytophagous and pest mite species are discovered in Hungary. Due to the intensively study, a revised species list was made for tenuipalpids and tetranychids. Furthermore, numerous doubtful data were deleted. The following species are not members of the Hungarian fauna, Tenuipalpidae: *Aegyptobia beglarovi* Livsic & Mitrofanov, 1967, *Brevipalpus russulus* (Boisduval, 1867), *Tenuipalpus rosae* Kadzhaja, 1955; Tetranychidae: *Bryobia alpina* Mathys, 1962, *Bryobia kakuliana* Reck, 1956, *Bryobia lonicerae* Reck, 1956, *Panonychus citri* (McGregor, 1916), *Petrobia apicalis* Banks, 1917 and *Tetranychus spireae* Reck, 1948.

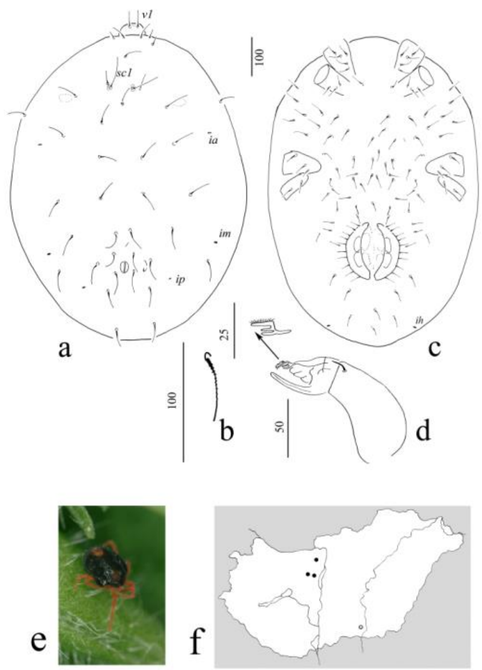


Aegyptobia bozaii **Kontschán & Ripka, 2018, *female* a) dorsal view, b) ventral view, c) gnathosoma in ventral view, d) tasus of leg I, e) leg I, e) leg II, f) leg III, g) leg IV, *deutonymph*: h) dorsal view, i) ventral view, j) leg I, k) leg II, l) leg III, n) leg IV, *protonymph*: m) dorsal view, o) ventral view, p) leg I, q) leg II, r) leg III, s) leg IV, *larva*: t) dorsal view, v) ventral view, w) 1 leg I, x) leg II, y) leg III.**

The following new pest spider mite species were recorded in first time from Hungary: *Bryobia ulmophila* Reck, 1947; *Petrobia harti* (Ewing, 1909); *Eurytetranychus latus* (Canestrini & Fanzago, 1876), *Platytetranychus thujae* (McGergor, 1950); *Platytetranychus libocedri* (McGregor, 1936, *Schizotetranychus bambusae* Reck, 1941 and *Stigmaeopsis nanjingensis* (Ma & Yuan, 1980).
The systematic position of the following species are revised with new morphological description: *Tenuipalpus pacificus* Baker, 1945; *Petrobia latens* (Müller, 1776).
A new tenuipalpid mite species, *Aegyptobia bozaii* Kontschán & Ripka, 2018 is described from Central-Hungary. This species was collected on leaves of the endemic Hungarian statice *Limonium gmelinii* subsp. *hungaricum* (Plumbaginaceae), and was described based on females, nymphs and larva. The previously described endemic flat mite, *Tenuipalpus szarvasensis* Bozai, 1970 was redescribed. This species had been treated as a junior synonym of *Tenuipalpus cheladzeae* Gomelauri, 1960, but our new investigation shows that the two species are different. Several new occurrences were published together with a key to the Hungarian tenuipalpids and tetranychids. On the basis of the updated list, the Hungarian fauna contains 21 tenuipalpid and 37 tetranychid species.
The number of the spider mites (37) and flat mites (21) will surely increase in the future. In the last five years, six species were collected for the first time in Hungary, and the majority of them were non-native species, introduced from East-Asia (*Stigmaeopsis nanjingensis, Schizotetranychus bambusae*) and North-America (*Platytetranychus thujae, Platytetranychus thujae*). Other invasive species are expected due to the intensive global trades. Numerous species were recorded in Hungary only once, more than twenty years ago. These records need to be confirmed in the future.

