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RESEARCH ARTICLE

Aculus taihangensis (Acari: Prostigmata: Eriophyidae), a potential biological control agent identified from the highly invasive pest plant, tree of heaven, in Türkiye

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ABSTRACT: Invasions by alien plant species are rapidly increasing in both their extent and intensity, leading to the widespread degradation of terrestrial and aquatic ecosystems across the world. One of the most widely dispersed, invasive, alien plant species in Europe, North America and many other countries, including Türkiye, is the tree of heaven, *Ailanthus altissima*. Numerous potential biological control agents, including eriophyoid mites, have been reported from this plant within its native range. A widespread collection of leaf specimens from the tree of heaven in Türkiye yielded only the eriophyoid, *Aculus taihangensis* (=*A. mosoniensis*), a new record for Türkiye. No obvious damage was observed on any of the leaf specimens. It appears highly unlikely that *A. taihangensis* is currently playing a meaningful role in the biological control of the tree of heaven in Türkiye.

Keywords: *Ailanthus altissima*, *Aculus mosoniensis*, eriophyid mite, new record, invasive species.
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INTRODUCTION

Invasions by alien plant species are rapidly growing in their extent and severity across the world, leading to an alarming level of degradation of both terrestrial and aquatic ecosystems. One of the most widely distributed, invasive, alien plant species in Europe and North America, and in many other countries, is the tree of heaven [*Ailanthus altissima* (Mill.) Swingle, 1916] (Sapindales: Simaroubaceae). It is native to northern and central China, Korea and Vietnam and is considered one of the worst invasive plants in Europe (Ding et al., 2006; Nava, 2014; Sladonja et al., 2015; EPPO, 2023). The tree of heaven is cultivated as an ornamental plant in many towns across Türkiye and has become naturalized (Cullen, 1967; Uludağ, 2015; Ulus et al., 2021). That means that this plant has been invading the landscape of Türkiye for more than 55 years.

Kashefi et al. (2022) did a short review of the history of the spread of the tree of heaven, its pest status in various jurisdictions, and potential biological control agents. They attributed the invasiveness of the tree of heaven to five characteristics, namely, tolerance of extreme environmental conditions, production of numerous allelopathic substances, high production and viability of seeds, clonal proliferation with copious sprouting after cutting, and limited herbivory by insects. Apart from its negative ecological impacts, the plant has also been reported to harm human health; the pollen of the tree causes sensitization, allergic rhinitis and asthma (Mousavi et al., 2017; Samei et al., 2020; Werchan et al., 2023).

In a literature review of natural enemies of the tree of heaven in China, Ding et al. (2006) listed 46 phytophagous arthropods, 16 fungi and one potyvirus, some apparently causing substantial damage, with the arthropods including three eriophyid mite species, *Aculops ailanthi* Lin, Jin & Kuang, 1997, *Aculops taihangensis* Hong & Xue, 2005 and *Aculus altissimae* Xue & Hong, 2005. *Aculops ailanthi* has since been reported from the tree of heaven in the United States of America (Gardner, 2008; Skvarla et al., 2021).

Later, *Aculus mosoniensis* (Ripka, 2014) was described from the tree of heaven in Hungary (Ripka and Ersek, 2014; de Lillo et al., 2017). However, the suggested synonymy between *Aculops taihangensis* and *Aculus mosoniensis* (de Lillo et al., 2017) was supported by the recent work of de Lillo et al. (2022) who stated that, based on new morphological and molecular data, *A. mosoniensis* has to be considered a junior synonym of *Aculus taihangensis* (Hong & Xue, 2005) new combination, with *Aculops taihangensis* reassigned to the genus *Aculus*. de Lillo et al. (2022) also described the deutogyne of *Aculus taihangensis*. In Europe, only *A. taihangensis* (=*A. mosoniensis*) has been reported from the tree of heaven; it has now been reported from at least 13 European countries (Ripka and Ersek, 2014; de Lillo et al., 2017, 2022; Marini et al., 2021; Kashefi et al., 2022).

Aculus taihangensis can form dense populations on the under surface of the leaflets of the young compound leaves of the tree of heaven, causing the leaf edges to curl upwards and turn yellowish. Drying of the upper parts of the stem can occur on heavily infested plants, and young plants can become water stressed and lose leaves prematurely (de Lillo et al., 2017). Host range tests on *A. taihangensis* indicated that it is a safe biological control agent that could help to control this highly invasive tree (Marini et al., 2021).

