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Diversity and significance of eriophyoid mites (Acari: Eriophyoidea) associated with coniferous trees in Poland: a review

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Abstract: Among the approximately 200 eriophyoid mite species associated with coniferous trees worldwide, 33 species (of the families Eriophyidae and Phytoptidae) infest conifers in Poland, and 24 of them can cause visible feeding symptoms. In this paper we discuss the importance of eriophyoid mites to coniferous plants in Poland and their potential impact on the decorative value of ornamental plants. We emphasize the general lack of knowledge about the diversity of eriophyoid mites associated with coniferous trees and its role in the management and control of this economically important mite group.

Keywords: Eriophyidae, Phytoptidae, Pinaceae, Cupressaceae, Taxaceae, species diversity, cryptic species

INTRODUCTION

Eriophyoid mites are plant parasites obligatorily associated with their hosts. Most of eriophyoid species are considered to be highly host-specific, and only several species are known to have broad host ranges (Skoracka et al. 2010). Eriophyoid mites are considered to be the second most economically important group of mites after tetranychids (van Leeuwen et al. 2010). They feed on various plant organs, causing direct damage to plant tissues, but some species also transmit damaging plant viruses. Therefore, many eriophyoid species are a serious threat to cultivated plants and a growing number of them are invasive in many countries (Oldfield & Proeseler 1996; Navia et al. 2010). The minute size of these mites, the refuge-seeking life style of many species, and the existence of cryptic species, lead to difficulties in their detection and identification, which increases their negative impact on agricultural crops as well as ornamental and forest trees (van Leeuwen et al. 2010). Despite their small size and low mobility, eriophyoid mites can disperse passively through air currents, rain, phoresy and, especially, human activity, as they can be spread through commercial trade over long distances (Michalska et al. 2010).

Coniferous trees offer exceptionally stable microhabitats, in which eriophyoid mites proliferate. The evergreen habit and long life span of coniferous trees as well as their frequent occurrence in monocultures facilitate eriophyoid mite dispersal and increase the availability of tissues on which these mites feed (Boczek & Shevchenko 1996). Conifers are present in almost all terrestrial habitats of the world, and they are commonly used as ornamental trees in gardens and urban green areas. Coniferous forests dominate among the forest communities in Europe and have a great environmental, social, and economic value (Paschalis-Jakubowicz 2012). Forests in Europe cover more than 1.02 billion hectares, i.e. 45% of the continent's land area, and are predominantly made up of coniferous stands (50%) and of broadleaved stands (27%), while the remaining 23% are mixed stands, including both conifers and broadleaves (San-Miguel Avanz et al. 2011). Similarly, in Poland, coniferous forests constitute 51% of the total forest communities (Zajączkowski et al. 2015).

Among the more than 4500 described eriophyid mite species worldwide, ca. 200 species are associated with coniferous plants, mostly with species of the families Pinaceae (about 120 species) and Cupressaceae (about 50 species) (Lewandowski 2014). To this day in Poland, 33 eriophyoid mites have been recorded from natural coniferous communities, as well as from conifers growing in urban areas, nurseries, and gardens, and among them 24 species cause damage to their hosts and induce visible symptoms of feeding (Skoracka et al. 2005; Lewandowski & Kozak 2008; Castagnoli et al. 2010; Lewandowski et al. 2014; Lewandowski 2014).

The goal of this paper is to characterize the current and most important research and applied problems concerned with conifer-associated eriophyoid mites in Poland. We particularly aimed to:

- provide a comprehensive review of eriophyoid fauna inhabiting coniferous plants in forests, gardens, ornamental tree nurseries, etc.;
- characterize the impact of eriophyoid mites on ornamental coniferous plants and their decorative value;
- emphasize the importance of accurate species identification for effective management strategies and discovery of the diversity of this economically important group.