Blue oat mite

In February 2017, numerous specimens of unusual mite species were collected from lettuce plants in a greenhouse located at Forráskút, Southern Hungary, resembleing the blue oat mite (*Penthaleus cf. major* (Dugés, 1837)), so far unrecorded from Hungary. The hereby observed Hungarian specimens of blue oat mite have an unusual character which was not mentioned in the detailed re-description of Qin and Halliday (1996). Smooth upper branch of trifurcated fixed digit of chelicerae was illustrated in Qin and Halliday (1996 on Fig. 26) and Pereira et al. (2017 on Fig. 6). In face of this, the Hungarian specimens have numerous short hair-like projection on their upper surface. Similar character state is visible in North-American (USA, Kansas) specimens (see Narayan, 1962 on Fig. 3, Walter, 2006) and specimens from France (André, 1932, Fig. 8). No other information is available about this character state of the previously presented blue oat mite specimens, this difference can be explained by the existence of two morphovarieties having distinct geographical distributions.



Penthaleus cf. major (Dugés, 1837) female a) dorsal view, b) dorsal seta, c) ventral view, d) chelicera, e) habitus, f) occurrences in Hungary (empty: from greenhouse, full: from field)

Specimens with hair-like process on fixed digit are presented till today only from the Northern Hemisphere while specimens with smooth fixed digit were mentioned from the Southern Hemisphere.

Other difference between the Hungarian and other specimens is the shape of the hysterosomal setae. The Hungarian specimens bear barbed setae, contrary the previously published ones (see André, 1932; Narayan, 1962; Qinand Halliday, 1996).

There are also differences in the number of the dorsal setae in publications of the different author. Narayan (1962 on Fig. 3) and André (1932 on Fig. 1) presented dorsal setae in larger number than what we found in the Hungarian specimens or what was found in the Australian specimens Qin and Halliday (1996 on Fig. 21).

Concerning a short analyses using by maximum likelihood methods and Juke-Cantor model for 18sRNA sequence, the investigated *Penthaleus* species clustered separately from Eupodidae/*Linopodes* spp. line. This finding confirms that the Penthaleidae is a separated family from Eupodidae (earlier the *Penthaleus* species were placed to Eupodidae; Wallace and Mahon, 1971). Within the Penthaleidae clade, the Hungarian specimens differ from the others. The unidentified "*Penthaleus* sp." (KU253785), from USA, WA can be an undescribed genus or species. The other two ("*Penthaleus cf. major*" (GQ864271) from Poland and "*Penthaleus minor"* (AY620909) from USA) species situated closer to the Hungarian specimens, but the Polish "*Penthaleus cf. major*" (GQ864271) seems to be more similar to the "*Penthaleus minor"* (AY620909), than to the Hungarian specimens. Regarding of the cox 1 gene, the Hungarian *Penthaleus* specimens show higher similarities with the penthalodid *Stereotydeus* species than the members of family Eupodidae. We need to suppose, beside the morphological similarities, that the families Penthaleidae and Penthalodidae are close related with each other, and their sister group can be the family Eupodidae.

Currently there are no information about the origin of these specimens, maybe they were introduced to Hungary by soil or plant transportation or native Hungarian populations colonized the greenhouse from the neighbouring habitats. On the basis of the Hungarian specimens and the earlier published illustrations and descriptions about the species, we need to suppose that the specimens published under the name of *Penthaleus major* belong to more than one species. Beside the population in greenhouses, three population were also discovered in western Hungary.

Predatory mites

Earlier a widely distributed and very important predatory mite species [*Stratiolaelaps scimitus* (Womersley, 1956)] from biological control of view was found firstly in Hungary in the soil of a *Hedera canariensis* plant, used as a culture for *Bryobia kissophila* species. Description and distinguishing characters from other close related species were given. This predatory mite species can be a possible biological control agent against spider mites and other invertebrate pests, which were investigated in our experimental studies.

