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Authors: Han, Xiao, Hong, Xiao-Yue, and Zhang, Zhi-Qiang

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Identification of *Aceria genistae* species complex (Acari: Eriophyidae) from broom, gorse and related plants (Fabaceae: Genisteae) in western US and a new record of *Aculops hussongi*

XIAO HAN[1], XIAO-YUE HONG[1,3] & ZHI-QIANG ZHANG[2,3]

[1]*Department of Entomology, Nanjing Agricultural University, Nanjing, Jiangsu 210095, China*

[2]*Landcare Research, 231 Morrin Road, St. Johns, Auckland 1072, New Zealand and School of Biological Sciences, University of Auckland, Auckland, New Zealand*

[3]*Correspondent authors: zhangz@landcareresearch.co.nz; xyhong@njau.edu.cn*

Abstract

This paper reports on a collection of eriophyid mites from broom (*Cytisus scoparius*), gorse (*Ulex europaeus*), and related plants (Fabaceae: Genisteae) in the western USA, to clarify the taxonomic problems within the "*Aceria genistae*" complex on different hosts. The mites from *U. europaeus* and *Genista monspessulana,* which were previously identified as or suspected to be *Aceria genistae*, are herein confirmed as *Aceria davidmansoni*—previously known only from *U. europaeus* in New Zealand. The mites from *Lupinus albicaulis* (no galls), *Lupinus densiflorus* (with gall-like deformities although not true galls), *Cytisus striatus* and *C. scoparius* are confirmed as *A. genistae* (the first three species were used in host specificity tests for *A. genistae* from *C. scoparius* and only *C. striatus* is confirmed as a new host for *A. genistae*)*.* Another unrelated species, *Aculops hussongi* Keifer, was found on *L. albicaulis* in Nisqually, Washington, USA.

Key words: eriophyoid mites, taxonomy, identification, morphology, host plants, *Aceria genistae*

Introduction

The Eriophyoidea is a large superfamily of obligate plant-feeding mites, with over 4,000 described species (Zhang *et al*. 2011). The eriophyoid mites are highly host-specific, with nearly 80% of them known from a single host species, 95% from one host genus, and 99% from one host family; furthermore, non-monophagous species are often found on closely related host species (Skoracka *et al.* 2010).

Aceria genistae (Nalepa, 1891) *sensu lato* is native to Europe and has been reported from species of three plant genera *Cytisus*, *Ulex* and *Genista* (Fabaceae) (Amrine & Stasny 1994; Smith *et al.* 2010). This is an unusually wide host range for a species of *Aceria*, most of which are monophagous; only some species of *Aceria* are known to feed on multiple species within one plant genus, and a species of *Aceria* rarely attacks related plant genera (Lindquist 1996a). It has been suggested that there might be a complex of cryptic mite species or host-specific biotypes associated with the brooms and gorse (Chan & Turner 1998; Syrett *et al.* 1999; Smith *et al.* 2010). Castagnoli (1978), working in Italy, showed that the mite resembling *A. genistae* on *Spartium junceum* L. (Spanish broom) was a distinct species, *A. spartii* (Canestrini). Working on the *Aceria genistae* species complex in New Zealand, Xue *et al.* (2015) recently described a new species, *Aceria davidmansoni*, found on gorse *Ulex europaeus* L., which Manson (1989) had previously misidentified as *A. genistae*. They confirmed the earlier suspicion of a species complex on Scotch broom and gorse in New Zealand: *A.*

genistae on *Cytisus scoparius* only and *A. davidmansoni* on *U. europaeus*. Xue *et al.* (2015) presented both qualitative and quantitative descriptions and comparisons for differentiating *A. genistae* and *A. davidmansoni* in New Zealand. They also fixed the identity of *A. genistae* by designating a neotype collected from *C. scoparius* in Europe. This provides a foundation for clarifying taxonomic problems for mites identified or reported as *A. genistae* in other areas such as USA (Chan & Turner 1998; Smith *et al.* 2010; Andreas *et al.* 2013).