RELATIONS WITH HOST PLANTS AND A REVIEW OF ERIOPHYOID FAUNA INHABITING CONIFEROUS PLANTS IN POLAND

Eriophyoid mites inhabit various plant parts of conifers, such as the needles, shoots, buds, cones, and seeds (Castagnoli 1996). Sparse information on the distribution of eriophyoids on coniferous plants shows that they prefer young tissues (Boczek & Shevchenko 1996), which leads to infestation of only the external shoots of the tree crown. However, Lewandowski & Kozak (2008) have shown that mite population densities on coniferous plants are rather low, especially in the wild. Moreover, the species composition and density of eriophyoids do not differ significantly between young and adult trees. The lack of preference for specific tree parts has also been suggested (LEWANDOWSKI & KOZAK 2008) because coniferous trees offer stable and long-lasting conditions for mite survival and reproduction, thus mites do not need to migrate to seek winter shelters (BOCZEK & SHEVCHENKO 1996). Moreover, the young tissues that appear each year on the apical parts of the shoots on the whole tree make it unnecessary for eriophyoid mites to move towards the top parts of the plant, as is the case of annual plants (LEWANDOWSKI & KOZAK 2008).

Our review of the literature (BOCZEK et al. 2002, SKORACKA et al. 2005, LEWANDOWSKI & KOZAK 2008, LEWANDOWSKI 2014, LEWANDOWSKI et al. 2014) shows that coniferous plants in Poland are inhabited by eriophyoid mites of 2 families: the Eriophyidae (10 genera) and Phytoptidae (3 genera) (see Table 1). The most diverse genera were *Trisetacus* and *Nalepella*, represented by 10 and 5 species, respectively. Altogether, 33 species have been recorded up to now in Poland. Among them, 27 species are found on native coniferous plants growing on natural sites (mainly in forests), 21 species have been noted in gardens, and 14 species in nurseries. So far, no eriophyoid mite species have been reported as pests in Polish Christmas tree plantations. Out of the conifer-infesting eriophyoid mites, 8 species are associated with firs (*Abies*), 7 with pines (*Pinus*) and spruces (*Picea*), and 5 species with junipers (*Juniperus*). The coniferous species most often infested by eriophyoid mites in Poland are Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*). The former is a dominant coniferous plant in Poland, as it accounts for about 58.5% of the area of Polish forests (ZAJĄCZKOWSKI et al. 2015). Plants of other coniferous genera are hosts to single species. Most of the eriophyoid species reported from were free-living, found mostly on needles and stems. Only 6 species inhabited galls or were refuge-seeking, by colonizing buds or berries (Table 1).

HARMFULNESS AND ECONOMIC IMPORTANCE

Eriophyoid mites can cause damage to their host plants, with visible symptoms such as discolorations, gall formation, witch's brooms, inhibition of bud development as well as destruction of berries and seeds (CASTAGNOLI 1996). Among the 33 species of eriophyoid mites associated with coniferous shrubs and trees in Poland, 6 eriophyoid species may cause particularly serious damage to conifers in the Polish forest industry (Table 1). These include *Cecidophyopsis psilaspis* (NALEPA), *Eriophyes junipereti* KEIFER, *Nalepella shevtchenkoi* BOCZEK, *Nalepella danica* BOCZEK, HARDING & SHI, *Setoptus pini* BOCZEK, and *Trisetacus juniperinus* (NALEPA) (SOIKA & ŁABANOWSKI 1999; BOCZEK et al. 2002; SKORACKA et al. 2005; LEWANDOWSKI 2014). The most economically important species is *T. juniperinus*, which causes the death of terminal buds and considerable shortening of internodes, in consequence leading to shoot-rosetting of *Juniperus procumbens*, *J. chinensis*, *J. sargentii*, *J. virginiana* (CASTAGNOLI et al. 2010), and *Cupressus sempervirens* (CASTAGNOLI & SIMONI 2000). It is a key pest species on evergreen cypress (*C. sempervirens*), which is widely cultivated for its ornamental value and high quality of wood. In the Mediterranean region, *T. juniperinus* and fungal cypress canker, *Seiridium cardinal* (WAG) SUTTON & GIBBSON, constitute a major problem for young, cultivated plants. For the latter

Table 1. List of eriophyoid mites species inhabiting coniferous trees in Poland, indicating their host plant species, microhabitat, habitat, life style, and damages induced by them (Boczek et al. 2002; Skoracka et al. 2005; Lewandowski & Kozak 2008; Lewandowski 2014; Lewandowski et al. 2014)