Mites associated with pest animals

Majority of the mites live in the soil, leaf litter, among moss, on different parts of plants and in several cases inside or on the body of vertebrates. Some mite groups are often found on the outer surface of bodies of insects. The majority of the insect-associated mites are parasites, whereas a few known species use insects just for transportation (=phoresis) without actually reducing their fitness. Some groups of both major mite groups, such as Acaridae and

Tarsonemidae (Acariformes), and the Macrochelidae, Parasitidae, Uropodidae, Polyaspididae and Trematuridae (all Parasitiformes), are often associated with insects (Eickwort, 1990; Wang et al., 2002; Bajerlein & Błoszyk, 2004; Błoszyk et al., 2006; Napierała et al., 2015). The main question in those cases whether the mite that we found on the insect's body is a parasite in a strict sense (i.e. feeds from the body insect), or just a "hitchhiker", i.e. a phoretic mite (Walter & Proctor, 2013; Farish & Axtell, 1971). Some groups, for example the larvae of Parasitengona are unquestionably parasites, because they join the host by their gnathosma (the mouth and feeding parts of mites). In most other cases, however, the nature of this relationship is unknown.

Slugs

Some specimens of the slug mite (*Riccardoella oudemansi* Thor, 1932) were discovered on the horticultural pest *Arion vulgaris*. A short description of the species and some notes to the biology of the slug mite were given. This species can be role in the possible biological control against the native and invasive pest slugs.

Aphids

A parasite mite species was found on the specimens of an aphid species during our study on mites as parasites of insect pests in Hungary. The larva of this mite (*Allothrombium pulvinum* Ewing, 1917) uses primarily different aphid species as its hosts. The mite specimens were collected from the common aphid, *Dysaphis pyri* (Boyer de Fonscolombe, 1841). A short morphological description and new illustrations were given. This species is beneficial mite species, which has important role in the regulation of the aphid populations.

Allothrombium pulvinum jointed to its aphid host

Bark beetles

Mites of the genera *Trichouropoda* and *Uroobovella* are characteristic associates of bark beetles which act as agents of their dispersal in many types of forest ecosystems worldwide. We compared the phoretic assemblages of *Trichouropoda* and *Uroobovella* species on six species of bark beetle associated with Norway spruce (*Picea abies*), namely: *Dryocoetes autographus* Ratzeburg, *Hylastes cunicularius* Erichson, *Hylurgops palliatus* (Gyllenhal), *Ips typographus* (Linnaeus), *Pityogenes chalcographus* (Linnaeus) and *Polygraphus poligraphus* (Linnaeus). Bark beetles were caught at random in nonbaited flight-interception traps set in the shrub layer of a declining mountain spruce forest in the Tatra Mountains, West Carpathians, Slovakia. Over four years of a bark beetle outbreak, a total of six species of mites and 12 phoretic associations between mites and beetles were recorded. A newly documented host association includes *Trichouropoda pecinai* Hirschmann &

Wiśniewski with *H. palliatus*. The most frequently recorded mite-beetle associations were: *T. pecinai* with *H. cunicularius*, *Trichouropoda obscura* (Koch) with *H. palliatus, Trichouropoda polytricha* (Vitzthum) with *P. chalcographus* and *I. typographus* and *Uroobovella vinicolora* (Vitzthum) with *D. autographus*. The results suggest that most of the recorded mite species have distinct bark beetle dispersants and that niche partitioning in these dispersants may be reflected by the observed mite-host associations.