MATERIALS AND METHODS

Leaf samples were collected during the vegetation period of tree of heaven in many parts of Türkiye in 2022 and 2023 (Table 1, Fig. 1). Apart from some trees in parks, most of the plants were on disturbed sites, especially along roadsides in both urban and rural areas. Almost all were self-seeded plants that were often growing in small clumps or thickets. Four or five young compound leaves were randomly collected at each site. They were wrapped in paper, labelled, and then kept in cold storage until they were processed. Both surfaces of the leaflets were observed under a stereomicroscope (Olympus® SZ 61) at 45x magnification. The collected eriophyoid mites were stored in 70% ethyl-alcohol until they were identified. For that purpose, they were mounted in Hoyer's medium without the use of fibers, and then kept on a heating plate for two hours at 80 °C. The permanent slides were examined under an Olympus® BX51 phase-contrast microscope for identification which was made following Ripka and Ersek (2014) and de Lillo et al. (2010, 2017, 2022). All morphological measurements were done according to de Lillo et al. (2017, 2022). Measurements are given in micrometers (µm). Images were taken with a digital camera (Toupcam E31SPM20000KPA). The examined specimens are in the mite collection of the Acarology Laboratory, Department of Plant Protection, Faculty of Agriculture, Ondokuz Mayis University, Samsun, Türkiye.

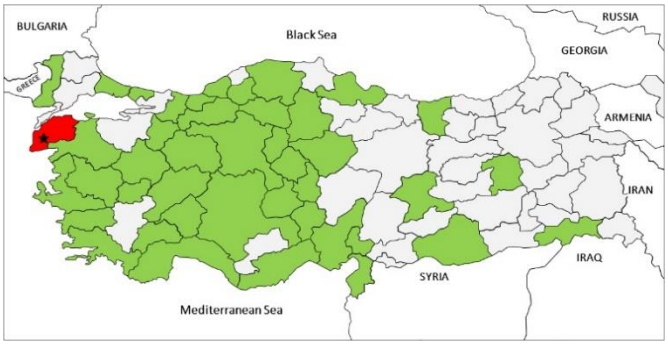

Figure 1. Map of Türkiye showing the provinces from which leaf samples were collected from the tree of heaven in 2022 and 2023 (* indicates the site in Çanakkale Province at which the eriophyid mite, *Aculus taihangensis*, was collected).

Table 1. Collection dates and locations for leaf sampling from the tree of heaven in Türkiye in 2022 and 2023.

Collection Date	Location (Town/Province)	Collection Date	Location (Town/Province)
09.08.2022	Hekimhan/Malatya	12.06.2023	City center/Kırşehir
11.08.2022	City center/Bingöl	12.06.2023	Ürgüp/Nevşehir
13.08.2022	City center/Şırnak	12.06.2023	Uçhisar/Nevşehir
15.08.2022	City center/Şanlıurfa	12.06.2023	Gülpınar/Gülağaç/Aksaray
09.09.2022	Koparan/Çorum	13.06.2023	University campus/Niğde
09.09.2022	Delice/Kırıkkale	13.06.2023	Acıkuyu/Ereğli/Konya
10.09.2022	Tepebaşı/Eskişehir	13.06.2023	Pozantı/Adana
11.09.2022	City center/Balıkesir	13.06.2023	Karacalar/Osmaniye
12.09.2022	Burhaniye/Balıkesir	14.06.2023	Altınçağ/Dörtyol/Hatay
13.09.2022	Adatepe/Ayvacık/Çanakkale	14.06.2023	Ceyhan/Adana
14.09.2022	Kilitbahir/Çanakkale	15.06.2023	Darısekisi/Toroslar/Mersin
14.09.2022	Uzunköprü/Edirne	17.06.2023	Çaybaşı/Muratpaşa/Antalya
15.09.2022	Ataşehir/İstanbul	19.06.2023	Palm Center/Köyceğiz/Muğla
16.09.2022	Sapanca/Sakarya	19.06.2023	Döğüşbelen/Köyceğiz/Muğla
17.09.2022	City center/Bolu	20.06.2023	Selçuk/İzmir
17.09.2022	Ilgaz/Çankırı	20.06.2023	University campus/Aydın
05.10.2022	Cihanbeyli/Konya	21.06.2023	Baklacı/Alaşehir/Manisa
05.10.2022	Tavşancalı/Konya	21.06.2023	Güre/Uşak
09.10.2022	City center/Isparta	21.06.2023	Aliağa/Gediz/Kütahya
09.10.2022	Kargı/Bucak/Burdur	22.06.2023	Adapazarı/Sakarya
09.10.2022	Avşar/Afyonkarahisar	22.06.2023	Darıdere/Bozüyük/Bilecik
10.10.2022	Polatlı/Ankara	22.06.2023	Döngelli/Akçakoca/Düzce
10.10.2022	Elmadağ/Kırıkkale	23.06.2023	Safranbolu/Karabük
10.05.2023	İlkadım/Samsun	23.06.2023	City center/Zonguldak
13.05.2023	Atakum/Samsun	24.06.2023	Asağıçaylı/İnebolu/Kastamonu
11.06.2023	Yerköy/Yozgat	30.06.2023	Yılgın/Tirebolu/Giresun