Mite species	Host plant	Microhabitat	Type of habitat	Life style and damages
Family: Eriophyidae				
	Cupressaceae			
Acaricalus juniperi Szulc, 1967	*Juniperus communis* L.	berries, needles, and stems	forests	vagrant; no damages observed
Epitrimerus insons Boczek, 1961	*Thuja occidentalis* L., *Chamaecyparis* sp.	needles and stems	gardens and nurseries	vagrant; no damages observed
Epitrimerus taxodii (Keifer, 1939)	*Taxodium distichum* L.	needles	gardens and nurseries	vagrant; slight discoloration
Eriophyes junipereti Keifer, 1960	*Juniperus communis* L.	needles and stems	forests, gardens, and nurseries	vagrant; growth inhibition of youngest shoots
Keiferella juniperici Boczek, 1964	*Juniperus communis* L.	needles and stems	forests and gardens	vagrant; local discoloration
	Pinaceae			
Calepitrimerus lutocinus Lewandowski, 2006	*Picea abies* (L.) H. Karst	needles and stems	forests	vagrant; no damages observed
Cupacarus octogibbus Lewandowski, 2014	*Abies alba* Mill.	needles and stems	forests	vagrant; no damages observed
Epitrimerus taxifoliae Łabanowski, 1999	*Pseudotsuga menziesii* Carriere	needles and stems	gardens and nurseries	vagrant; no damages observed
Keiferella abietis Boczek, 1969	*Abies koreana* E. H. Wilson *Abies alba* Mill.	needles and stems	forests, gardens, and nurseries	vagrant; no damages observed
Keiferella piceae Boczek, 1969	*Picea abies* (L.) H. Karst	needles and stems	forests	vagrant; discoloration and defoliation of needles

Phyllocoptes farkasi Boczek, 1969	*Pinus nigra* Arn. *Pinus jeffreyi* Balf. *Pinus sylvestris* L.	needles and needle sheaths	forests, gardens, and nurseries	refuge-seeking; slight discoloration
Phyllocoptes piceae Soika, 1999	*Picea abies* (L.) H. Karst	needles and stems	forests, gardens, and nurseries	vagrant; slight mosaic discoloration
Platyphytoptus sabinianae Keifer, 1938	*Pinus mugo* Turra *Pinus nigra* Arn.	needles and needle sheaths	forests, gardens, and nurseries	refuge-seeking; necrosis of needle bases
Tegonothus carpaticus Lewandowski, 2014	*Abies alba* Mill.	needles and stems	forests	vagrant; no damages observed
	Taxaceae			
Cecidophyopsis psilaspis (Nalepa, 1893)	*Taxus baccata* L.	buds	forests, gardens, and nurseries	refuge-seeking; swollen and dried buds and needle malformation
Family: Phytoptidae				
	Pinaceae			
Nalepella brewerianae Domes, 2004	*Picea glauca* (Moench) Voss *Picea abies* (L.) H. Karst	needles and stems	forests and gardens	vagrant; discoloration and loss of needles
Nalepella danica Boczek, Harding & Shi, 2002	*Abies alba* Mill. *Abies concolor* (Gordon & Glend.) Lindl. ex Hildebr. *Abies lasiocarpa* (Hook.) Nutt.	needles and stems	gardens and forests	vagrant; tiny rusty-bronze spots and loss of needles
Nalepella ednae Keifer, 1951	*Abies nordmanniana* (Steven) Spach	needles	gardens	vagrant, no damages observed
Nalepella shevtchenkoi Boczek, 1969	*Abies alba* Mill. *Abies nordmanniana* (Steven) Spach *Picea abies* (L.) H. Karst	needles and stems	gardens and forests	vagrant; tiny rusty-bronze spots and loss of needles
Nalepella triceras (Börner, 1906)	*Abies alba* Mill. *Abies concolor* (Gordon & Glend.) Lindl. ex Hildebr. *Abies koreana* E. H. Wilson	needles and stems	forests, gardens, and nurseries	vagrant; tiny rusty-bronze spots