Scarabaeid beetles

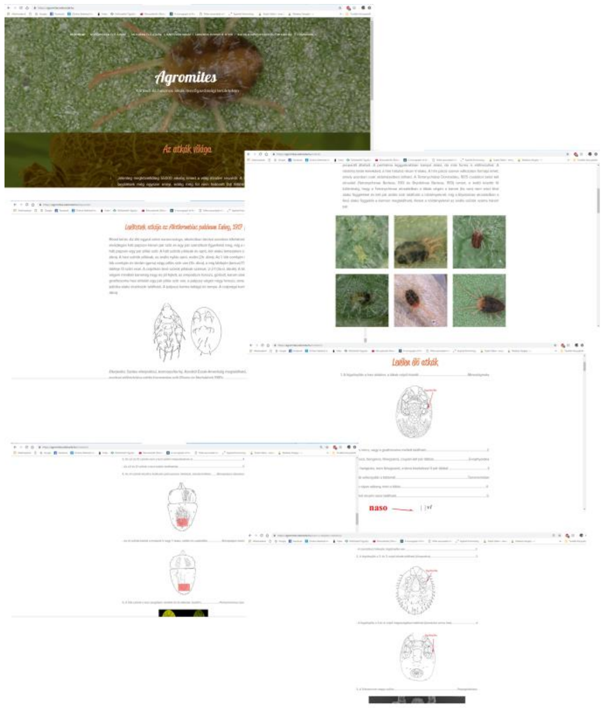
The phoretic species from the genus *Sancassania* are very rarely found on beetle pests, only Al-Deeb and Enan (2010) mentioned the first record of this genus from United Arab Emirates collected on beetle *Oryctes agamemnon* Burmeister 1847, which is one of the most important pest beetles of date palm in Middle-East. The hypopi of the species *Sancassania chelone* Oudemans, 1916 were collected from four pest beetle species, namely *Melolontha melolontha* (Linnaeus, 1758); *Melolontha hippocastani* Fabricius, 1801; *Holochelus aequinoctialis* (Herbst, 1790) and *Tropinota hirta* Poda, 1761.The beetles *M. hippocastani, H. aequinoctialis* and *T. hirta* were new host species of *S. chelone*. Only five specimens of *H. aequinoctialis* were collected in the sampling place, for of which were infested by the mite hypopi, making the infestation rate 80%. Two beetle specimens had mites on their wings in small number. The beetle bodies were covered in high number by the mites, all infested *H. aequinoctialis* carried mites on their abdomens. The highest mite number on a single abdomen was 159, the lowest was 8 (average: 48). More than half (55%) of the investigated *M. hippocastani* specimens were infested with *S. chelone* hypopi, 90% of the infested beetle specimens had mites on their wings and 54% had mites on the abdomen. The average numbers of the mite specimens were 7 and 3 on the wings and on the abdomen, respectively. Within the investigated beetle species we found mites on the thorax only in the case of *M. hippocastani*. The infestation rate was lower in the specimens of *M. melolontha*, only 28% of the studied specimens carried mites on their wings and abdomen. The average mite number was similar to the previous species, six on the wings and three on the abdomen. In *T. hirta*, only three specimens of the investigated 22 had *S. chelone* on their body; the infestation rate is 13%, which is the lowest within the studied pest beetles. We did not find mites on the wings and only few hypopi (2-1-2) were detected on the beetles' abdomen. The reason of the absence of the mites on wings of *T. hirta* can be the different type of elytra of this beetle. The two elytra are fused on their central part and the beetle cannot elevate them during the flight therefore the wings are mostly hidden. On the contrary, the elytra are not fused in the other three investigated species, during the flight the elytra are elevated, the wings are free and the hypopi can colonize them more easily. Our results show, that further investigations are needed to reveal the significance of these beetles in transportation of mites belonging to different acarine taxa.

A new species, *Macrocheles kekensis* Kontschán, 2018 from the family Macrochelidae was described based from three specimens associated with a cetoniin beetle (*Hoplia hungarica* Burmeister, 1844). The new species differs from the other known European macrochelid species in having 29 pairs of dorsal setae, j1 and z1 short and robust, other dorsal setae long and pilose, and the absence of apodemes between the genital and ventrianal shields. This was the 34th recorded Hungarian macrochelid species.

Only a few beetle-associated macrochelids have been mentioned (Kontschán 2006) from Hungary, while macrochelid mites associated with centoniin beetles are rarely collected. The association of macrochelid mites with flower beetles seems to be rare. Mašán (2003) mentioned only four species associated with a centoniin species (*Potosia cuprea* Fabricius, 1775).

Development of keys to the agricultural mites

The homepage for the identification of the agricultural mites is available here: http://agromites.webnode.hu/.



Pictures about the identification homepage

Other illustrated keys to the all spider mites and flat mites are published in Kontschán et al. (2018).