Table 2. Morphological measurements of *Aculus taihangensis* females.

Characters	Protogyne (n=5)	Deutogyne (n=3)	Protogyne (n=7) (de Lillo et al., 2017)	Deutogyne (n=18) (de Lillo et al., 2022)
Body (including gnathosoma)	242-290	216-222	237-275	194-292
Body thickness	64-67	45-58	54-70	42-60
Body width	56-60	42-58	55-57	42-56
Gnathosoma	21-22	21-22	-	21-25
Palp	21-23	22	22-27	-
Chelicerae	19-20	19-20	17-18	16-19
Shield length (including anterior lobe)	42-45	35-36	40-45	35-40
Shield width	46-48	34-46	47-49	35-45
Anterior lobe	4-6	-	4-7	-
Setae *sc*	68-77	42-43	68-81	36-43
Spacing *sc*	27-30	22-24	27-29	22-26
Leg I	42-44	40-45	40-45	41-46
Tibial setae *l´*	5-7	5-7	5-7	4-7
Tarsal setae *ft´*	20-21	21-23	19-21	21-23
Tarsal setae *ft´´*	24-26	25-28	23-27	24-29
Empodium	6-7	6-7	6	6-7
Empodium rays	5	5	5	5
Solenidion	8-9	10	8-9	9-10
Leg II	38-40	38-41	37-41	36-42
Tarsal setae *ft´*	6-7	6-7	6-7	5-8
Tarsal setae *ft´´*	21-25	25-29	22-27	24-32
Empodium	6-7	6-7	6	6-7
Empodium rays	5	5	5	5
Solenidion	8-9	10	8-9	9-10
Setae *1b*	12-13	10-13	12-15	10-14
Setae *1a*	26-32	34-47	27-38	32-45
Setae *2a*	37-45	52-59	38-42	51-63
Dorsal semiannuli	44-46	66-75	45-50	66-76
Ventral semiannuli	71-79	77-80	73-85	67-80
Semiannuli between coxae and genitalia	7-8	5-6	7	5-6
Setae *c2*	26-27	22-29	22-28	17-26
Location *c2*	9-10	8-9	9-10	8-10
Setae *d*	72-88	68-82	73-85	52-83
Location *d*	24-25	22-25	24-27	23-27
Setae *e*	27-32	22-27	32-37	22-27
Location *e*	41-49	43-48	49-52	42-48
Setae *f*	38-39	45-47	36-39	36-47
Location *f*	67-74 5 annuli to the rear	71-73 5 annuli to the rear	68-77 5 annuli to the rear	63-75 5 annuli to the rear
Genitalia width	21-22	22-24	21-22	21-25
Genitalia length	10-12	10-12	10-12	10-14
Coverflap ridges	10	10	10	8-10
Setae *3a*	22-26	28-29	19-29	20-28
Spacing *3a*	21-22	17-18	21-22	14-17
Setae *h2*	102-124	107-142	92-134	62-150
Setae *h1*	4-5	4-5	4	4-5

RESULTS

Eriophyid mites were found on leaf samples of the tree of heaven, *Ailanthus altissima*, collected at only one site, Adatepe (39°34'12.3"N 26°37'10.7"E) on 13.09.2022 in Çanakkale Province, in northwest Türkiye, of a total of 52 sites across 42 provinces of Türkiye, despite the large number of leaves checked (Table 1, Fig. 1). Fifty seven slides, that included protogynes, deutogynes and males, were prepared. The specimens were identified as *Aculus taihangensis* (Hong & Xue, 2005), which is a new record for Türkiye. Both the protogynes and deutogynes that were examined had very similar morphological characters and measurements to the specimens of de Lillo et al. (2017, 2022) (Figs 2-5, Table 2).