Nalepella tsugae Keifer, 1951	*Tsuga canadensis* (L.) Carr.	needles and stems	gardens and nurseries	vagrant; local needle discolorations
Setoptus multigranulatus Castagnoli, 1973	*Pinus sylvestris* L.	needle sheaths	forests	refuge-seeking; no damages observed
Setoptus pini Boczek, 1964	*Pinus sylvestris* L. *Pinus mugo* Turra *Pinus nigra* Arn.	needle sheaths	forests, gardens, and nurseries	refuge-seeking; shortening and discoloration of needles
Trisetacus cembrae (Tubeuf, 1910)	*Pinus mugo* Turra	needles and stems	forests	refuge-seeking; bud proliferation, witches' brooms, and needle discoloration
Trisetacus laricis (Tubeuf, 1897)	*Larix decidua* Mill.	buds	forests	refuge-seeking; bud destruction
Trisetacus monteabietus Lewandowski, 2014	*Abies alba* Mill.	under scales at bases of current year's shoots	forests	refuge-seeking; inhibition of young shoot development
Trisetacus piceae (Roivainen, 1951)	*Picea abies* (L.) H. Karst	buds	forests	refuge-seeking; bud destruction
Trisetacus pini (Nalepa, 1887)	*Pinus sylvestris* L.	galls	forests, gardens, and nurseries	gall-making; galls on twigs inhibit seedling development
Trisetacus relocatus Bagnyuk and Shevchenko, 1982	*Picea abies* (L.) H. Karst	under scales at bases of current year's shoots	forests	refuge-seeking; inhibition of young shoot development
Trisetacus silvestris Castagnoli, 1973	*Pinus sylvestris* L. *Pinus mugo* Turra	needle sheaths	forests	refuge-seeking; necrosis of needle bases
	Cupressaceae			
Trisetacus cupressi (Keifer, 1944)	*Thuja occidentalis* L.	needles	gardens and nurseries	vagrant; needle discolorations
Trisetacus juniperinus (Nalepa, 1911)	*Juniperus communis* L. *Juniperus procumbens* (Siebold ex Endl.) Miquel	galls, buds, berries	forests, gardens, and nurseries	gall-making; galls on twigs, basal enlargement and necrosis of needles, and bud destruction

Trisetacus quadrisetus (Thomas, 1890)	*Juniperus communis* L.	seeds	forests and gardens	refuge-seeking; deformation of berries (cones) and seed destruction

species, control by selection of resistant varieties leads to an increased risk of *T. juniperinus* infestation, on account of the susceptibility of canker-resistant clones to eriophyoid mite attack (Castagnoli et al. 2002). In Poland this species was observed to cause the death of terminal buds and considerable shortening of internodes and, in consequence, shoot-rosetting on ornamental junipers growing in containers in nurseries (Łabanowski & Soika 2000).

The most serious damage is observed when mites occur in large colonies or during outbreaks of the *Trisetacus* species, which have been reported in forests (Kruel 1963; Keifer & Saunders 1972; Styer et al. 1972; Shevchenko 1995; Marshall & Clayton 2004). Some other *Trisetacus* species attack berries and destroy their seeds (Shevchenko 1962) or cause serious damage in nurseries and young stands (Simoni et al. 2004). For example, *T. quadrisetus* (Thomas) is known as a pest of *Juniperus communis*, and its large populations on berries cause total destruction of the seeds. Another species, *T. kirghisorum* Shevchenko, causes damage to *Juniperus semiglobosa* Regel seeds (Shevchenko 1962). The significant decline in juniper populations due to pest feeding has caused erosion of the mountain slopes in Kyrgyzstan (Orozumbekov & Moore 2007). Another serious pest of conifers is *T. pini* (Nalepa), commonly found on pine trees in the temperate zone and also reported on spruce and larch (Castagnoli et al. 2010). It causes the formation of galls and damage to young seedlings (Shevchenko et al. 1993; Petanovic al. 1996).