Study the mites from biological control point of view.

Application of *Stratiolelaps scimitus* predatory mite

Biological control studies focused on the species *Stratiolelaps scimitus*, but two other predatory mite species tried to use as well: *Machrocheles glaber* and *Veigaia nemorensis*. Keeping the latter two species were problematic, because they died fast after they were collected. However, *Stratiolelaps scimitus* could be kept under laboratory conditions. Continuing the investigations of the previous years, these two species against were treated by three invasive pest spider mites (*Eurytetranychus latus, Schizotetranychus bambusae*, *Stigmaeopsis nanjingensis*), but we did not get positive results. We used them also against to the eggs and larvae of boxwood moth (*Cydalima perspectalis*). This experiment was also not successful. Therefore, we finished the study of these two species, because they were not suitable in the biology control tests. Then, we used again the *Stratiolelaps scimitus* species against to larvae of *Drosophila suzukii*, first stage of *Halyomorpha halys*, small melolonthid larvae and meloidogynids. In these cases the *S. stimitus* did not reduce the number of pests. Maybe *S. scimitus* can be a good biology control agent against the leaf dwelling mites and insect larvae and eggs.

Two invasive spider mite species (*Stigmaeopsis nanjingensis* Ma and Yuan, 1980 and *Schizotetranychus bambusae* Reck, 1941) were spotted on bamboo collections in Hungary. The possibilities of biological control were investigated on these mites with two different predatory mite species (*Phytoseiulus persimilis* Athias-Henriot, 1957 and *Hypoaspis miles* Berlese, 1892 [*Stratiolaelaps scimitus* Womersley, 1956]). The species *Phytoseiulus persimilis* consumed larger amount of *S. bambusae* mites than *Stratiolaelaps scimitus* mites and none of the predatory mite species could consume *S. nanjingensis* with its special nets. In Hungary only two tetranychid mite species have been found on bamboo taxa: *Stigmaeopsis nanjingensis* and *Schizotetranychus bambusae*. Both species are non-native pests introduced by human transport from East Asia. Based on the biological control test both of the commercially available predatory mites (*Phytoseiulus persimilis* and *Stratiolaelaps scimitus*) were able to consume the spider mites without their webs in laboratory conditions. However, *P. persimilis* consumed twice as much spider mites than the other predator.
The web of *S. bambusae* did not inhibit the predator activity. On the other hand, the predatory mites were unable to break through or crawl under the tightly woven web of *S. nanjingensis*. The only known natural enemy of *S. nanjingensis* is the predatory mite *Typhlodromus bambusae* which can crawl under their net and destroy the mites there.

Other biocontrol studies

Specialist and generalist predator mites have been recommended against the two-spotted spider mite (*Tetranycus urticae*) as biological control agents, but their effectiveness in population regulation has been rarely examined under circumstances when prey had the opportunity to express antipredatory responses. We tested the efficiency and preference for prey life stages of three predator mites, one specialist (*Phytoseiulus persimilis*) and two generalists (*Amblyseius swirskii* and *Iphiseius degenerans*). We used two predator densities and performed the experiment under 'seminatural' conditions. We found that significantly less eggs and adult spider mites survived in the presence of *P. persimilis* compared to the control group, and this predator mite consumed more eggs at high density than the other predators. In the presence of *A. swirskii* fewer adult spider mites survived at low density compared to the control, whereas egg survival was lower than in the control group at both densities. In the presence of *I. degenerans*, only the survival of eggs was lower than in the control group and only at high density. Our results suggest that the generalist *A. swirskii*, but not *I. degenerans*, may be efficient in regulating prey populations through egg consumption, and, thus, represents an alternative to the effective specialist predator.