Protogyne (n=5). Body fusiform, prodorsal shield including rounded anterior lobe; shield pattern composed of a network of lines with a short median line and complete admedian lines; three transverse lines on the shield, first two transverse lines from the rear connect the median line with the admedian lines, forming four cells; the third transverse line joins the admedian lines, forming two median cells; third transverse line continues as arched submedian lines, forming five cells between the submedian lines and the anterior edge of the shield; five more pairs of cells between the rear margin of the shield and the admedian and submedian lines. Setae *sc* directed posteriorly, tubercles subcylindrical, on rear shield margin; solenidia distally tapered and empodium simple and 5-rayed on both legs; opisthosoma dorsally arched, dorsal semiannuli almost half the number of ventral semiannuli; dorsal opisthosoma with elliptical, elongated microtubercles, last 6-7 ventral semiannuli with elongated and linear microtubercles; genital coverflap with longitudinal striae (Fig. 2A, Table 2).

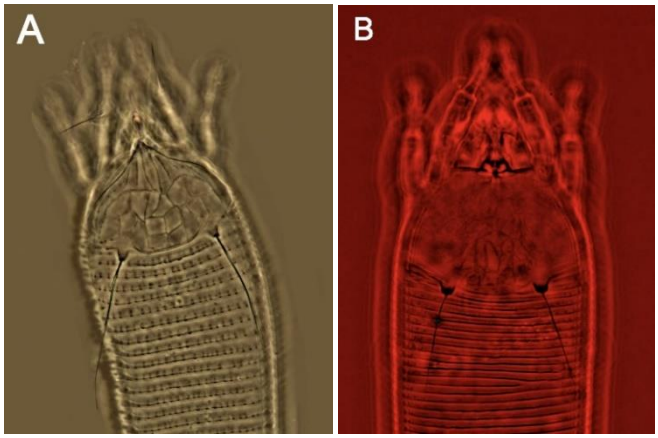

Figure 2. *Aculus taihangensis*. Prodorsal shield and part of dorsal opisthosoma: A. Protogyne, B. Deutogyne.

Deutogyne (n=3). Body vermiform, prodorsal shield including rounded anterior lobe; shield pattern indefinite, lines thinner than those of the protogyne; complete median and admedian lines connected by three transverse lines, forming cells; scapular setae *sc* directed posteriorly, tubercles *sc* subcylindrical, on rear shield margin; solenidia distally rounded, empodium simple and 5 rayed on both legs, same as protogyne; opisthosoma dorsally arched, number of the dorsal semiannuli and ventral semiannuli almost same; dorsal opisthosoma with not well defined microtubercles, last 5 dorsal and ventral semiannuli with elongated microtubercles; genital coverflap with longitudinal striae (Figs 2B, 3A-B, Table 2).

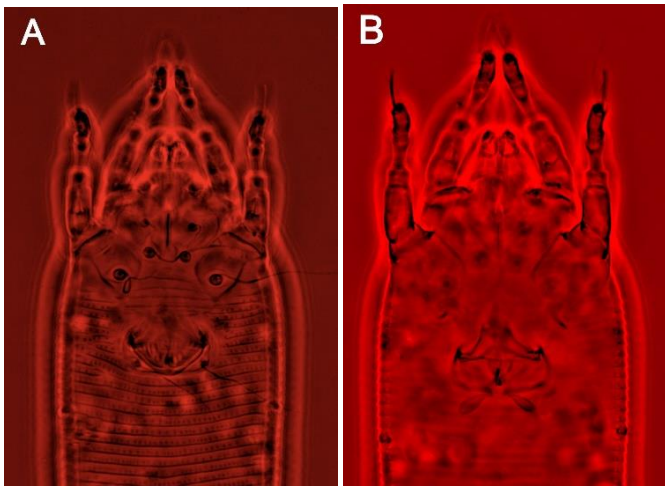

Figure 3. *Aculus taihangensis* – Deutogyne: A. Coxigenital region, B. Internal genitalia.