In urban green areas, *Nalepella shevtchenkoi*, which causes severe mosaic discolorations on *Picea jezoensis*, has so far been one of the most harmful eriophyoid species on coniferous plants (Castagnoli et al. 2010). In contrast, it causes no visible damage to *Abies alba* and *A. nordmanniana* (Boczek 1969). However, both discoloration and needle loss due to an attack of this species were noted on *A. nordmanniana* in Denmark, which makes it a major pest in Christmas tree plantations there (Boczek et al. 2002). *N. shevtchenkoi* can co-occur with another pest of conifers, *N. danica*, which causes similar damage. Severe infestation by *N. danica* may result in defoliation of the host (Boczek et al. 2002). This species has been also recorded in Poland on *A. alba* growing in forests as well as on *A. concolor* and *A. lasiocarpa* in gardens, but no information about damages caused by this species has been provided (Lewandowski 2014). Discoloration and needle loss on *Picea glauca* in gardens due to the feeding of *N. brewerianae* Domes (originally noted on *P. breweriana* in Germany, Domes 2005) has also been observed in Poland (Lewandowski M., personal observation).

DISCOVERY OF THE DIVERSITY OF ECONOMICALLY IMPORTANT SPECIES, USING AN INTEGRATIVE APPROACH

Despite the variety of reported symptoms and potential impact of eriophyoid mites on coniferous plants in Poland, their importance is underestimated and there are still many gaps in knowledge of this topic. This may result from: (i) a long period of symptom development, which induces problems with mite detection, e.g. 2 years after transplanting (Castagnoli et al. 2002) or even after the mites died or left the tree (Simoni et al. 2004); ii) difficulties in sampling from large-sized and old trees (Castagnoli et al. 2010); iii) the diversity of microhabitats that may be inhabited by these mites and diverse mite strategies as well as frequently observed low population densities (which makes it necessary to collect very large samples from various plant parts); iv) the existence of cryptic diversity within eriophyoids inhabiting coniferous plants, which may confound the systematics of this group and, moreover, is crucial for the development of effective management strategies for these pests (Lewandowski et al. 2014).

Due to the great economic importance of eriophyoid mites inhabiting ornamental coniferous trees and shrubs, especially in nurseries and gardens where their decorative value can be decreased by mite feeding, their control and management are imperative. However, successful control strategies largely depend on adequate pest identification (Hoy 2011). The identification of eriophyoid mites is difficult due to their small size, structural simplicity, and limited number of diagnostic traits (which are often variable and overlap among different taxa). All this often leads to misidentification, which can impair both the systematics of this group and agricultural strategies (Lindquist et al. 1996). Additionally, recent evidence based on barcoding (i.e. identification of species by using DNA fragments) has shown that cryptic species (i.e. morphologically identical or very similar species) are very common within the Eriophyoidea (e.g. Skoracka & Dabert 2010; Miller et al. 2013; Skoracka et al. 2013; 2015; Lewandowski et al. 2014). Hence, species diversity within this group may be much greater than is currently thought.

Cryptic species are particularly common among parasites and herbivores because they often exhibit various preferences toward hosts or habitat use. Such microhabitat and host specialization may play a large role in speciation because specialization may lead to reduced gene flow between populations associated with a specific host or microhabitat (Futuyma & Moreno 1988; Brooks & Mclennan 1993; Hebert et al. 2004; Steinauer et al. 2007). Host and habitat associations resulting in genetic and morphological differentiation (potentially leading to the formation of reproductive barriers) have also been observed in conifer-associated eriophyoid mites in Poland. Phylogenetic analyses conducted by Lewandowski et al. (2014) found *Trisetacus silvestris*, inhabiting 2 host plant species (*Pinus mugo* and *P. sylvestris*), to be a paraphyletic taxonomic group, with high statistical support for the monophyly of the 2 host-associated lineages (Fig. 1). The estimates of genetic variation between these 2 lineages were comparable with inter-specific variation in other taxonomic groups of mites (Hebert et al. 2003; 2004). In addition, morphological analysis supported the divergence of populations living on those woody species and suggested the existence