Aceria genistae has become an important species of *Aceria* because of its potential as a biological control agent against Scotch broom (*C. scoparius*) in Australia and New Zealand (Syrett *et al.* 1999). In North America, *A. genistae* was first discovered on Scotch broom in Portland, Oregon, and Tacoma, Washington in 2005 and was believed to be accidentally introduced (Andreas 2010; Smith *et al.*, 2010; Andreas *et al.* 2013). It is now widespread between Oregon and Washington in the USA and extends to southern British Columbia in Canada (Andreas *et al.* 2013), and has been found at many sites in the northern half of California between 2014 and 2015 (Andreas, personal communication). The mite appears to damage *C. scoparius* in the field, reducing flowering and plant biomass, although quantitative data from controlled experiments are not available (Smith *et al.*, 2010). At high mite densities, stem mortality and even whole plant mortality were observed (Andreas, pers. comm.). Chan & Turner (1998) reported *A. genistae* from both gorse and French broom in California, USA, but also discussed the possibility of a species complex. Host specificity tests (in both greenhouse and fields) of *A. genistae* against *C. striatus* (Portuguese broom), *Lupinus densiflorus* and *Lupinus albicaulis* were conducted using mites from *C. scoparius* in Washington State and a species complex is suspected (Andreas 2010 & pers. comm.).

This study was initiated during our earlier work on New Zealand eriophyoid mites in general (Xue & Zhang 2008) and the "*Aceria genistae*" complex in particular (Xue *et al.* 2015). For comparison with New Zealand material, we loaned specimens identified as "*Aceria genistae*" from Europe and North America, including specimens from California sent by both K. L. Chan and Jim Amrine. J. Andreas also sent specimens of her host specificity tests and collections from western US (Andreas 2010). In this study, we examined these mite specimens suspected to be *A. genistae* from a series of plant hosts of the tribe Genisteae, including *C. scoparius*, *C. striatus*, *U. europaeus*, *L. densiflorus* and *L. albicaulis*, and *G. monspessulana* from western USA and Canada. This paper aims to identify the eriophyoid mite species from different hosts in USA. We also briefly discuss mite-plant association in relation to phylogenetic relationship among those host species (Genisteae).

Material and methods

Specimens of eriophyoid mites were collected from USA and Canada, with details presented in the material examined section for each species. The morphological terminology used in this paper is that of Lindquist (1996b) whereas the system of classification follows that of Amrine *et al*. (2003). General methods of study follow Xue *et al*. (2015). There were not enough specimens from every host plants to allow a full multivariate discriminant analysis; thus a simple analyse of variance (see Table 1) in GenStat 10 was used for measurements and LSD was used to separate means in multiple comparisons at the significance level of 0.05. The sample sizes are listed in specimen examined section for each species. All slide-mounted specimens are vouchered in the New Zealand Arthropod Collection (NZAC), Landcare Research, Auckland.

TABLE 1. Analysis of variance main morphological distinguished characters among *Aceria genistae* (Nalepa) and *Aceria davidmansoni* Xue, Han & Zhang 2015 from different hosts and locations (for female individuals).

species	host	location	body length	prodorsal shield length	prodorsal shield width	length of setae *sc*	no. of dorsal annuli	no. of ventral annuli	length of setae *c2*
1 *A. d.*	*U. e.*	Naselle, OR	216.7±14.5 ab	26.5±1.2 c	30.0±2.7 a	17.0±1.4 ab	92.5±3.7 ab	83.5±3.6 b	24.0±2.0 d
2 *A. d.*	*U. e.*	Ocean Shores, WA	243.6±9.5 a	31.1±0.6 a	31.2±1.1 a	17.8±0.5 ab	88.0±2.0 bc	78.6±1.9 bc	21.6±1.1 de
3 *A. d.*	*U. e.*	Albany, CA	240.0±11.3 a	30.0±0.8 ab	30.0±2.7 a	17.0±0.6 ab	98.2±2.1 a	91.5±2.1 a	24.5±1.1 d
4 *A. d.*	*U. e.*	Daly, CA	191.1±8.4 b	30.6±0.6 ab	31.0±1.0 a	15.9±0.5 bc	83.9±2.0 cd	72.4±2.3 cd	17.4±1.0 e
5 *A. d.*	*G. m.*	Daly, CA	210.0±12.6 ab	26.7±1.0 c	27.5±1.9 a	17.3±0.7 ab	97.5±2.6 a	91.0±2.5 a	23.7±1.4 d
6 *A. g.*	*L. a.*	Nisqually, WA	191.7±14.5 b	28.3±1.0 bc	30.0±1.9 a	14.3±0.8 c	79.3±3.0 d	65.5±3.6 d	33.7±1.6 bc
7 *A. g.*	*L. d.*	Greenhouse, WA	187.0±11.3 b	29.7±0.8 ab	30.0±1.9 a	16.0±0.8 bc	79.8±2.3 d	70.0±2.3 d	32.2±1.2 bc
8 *A. g.*	*C. sc.*	Greenhouse, WA	185.0±25.2 b	30.0±1.7 ab	30.0±2.7 a	16.0±1.4 bc	80.0±5.2 cd		35.0±2.8 b
9 *A. g.*	*C. sc.*	Nisqually, WA	208.9±9.5 ab	29.2±0.7 abc	31.7±1.6 a	19.2±0.6 a	81.1±2.0 cd	70.1±1.9 d	39.6±1.1 a
10 *A. g.*	*C. st.*	Pierce Plot, WA	197.5±10.3 b	28.5±0.7 abc	32.4±1.2 a	16.0±0.6 bc	79.7±2.6 d	67.0±2.5 d	30.2±1.1 c
		d.f.	9.00	9.00	9.00	9.00	9.00	8.00	9.00
		P	<.001	0.01	0.75	<.001	<.001	<.001	<.001