Applying predatory mites as biological control agents is a well-established method against spider mites which are major pests worldwide. Although antipredator responses can influence the outcome of predator-prey interactions, we have limited information about what cues spider mites use to adjust their behavioural antipredator responses. We experimentally exposed two-spotted spider mites (*Tetranychus urticae*) to different predator-borne cues (using a specialist predator, *Phytoseiulus persimilis*, or a generalist predator, *Amblyseius swirskii*), conspecific prey-borne cues, or both at the same time, and measured locomotion and egg-laying activity. The reactions to predator species compared to each other manifested in reversed tendencies: spider mites increased their locomotion activity in the presence of *P. persimilis*, whereas they decreased it when exposed to *A. swirskii*. The strongest response was triggered by the presence of a killed conspecific: focal spider mites decreased their locomotion considerably compared to the control group. Oviposition activity was not affected by either treatment. Our results point out that spider mites may change their behaviour in response to predators, and also to the presence of killed conspecifics, but these effects were not enhanced when both types of cues were present. The effect of social contacts among prey conspecifics on predator-induced behavioural defences is discussed.

Summary of the results

- During this project, I investigated the mites of the Hungarian and subtropical and tropical agricultural soils. This habitat is scarcely investigated, numerous new species from the Hungarian fauna were reported and ten new species were discovered and named from the different tropical plantations. These habitats are good refuges for these species and thus these areas contribute significantly to conservation of the biodiversity.
- During the study of the plant-dwelling mites numerous pest species were reported firstly from Hungary, and one new species was discovered and described. A new comprehensive monograph was published with illustrated key to the pest spider mites and flat mites, including new occurrences in Hungary.
- The role of the mites of the pest invertebrates wasalso investigated. New species for the Hungarian fauna and scarcely investigated mite species are reported from different pests. A new mite species, which is associated to a flower beetle, was described and named from Hungary.
- New online key was developed and available here: http://agromites.webnode.hu/.
- The *P. persimilis* mite is more effective in the consumption of the invasive and native spider mites than other predator species. But if the predatory mite present in the foliage, the plant feeding mites change their behaviour and oviposition. The investigated predatory mites (from family Laelapidae, Macrochelidae, Veigaiaidae and Phytoseidae) were not effect against the pest (and often the invasive) insects, the laelapids and phytoseids were very effective only against to the spider mites.
- During the project I published 12 papers in journals with impact factor, 12 papers in journals without impact factors and 14 papers in Hungarian in the journals of the Hungarian plant protection and two books.

References

AL-DEEB, M. & ENAN, M. (2010): First record of a phoretic Astigmatid mite Sancassania sp. (Acaridae: Astigmata) on Oryctes agamemnon Burmeister (Coleoptera: Scarabaeidae) in UAE. Int. J. Agri. Biol., 12, 157–160.

ANDRÉ, M. (1932): Note sur un Acarien (*Penthaleus major* Dugés) nuisible aux plantes potagéres. Bull. Mus. Natl. Hist. Nat., 4, 284–291.

BAJERLEIN, D. & BŁOSZYK, J. (2004): Phoresy of Uropoda orbicularis (Acari: Mesostigmata) by beetles (Coleoptera) associated with cattle dung in Poland. Eur. J. Entomol., 101, 185– 188.

BŁOSZYK, J., KLIMCZAK, J. & LESNIEWSKA, M. (2006): Phoretic relationships between Uropodina (Acari: Mesostigmata) and centipedes (Chilopoda) as an example of evolutionary adaptation of mites to temporary microhabitats. Eur. J. Entomol., 103, 699–707

EICKWORT, G.C. (1990): Associations of mites with social insects. Ann. Rev. Entomol., 35, 469–488.

FARISH, D.J. & AXTELL, R.C. (1971): Phoresy redefined and examined in Macrocheles muscaedomesticae (Acarina: Macrochelidae). Acarologia, 13, 16–29.

GERSON, U. & SMILEY, R.L. (1990): Acarine biocontrol agents. An illustrated key and manual. Chapman and Hall, London, Great Britain, 174 pp

GOBBI, J.A. (2000): Is biodiversity-friendly coffee fi-nancially viable? An analysis of five different coffee production systems in western El Salvador. Ecol.Econ., 33, 267–281.