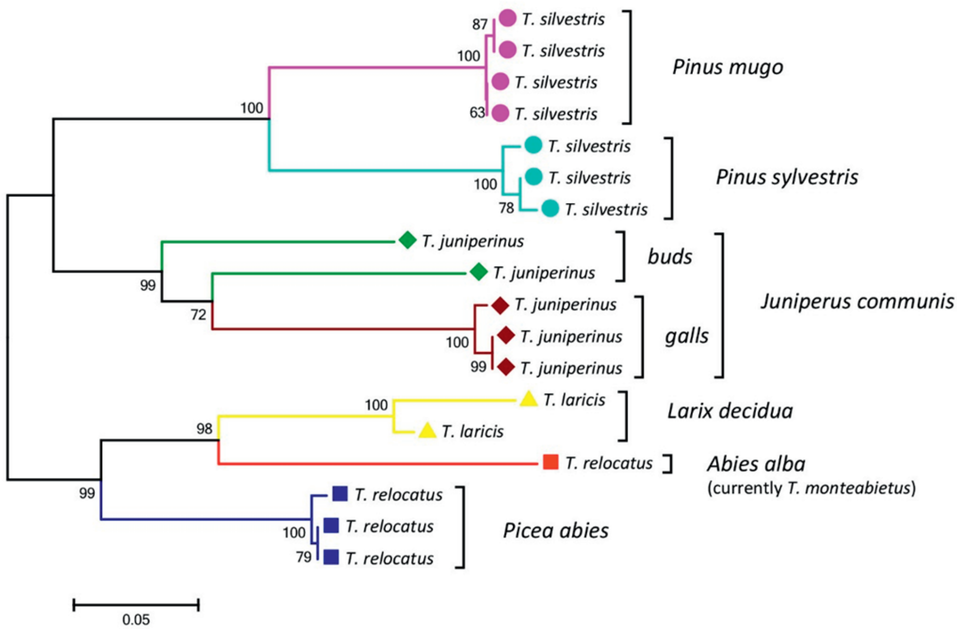

Fig. 1. Maximum Likelihood tree constructed using the GTR + I + G model on data from the cytochrome *c* oxidase subunit I sequences of *Trisetacus* (GenBank Acc. No: KC776529-KC776535, KC776543-KC776553, reported by Lewandowski et al. 2014). After square brackets, microhabitats and host plant species are given. Statistical support is indicated by maximum likelihood aLRT values greater than 60 (above branches).

of host races or even cryptic species within *T. silvestris*. A lack of monophyly has also been detected between 2 host-associated populations of *Trisetacus relocatus* Bagnyuk & Shevchenko reported from *Abies alba* and *Picea abies*, which proved to be morphologically and genetically distinct (Lewandowski et al. 2014). On the basis of this finding, the fir-associated population was described as a separate species, *Trisetacus monteabietus* Lewandowski, (Lewandowski 2014). This species is more closely related to *T. laricis* (Tubeuf) than to *T. relocatus* (Lewandowski et al. 2014) (Fig. 1).

Some species of conifer-associated eriophyoids inhabit more than one type of microhabitat, e.g. *T. juniperinus* is found inside buds (causing needle agglomeration, enlargement, and necrosis), galls (Jeppson et al. 1975; Łabanowski & Soika 2000; Castagnoli et al. 2010), or berries (Lewandowski et al. 2014). Phylogenetic analyses showed considerable variation within these populations, thus suggesting habitat specialization. Gall-associated populations diverged as a morphologically uniform cluster as well as a monophyletic genetic lineage (Fig. 1). These morphological, genetic, and ecological variations suggest the existence of host-specialized races or even cryptic species within *T. juniperinus* (Lewandowski et al. 2014).

CONCLUSIONS

In this paper we have reviewed the current and most important topics regarding eriophyoid mites associated with coniferous plants in Poland by characterizing all species that are present in Poland, and especially their impact on host plants. We emphasized the major challenges that make studies on this group both time-consuming and technically difficult, and which lead to gaps in knowledge in this field.

Since coniferous trees and shrubs dominate in the Polish forest industry and represent a high decorative value in gardens, studies on conifer-associated eriophyoid mites undoubtedly deserve further attention. It is necessary to improve: (i) sampling techniques, which currently generate serious problems because of inconsistent sampling methodology (Castagnoli et al. 2010), as well as (ii) species identification, by more extensive application of DNA barcoding methods.

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