species	host	location	setae *c2* apart	length of setae *d*	setae *d* apart	length of setae *e*	setae *e* apart	length of setae *f*	setae *f* apart
1 A. d.	*U. e.*	Naselle, OR	50.0±5.3 ab	54.0±1.7 a	42.0±4.7 ab	5.5±0.8 de	22.0±1.8 bcd	19.0±1.1 ab	21.0±1.7 ab
2 A. d.	*U. e.*	Ocean Shores, WA	50.1±2.0 ab	50.4±1.1 a	39.7±1.8 abc	6.4±0.4 d	23.3±0.7 abc	19.4±0.6 a	20.8±0.8 ab
3 A. d.	*U. e.*	Albany, CA	37.0±5.3 c	52.8±1.0 a	30.0±4.7 d	5.8±0.4 de	20.0±1.8 cd	20.0±0.6 a	18.0±1.7 bcd
4 A. d.	*U. e.*	Daly, CA	48.0±2.1 abc	40.0±1.0 b	38.2±2.1 bcd	5.3±0.4 de	21.7±0.7 bcd	19.1±0.5 ab	20.7±0.7 ab
5 A. d.	*G. m.*	Daly, CA	40.0±5.3 bc	50.7±1.2 a	36.5±3.3 bcd	4.7±0.5 e	25.0±1.8 ab	20.0±0.9 a	19.0±1.7 abc
6 A. g.	*L. a.*	Nisqually, WA	44.5±3.7 abc	40.7±1.4 b	35.5±3.3 bcd	8.3±0.6 c	19.5±1.2 d	16.5±1.1 b	19.5±1.2 abc
7 A. g.	*L. d.*	Greenhouse, WA	37.5±3.7 c	41.8±1.1 b	31.7±2.7 cd	9.6±0.5 bc	20.2±0.9 cd	18.0±0.9 ab	15.4±0.8 d
8 A. g.	*C. sc.*	Greenhouse, WA		40.0±2.4 b		12.0±1.1 a		19.0±1.5 ab	
9 A. g.	*C. sc.*	Nisqually, WA	53.2±2.6 a	41.8±1.0 b	47.2±2.3 a	10.8±0.4 ab	26.5±0.9 a	19.3±0.6 a	21.7±0.9 a
10 A. g.	*C. st.*	Pierce Plot, WA	43.3±3.1 abc	35.8±1.1 c	34.2±1.9 bcd	9.6±0.5 bc	19.2±0.9 d	16.7±0.7 b	16.2±0.8 cd
		d.f.	8.00	9.00	8.00	9.00	8.00	9.00	8.00
		P	0.03	<.001	0.01	<.001	<.001	0.04	<.001

Note: *A. d.—Aceria davidmansoni, A. g.—Aceria genistae, U. e.—Ulex europaeus, G. m.—Genista monspessulana, L. a.—Lupinus albicaulis, L. d.—Lupinus densiflorus, C. sc.—Cytisus scoparius,C. st.—Cytisus striatus.*

Species accounts

Aceria genistae (Nalepa, 1891)

Phytoptus genistae Nalepa, 1891: 162 (Chetverikov *et al*., 2016's interpretation of the date for this species is followed here).
Phytoptus genistae Nalepa; Nalepa, 1892: 532.
Aceria genistae (Nalepa); Roivainen, 1953: 13–14.