On the infested leaflets, there were quite dense aggregations of eggs, nymphs and adults of *A. taihangensis* along the midribs on the lower surfaces of the leaflets but no leaf curling, yellowing or other damage was observed (Fig. 5).

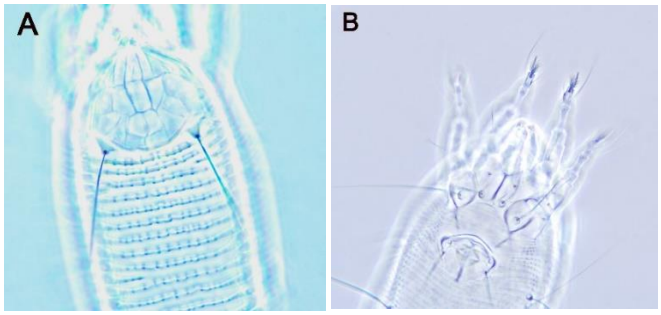

Figure 4. *Aculus taihangensis* – Male: A. Prodorsal shield and part of dorsal opisthosoma, B. Coxigenital region.

Figure 5. Dense aggregation of *Aculus taihangensis* along the midrib of a leaflet of the tree of heaven.

DISCUSSION

The tree of heaven, *Ailanthus altissima*, is an invasive plant in Türkiye where it has colonized forest edges, agricultural areas, historical sites and railway corridors, and its planting continues, without consideration of its invasiveness. Therefore, it will become a much bigger problem in the future, considering climate change scenarios for Türkiye (Uludağ, 2015). That point was reinforced by Ulus et al. (2021) who stated that there is no regional or national strategy for the management and control of *A. altissima* in Türkiye, even though it is accepted as an invasive plant species. The current study, which was focused on the collection of potential eriophyoid biological control agents of the tree of heaven, further confirmed its invasiveness in that large numbers of individual plants and clumps were observed in disturbed areas in 42 provinces across Türkiye in 2022 and 2023.

In Europe, *A. taihangensis* (=*A. mosoniensis*), was first reported from the tree of heaven in Hungary (Ripka and Ersek, 2014), and later in another 12 countries, namely Albania, Austria, Bulgaria, Croatia, Greece, Italy, Macedonia, Montenegro, Romania, Serbia, Slovenia and France (Cristofaro et al., 2018; Marini et al., 2021; de Lillo et al., 2022). The current study reports *A. taihangensis* from Türkiye for the first time.

With the presence of the tree of heaven confirmed in 27 countries in Europe (EPPO, 2023), and the presence of *A. taihangensis* (=*A. mosoniensis*) confirmed in 13 European countries, including two of its neighbouring countries, Bulgaria and Greece (Marini et al., 2021; de Lillo et al., 2022), it was not surprising to find the eriophyid, *A. taihangensis,* in Türkiye. However, despite the collection of a substantial number of leaf samples from *A. altissima* at numerous sites across Türkiye, *A. taihangensis* was detected at only one site, Adatepe, in Çanakkale Province.

It is possible that *A. taihangensis* may have been present in small numbers in some areas but inactive during the hot, dry summer period. However, there was no evidence of leaf curl or other evidence of damage on the collected leaves. A detailed study on the population dynamics of *A. taihangensis* during the entire vegetation period, and considering its protogyne and deutogyne forms, would elicit useful information on its biology and ecology.

Conclusions

The eriophyid mite, *Aculus taihangensis* (=*A. mosoniensis*), was detected on the leaves of the tree of heaven, *Ailanthus altissima*, at only one site, despite a widespread collection of samples across Türkiye. Also, no evidence of leaf damage was observed. It therefore seems highly unlikely that *A. taihangensis* is presently playing a meaningful role in the biological control of the tree of heaven in Türkiye.

Authors' contributions

Sebahat K. Ozman-Sullivan: conceptualization (equal), Methodology (equal), investigation (lead), data curation (lead), writing-original draft (equal), writing-review & editing (equal), project administration (equal). **Gregory T. Sullivan:** Conceptualization (equal), writing-original draft (equal), writing-review & editing (equal), investigation (equal). **Philipp E. Chetverikov:** Conceptualization (equal), methodology (equal), writing-review & editing (equal), project administration (equal). **Esma Kaplan:** Methodology (supporting), investigation (equal), data curation (supporting).

Statement of ethics approval

Not applicable.

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Conflict of interest

The authors have no conflicts of interest to declare in relation to the subject matter of this research.

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