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Aulacaspis madiunensis (Zehntner) (Hemiptera: Diaspididae) – an additional danger to the endangered *Cycas circinalis* L.

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ABSTRACT: Armored scale insects (Hemiptera: Diaspididae) are major economic pests and are among the world's most invasive species. Most armoured scale insect pests are invasive and with increased international trade, these concealed and cryptic pests pose a serious threat to the world agricultural economy causing economic losses in the US to be as high as $1 billion annually. *Aulacaspis* Cockerell is one of the largest genera of armoured scale insects with 151 species known worldwide, and 23 species from India. Five species of *Aulacaspis* are associated with *Cycas* spp. throughout the world. Through this correspondence, we report the occurrence and severe infestation of *A. maduinensis* (Zehntner) on *C. circinalis* from India, though it has been reported to infest other species of *Cycas* from elsewhere. We provide information about nature and extent of damage, field and taxonomic diagnostic characters which will be helpful in quick diagnosis of the pest, monitoring its spread to different geographical areas, and generation of awareness about the pest species to avoid further economic loss.

Keywords: Armoured scale insects, cycads, taxonomy, diagnostic characters, outbreak

INTRODUCTION

Armored scale insects (Hemiptera: Diaspididae) are major economic pests and are among the world's most invasive species (Nomark *et al*., 2019). Out of a total 8373 scale insects (Superfamily Coccoidea) recorded throughout the world, 640 species (7.6 percent) are considered as pest species. Of these, 7.6 percent, armoured scale insects top the list with 222 species (34 percent) being considered pests in agriculture, horticulture, and forestry (Kondo and Watson, 2022). Most armoured scale insect pests are invasive and with increased international trade, these concealed and cryptic pests pose a serious threat to the world agricultural economy causing economic losses in the US to be as high as $1 billion annually (Miller and Davidson 2005).

In India, 236 species under 66 genera of armoured scale insects have been reported so far. Recently, *Aulacaspis crawii* (Cockerell) was reported to have invaded and caused heavy damage to *Melia dubia* Cav. (Meliaceae) plantation of Kerala (Joshi *et al*., 2022), similarly, a heavy incidence of *Rutherfordia major* (Cockerell) on lovi-lovi *Flacourtia inermis* Roxb. (Salicaceae) was reported in Kerala (Prathapan, 2022). Earlier to this, *Lopholeucaspis japonica* (Cockerell) was reported as an emerging pest of pomegranate in Gujarat (Harsur *et al*. 2018). In south India, a serious infestation of *Myrtaspis ramakrishnai* (Rao) covering the whole trunk and branches of *Syzygium cumini* and *S. calophyllifolium* is a regular sight in homesteads (Sankaran, 1984). Of late, a newly described species *Aulacaspis elettaria* Joshi & Nafeesa was reported causing substantial damage to economically important *Elettaria cardamomum* (L.) Maton (Zingiberaceae) in Idukki high ranges of Kerala (Joshi *et al*., 2023).

The genus *Cycas* (Cycadales: Cycadaceae), with approximately 98 known species, belongs to one of the oldest plant groups. Due to its structure, *Cycas* species are utilized as ornamental plants in urban gardens shaping the landscape of different cities (Valverde, 2015). It is a Red Listed Endangered species (IUCN Red List: Varghese *et al*., 2009) and apart from other reasons, incidence of insect pests is cited as an important factor for its declining population. In south India, young leaves are used as food whereas, mature leaves are used for thatching and during religious and cultural events for decorations. Seeds, pith and male cones are also used as insect repellent (Verghese and Ticktin, 2006).

It is considered as Indian endemic gymnosperm species restricted to the Western Ghats and hills of the southern peninsular, as far north-east as Chennai, in the states of Kerala, Karnataka, Tamil Nadu and Maharashtra (Hill 1995; Hill *et al*., 2003), but it has been claimed that the plant is widely cultivated in Hawaii for its appearance in landscapes and interiors, and for cut foliage (Ruth and Rauch, 1988). However, Lindstrom and Lindstrom stated *C. circinalis* to be native to southern India and Sri Lanka, they further specified that the species name was formerly widely used for similar cycads in Southeast Asia, which leads to confusion about its distribution in the world. The specimens described as *C. circinallis* in Indonesia and New Guinea are now recognized as *C. rumphii*, while the taxon formerly described as the subspecies *C. circinalis* ssp. *riuminiana* from the Philippines is now regarded as a separate species, *C. riuminiana* (Lindstrom *et al*., 2008; Lindstrom *et al*., 2009). The table 1 enlists scale insect pests reported on *C. circinalis* throughout the world (García Morales *et al*., 2016), which also indirectly indicates presence of *C. circinalis* in 16 countries, however, the authenticity of identification of the host plants in these studies has to be confirmed.

Aulacaspis Cockerell is one of the largest genera of armoured scale insects with 151 species known worldwide, and 23 species from India, 13 of which are known from south India. Five species of *Aulacaspis* are associated with *Cycas* spp. throughout the world (García Morales *et al*., 2016). Through this paper, we report another species *Aulacaspis maduinensis* (Zehntner) severely infesting *C. circinalis* in Kerala, though it has been reported to infest other species of *Cycas* from elsewhere (Suh, 2016).