KARG, W. (1983): Verbreitung und Bedeutung von Raubmilben des Cohors Gamasina als Antagonisten von Nematoden. Pedobiologia, 25, 241–247.
KARG, W. (1989): Acari (Acarina) Milben, Parasitiformes (Anactinochaeta), Uropodina Kramer Schildkrötenmilben. In: Die Tierwelt Deutschlands, 67. Teil. G. Fischer, Jena, 203 pp.
KETHLEY, J.B., NORTON, R. A., BONAMO, P. M. & SHEAR, W.A. (1989): A terrestrial alicorhagiid mite (Acari: Acariformes) from the Devonian of New York. Micropaleontology, 35, 367–373.
Koehler, H.H. (1999): Predatory mites (Gamasina, Mesostigmata). Agricult., Ecosys. Environ., 74, 395–410.
KONTSCHÁN, J (2006): Check list of the Hungarian Mesostigmatid mites. I–II. Zerconidae and Macrochelidae. Fol. Hist. Nat. Mus. Matra., 30, 129–136.
KRANTZ, G.W. & WALTER, D.E. (2009): A Manual of Acarology. Third Edition. Texas Tech University Press, Lubbock, Texas, USA.
McMurtry, J.A. & Croft, B.A. (1997): Life-styles of Phytoseiid mites and their role in the biology control. Ann. Rev. Entomol., 42, 291–321.
MAHUNKA, S. (1969): Sechs neue Milben-Arten aus der Familie Pyemotidae (Acari, Trombidiformes). Acarologia, 11, 527–536.
MAŠÁN P (2003): Macrochelid Mites of Slovakia (Acari, Mesostigmata, Macrochelidae). Bratislava, Institute of Zoology, Slovak Academy of Sciences, 149 pp.
NAPIERAŁA, A., KSIĄŻKIEWICZ, Z., LEŚNIEWSKA, M., GWIAZDOWICZ, D.J., MĄDRA, A. & BŁOSZYK, J. (2015): Phoretic relationships between uropodid mites (Acari: Mesostigmata) and centipedes (Chilopoda) in urban agglomeration areas. Int. J. Acar., 41, 250–258.
NARAYAN, D. S. (1962): Morphological, biological and ecological studies on the winter grain mite, *Penthaleus major* (Duges), Penthaleidae; Acarina. Part 1. J. Zool. Soc. India, 14, 45–63.
NORTON, R.A, BONAMO, P.M., GRIERSON, J.D. & SHEAR, W.A. (1988): Oribatid mite fossils from a terrestrial Devonian deposit near Gilboa, New York. J. Paleo., 62(2), 259–269.
PEREIRA, P. R. V. DA SILVA, SALVADORI, J. R., NAVIA, D., LAMPERT, S. & SAVARIS, M. (2017): First Record of *Penthaleus major* (Acari: Penthaleidae) in Brazil. Proc. Entomol. Soc. Wash., 119, 157–161.
PERFECTO, I., RICE, R.A., GREENBERG, R. & E. VAN DER VOORT, M. (1996): Shade coffee: a disappearing refuge for biodiversity. BioScience, 46(8): 598–608.
QIN, T. K. & HALLIDAY, R. B. (1996): The Australian species of *Chromotydaeus* Berlese and *Penthaleus* C. L. Koch (Acarina: Penthaleidae). J. Nat. Hist., 30, 1833–1848.
SCHROT, G. & HARVAY, C.A. (2007): Biodiversity conservation in cocoa production landscapes: an overview. Biodiversity and Conservation, 16(8): 2237–2244.
WALTER, D.E. & PROCTOR, H.C. (2013): Mites: Ecology, Evolution & Behaviour. 2 nd Edition. Springer, New York/London.
WALTER, D. E. (2006): Invasive Mite Identification: Tools for Quarantine and Plant Protection, Lucid v. 3.3, last updated July 24, 2006, Colorado State University, Ft. Collins, CO and USDA/APHIS/PPQ
WANG, C., POWELL, J.E. & O'CONNOR, B.M. (2002): Mites and nematodes associated with three subterranean termite species (Isoptera: Rhinotermitidae). Florida Entomol., 85, 499–506
XUE, X-F. & ZHANG, Z-Q.(2008): An analysis of and index to new Acari described in Systematic & Applied Acarology (1996–2007). Syst. Applied Acarol., 13, 279–304.

19/11/2018. Jenő Kontschán