Eriophyes genistae (Nalepa); Castagnoli, 1978: 540–542.
Aceria genistae (Nalepa); Amrine & Stansy, 1994: 48–49.
Aceria genistae (Nalepa); Baker *et al*., 1996: 320–322.
Aceria genistae (Nalepa); Syrett *et al*., 1999: 19, 26, 28, 29.
Aceria genistae (Nalepa); Xue *et al*., 2015: 74–78.

Material examined. 7 females, from *Cytisus scoparius* (L.) Link (Fabaceae), Nisqually, Washington, USA, September 7, 2011, coll. J. Andreas; 1 female, from *Cytisus scoparius* (L.) Link (Fabaceae), a greenhouse located in Puyallup at the Washington State University, Puyallup Research and Extension Center, Washington, USA, September 17, 2010, coll. J. Andreas; 6 females, from *Cytisus striatus* (Hill) Rothm. (Fabaceae), Pierce Plot located in Lakewood, Washington, USA, October 3, 2010, coll. J. Andreas; 3 females, from *Lupinus albicaulis* (L.) Link (Fabaceae), Nisqually, Washington, USA, September 7, 2011, coll. J. Andreas; 5 females, from *Lupinus densiflorus* Benth. (Fabaceae), a greenhouse, in Washington, USA, August 12, 2010, coll. J. Andreas.

Remarks. *Aceria genistae* found in USA is similar to that found in New Zealand (introduced from France), but has fewer ventral annuli: 63–75 ventral annuli in *A. genistae* from USA versus 75–83 ventral annuli in *A. genistae* from New Zealand. Compared with *A. davidmansoni* from *U. europaeus* and *G. monspessulana*, *A. genistae* has fewer ventral annuli (except *Ulex*-Daly), longer setae c_2 and setae *e*, shorter setae *d* (except *Ulex*-Daly) (see the data in Table 1).

Aceria genistae from *C. striatus* were collected from plants placed under galled *C. scoparius* in open field choice tests where galled material of the latter was placed directly on the former to test if *A. genistae* could survive on the new host plant and induce galls. Small galls and infected buds were found 3 years after the experiment (Andreas, pers. comm.). Gall development was also observed in a hybrid *C. scoparius* x *C. striatus* (Andreas *et al*. 2013). This new plant host for this species confirms that *A. genistae* is not monophagous. It should be noted that in the mid-1990s, before *A. genistae* was introduced to Australasia, host specificity tests were conducted in greenhouses in France with no mite survival or gall-formation on *C. striatus*, *Chamaecytisus palmensis*, *S. junceum*, *G. tinctoria*, *Medicago arborea* and *Laburnum anagyroides* after 3 years (Q. Paynter, pers. comm.). Even in the control test, only two of the six *C. scoparius* plants had galls.

Lupinus albicaulis, commonly known as sickle-keel lupine, is often found in mountain habitats from California to Washington and has been cultivated for reforestation or revegetation of disturbed habitats in Oregon (Rumbaugh 1990). The plants in Nisqually were intermixed with naturally growing galled *C. scoparius*; although *A. genistae* were found on *L. albicaulis* for several years, no galls were present (Andreas, pers. comm.). It is obvious that *A. genistae* dispersed from *C. scoparius* to *L. albicaulis* although without gall formation and thus had limited effect on this host. Another mite species, which we identified as *Aculops hussongi* Keifer, 1966, was also found on *L. albicaulis* (personal correspondence from J. Andreas).

Lupinus densiflorus (also known as *Lupinus microcarpus* var. *densiflorus*) is considered a species at risk by Parks Canada Agency (2011). In greenhouse tests, *L. densiflorus* were exposed to galled *A. genistae* for seven weeks and later *A. genistae* without galls were found on *L. densiflorus* (Andreas, pers. comm.). Although substantial "gall-like" growth was found on *L. densiflorus* in greenhouses, Andreas (2010) could not be certain that mite transfers were not contaminated, and similar "gall-like" growth was not replicated under field conditions on Vancouver Island where only one eriophyid mite was present and Scotch broom intermixed with naturally occurring *L. densiflorus*. It should be noted that *A. genistae* on *L. densiflorus* was tentatively considered "as closely resembling *A. spartii*" by Jim Amrine, who was asked to identify the specimens (Andreas 2010). Our study of the specimens sent to us by Amrine confirms that it is *A. genistae*.

Aceria davidmansoni Xue, Han & Zhang, 2015

Aceria genistae (Nalepa); Manson, 1989: 39–40 [ex gorse—incorrect identification].
Aceria genistae (Nalepa); Chan & Turner, 1998: 55–57 [incorrect identification].
Aceria davidmansoni Xue, Han & Zhang, 2015: 78–83.

Material examined. 3 females, from *Ulex europaeus* L. (Fabaceae), Ilwaco, Washington USA, August 12, 2010, coll. J. Andreas; 7 females, from *Ulex europaeus* L. (Fabaceae), Ocean Shores, Washington, USA, September 28, 2010, coll. J. Andreas; 9 females and 4 males, from *Ulex europaeus* L. (Fabaceae), Albany, Alameda, California, USA, February 1, 1995, coll. K. L. Chan; 6 females and two males, from *Ulex europaeus* L. (Fabaceae), Daly City, San Mateo County, California, USA, May 3, 2000, coll. K. L. Chan; 4 females and one male, from *Genista monspessulana* (L.) L.A.S. Johnson (Fabaceae), Daly City, San Mateo County, California, USA, May 3, 2000, coll. K. L. Chan.

Remarks. This species was previously known only from gorse in New Zealand (Xue *et al.* 2015). *A. davidmansoni* found in USA is very similar to that in New Zealand.

Chan & Turner (1998) previously reported "*Aceria genistae*" from both gorse and French broom in California; we were able to study a sample of voucher material collected by Chan from gorse in 1995 (these specimens were sent by Chan to Jim Amrine for identification and we loaned them from Amrine) and also additional specimens Chan collected from both gorse and *G. monspessulana* in California in 2000; this species is *A. davidmansoni*. *G. monspessulana* is thus a new host record for this species, and the USA is a new distribution record for *A. davidmansoni*, which was known only from New Zealand. It should be noted that *Aceria* on gorse in Washington, USA was tentatively considered as "*Aceria spartii*" by Jim Amrine who sent the specimens for identification (Andreas 2010).

This species was collected from two host species in four localities from California to Washington. Measurements of quantitative characters of *A. davidmansoni* from *G. monspessulana* fall within the range of varation of these among four *A. davidmansoni* from *U. europaeus* in four localities (Table 1).

Aculops hussongi Keifer, 1966

Aculops hussongi Keifer, 1966: 11.

Material examined. 12 females, from *Lupinus albicaulis* L. (Fabaceae), Nisqually, Washington, USA, September 7, 2011, coll. J. Andreas.

Remarks. This rapid-moving mite species was found together with *A. genistae* on *L. albicaulis* in Nisqually, Washington (personal correspondence from J. Andreas). This species was originally described from *Lupinus obtusilobus* Heller (Fabaceae) in upper Kings Creek, Lassen National Park, Shasta County, California. The specimens from Nisqually, Washington agree with the original description with one exception: Keifer (1966) noted 72 ventral annuli in specimens from *L. obtusilobus*, whereas, we observed 61–66 annuli in specimens from *L. albicaulis. L. albicaulis* is a new host record for *Aculops hussongi* and Washington represents a new state record for this species in the US.

Discussions on host relationships

In both Australasia and North America, host specificity tests and biological observations suggested a complex of cryptic *Aceria* species associated with the brooms and gorse (Chan & Turner 1998; Syrett *et al.* 1999; Smith *et al.* 2010). In a previous paper, we showed that in New Zealand, the real *A. genistae* attacks only *C. scoparius*, and a related mite species—*A. davidmansoni*, previously misidentified as *A. genistae* by Manson (1989)—is present on *U. europaeus* (Xue *et al.* 2015). In this study, we showed that the mites from *U. europaeus* and *G. monspessulana* in California, USA, previously misidentified as *A. genistae* (Chan & Turner 1998), are in fact *A. davidmansoni*. In both cases, *A. davidmansoni* can be clearly distinguished from *A. genistae* qualitatively by the pattern on the prodorsal shield and quantitatively by several characters such as the number of annuli on the hysterosoma (Xue *et al.* 2015; Table 1 of this paper).

Specialist herbivores such as eriophyid mites show strong host-dependent morphological variation in adaptation to different host species and environmental conditions (Skoracka *et al.* 2002). For example, Skoracka *et al.* (2014) reported that some characters (the length of the *c2* setae, the number of dorsal annuli, and the length of chelicerae) could differentiate host-related species of eriophyoid mites (between the DBM and MT-1 genotypes), resolving the previous taxonomic confusion between wheat curl mite (*Aceria tosichella*) and dry bulb mite (*Aceria tulipae*). Our results, both this one and Xue *et al.* (2015), also showed that such characters as the length of setae *c2* and *e* could differentiate *A. genistae* and *A. davidmansoni*, in addition to qualitative features (the pattern on the prodorsal shield) Within species, there is evidence of morphological variation in adaptation to different environmental conditions and host species. For *A. genistae* on Scotch broom, mites in the field and greenhouses are similar in most characters, but setae *c*2 were slightly shorter in specimens from the greenhouse (Table 1, line 8 versus line 9). For *A. genistae* on *Cystius*, most dorsal setae (*sc*, *c*2, *d*, *f*) were shorter in specimens from *C. striatus* than those from *C. scoparius* (Table 1, line 9 versus line 10). For *A. genistae* on Scotch broom and *L. densiflorus* intermixed in greenhouses, divergence in only setal length of *e* was observed (Table 1, line 7 versus line 8). For *A. genistae* on Scotch broom and *L. albicaulis* intermixed in the field, divergence in setal lengths of *sc*, *c*2, *e*, and *f* was observed (Table 1, line 6 versus line 9).

We summarized the relationships within tribe Genisteae based on the phylogenetic information in Pardo *et al.* (2004) and Cristofolini and Feoli-Chiapella (1981), and listed different eriophyoid mite species known from these plants (Table 2). *Lupinus* is distantly related to *Cystius*, and it is therefore not surprising that *A. genistae* failed to form galls on *Lupinus* in host specificity tests in Washington. In contrast, *C. striatus* is of same genus as broom and *A. genistae* was able to establish on this host species. Likewise, *U. europaeus* and *G. monspessulana* are more closely related and it therefore does not seem surprising that *A. davidmansoni* was found naturally on both plants in the wild in Daly City, California. It should be noted that most other species of *Aceria* (except *A. spartii*) in Table 2 are poorly known and in serious need of taxonomic revision. There are significant gaps in both the knowledge of the relationship among the host plants in Genisteae and the knowledge of *Aceria* on these related host species. However, there seems little doubt that there is a complex of *Aceria* species on Genisteae, some being perhaps monophagous and some having slightly broader host ranges (feeding on closely related host species) with minor intraspecific variation.

TABLE 2. The relationships of host plants, eriophyoid mites from the related host plants and its reference source.

Relationships of host plants*	Host plants	*Aceria* species	Reference Source /new observation
1.1	*Crotalaria juncea*	*A. crotalariae*	ChannaBasavanna, 1966
1.2	*Crotalaria* sp.	*A. tanzanica*	Abou-Awad & El-Banhawy, 1992
2.1.1	*Lupinus albicaulis*	*A. genistae*	Field tested host plant (not fully established, without galls)
2.1.2	*Lupinus densiflorus*	*A. genistae*	Greenhouse tested host plant (not fully established, without galls)
2.2.1	*Cytisophyllum sessilifolium*	*A. cytisi*	Canestrini, 1891
2.2.1	*Cytisophyllum sessilifolium*	*A. grandipennis*	Canestrini, 1891
2.2.2.1	*Cytisus striatus*	*A. genistae*	New host record
2.2.2.2	*Cytisus scoparius*	*A. genistae*	Nalepa, 1892
2.2.3.1	*Echinospartum boissieri*	*A. boissieri*	Roivainen, 1953
2.2.3.2	*Spartium junceum*	*A. spartii*	Canestrini, 1893
2.2.4.1.1	*Genista tridentata*	*A. diasi*	Carmona, 1974
2.2.4.1.2	*Genista monspessulana*	*A. davidmansoni*	New host record (this study)
2.2.4.2	*Ulex europaeus*	*A. davidmansoni*	Xue *et al*., 2015

*The relationships of host plants were expressed here following the convention of Zhang (2011) with phylogenetic information from Ainouche *et al.* (2004), Pardo *et al.* (2004) and Feoli & Cristofolini (1981).

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