MATERIALS AND METHODS

Collection of insects

Scale insect-infested plant parts were collected and brought to the laboratory. The females of insects were carefully collected by removing the armour and preserved in 70 % ethanol. Parts of the infested plants were kept as such in the containers, each covered with a lid ventilated with wire mesh, for emergence of parasitoids and predators.

Mounting and identification

The field-collected preserved specimens were slide mounted in Canada balsam following Williams and Watson (1988). Morphological terminology also follows the same authors. The species was identified based on the description of *Aulacaspis* spp. attacking mangroves and cycads (Takagi and Faveri, 2009) and grasses and herbs (Takagi, 2015). Observations on the morphology of the slide-mounted female were based on 52 specimens mounted on 4 slides.

Photographic illustration

Photographs of the live coccids were taken using a camera (Leica DFC 420) mounted on a stereozoom microscope (Leica M205A). Slide-mounted adult females were observed through a microscope (Nikon Eclipse 80i) and photomicrographs were captured with a camera (Nikon DSVi1) mounted on the microscope. Figure 1 h, i and j were taken using a 60 mm Micronikon lens mounted on a Nikon D3000 camera body. All the plates were generated using Adobe Photoshop CS2.

Material examination

Kerala: Kozhikode, Vatakara, Chekkiad, 11.731716°N, 75.627268°E, 3 ♀♀ on *Cycas circinalis* (Cycadaceae), 18.viii.2023, Aparna Gokul Coll.; Kerala: Kozhikode, Vatakara, Thuneri, 11.706951°N, 75.629963°E, 4 ♀♀ on *Cycas circinalis* (Cycadaceae), 25.viii.2023, Aparna Gokul Coll.; Kerala: Kozhikode, Vatakara, Mudavantheri, 11.724145°N, 75.630161°E, 6 ♀♀ on *Cycas circinalis* (Cycadaceae), 29.viii.2023, Aparna Gokul Coll.; Kerala: Kannur, Panoor, Chokli, 11.708365°N, 75.572491°E, 39 ♀♀ on *Cycas circinalis* (Cycadaceae), 18.xi.2023, Sachin, K. Coll.

Voucher specimen deposition

Voucher specimens of *A. maduinensis* (accession nos NBAIR/HEM/Aula/180823-1-3; NBAIR/HEM/Aula/250823-4-7; NBAIR/HEM/Aula/290823-8-13; NBAIR/HEM/Aula/181123-14-52) are deposited in ICAR – National Bureau of Agricultural Insect Resources, Bengaluru.

RESULTS AND DISCUSSION

Incidence of *A. madiunensis* was first observed in March 2023 and several farmers from North Kerala brought the news of the incidence and spread of the new insect pest on *Cycas* to our notice. Our field surveys revealed that the infestation of the scale insect began from the base of the rachis and then spread on both the upper and lower surfaces of the leaflets, completely covering it with a crowded population of female and male scale insects (Fig. 1a). Later the infestation spread on megasporophyll and the surface of the nuts (Fig. 1b). In severe cases, the scale insects were seen to gather on the stem covering the whole length of the tree (Fig. 1c). As a result of continuous sap sucking from the parenchyma tissues of different plant parts, the leaflets, nuts, and complete crown started giving a dried appearance (Fig. 1d, e & f). At some locations, the whole crown decayed

which resulted in the death of the trees (Fig. 1g). Five to ten numbers of females and males were found to settle in a 1 cm^2 area of both leaf and bark. The panchayats viz., Chekkiad, Valayam, Tuneri, Nadapuram, Purameri, Kunnumal and Eramala of Kozhikode district and Tripangoottur, Panoor and Kunnothuparambu of Kannur district were severely affected. More than 260 trees were found to be heavily infested in the above locations and 90 percent of the heavily infested trees were more than 50 years old.

Field characters: Adult female cover flat, circular or oval, greyish white (Fig. 1h); shed skin marginal or submarginal, yellowish-brown. Male cover elongate, parallel-sided, bright white (Fig. 1h – marked with arrows), felted, with two longitudinal ridges on submarginal areas; shed skin marginal, yellow or brown. Body of adult female elongate to oval, with reddish brown prosoma and pygidium and pale yellow anterior abdominal segments (Fig. 1i). Marginal gland spine distinctly visible, pale whitish yellow. Eggs reddish yellow (Fig. 1j). Heavy infestation on leaf sheath, petiole, rachis, upper and lower surfaces of leaflets. Females initially crowded and overlapping around midrib of the leaflets and later disperse on the surfaces.

Slide-mounted specimens: Completely grown adult female with swollen prosoma (Fig. 2a), distinctly broader than metathorax, roughly trapezoid, with lateral margins oblique and straight; prosomatic tubercles slightly developed; abdominal segment II strongly produced laterally, as broad as metathorax, abdominal segment I recessed between them. Pygidium triangular, with four pairs of lobes (Fig. 1b). Median lobe sunken into apex of pygidium; mesal margin close together, nearly parallel or a little separated basally, then weakly divergent; each lobe minutely serrated on mesal and lateral margins, rounded apically; basal zygosis in an arch. Lobules

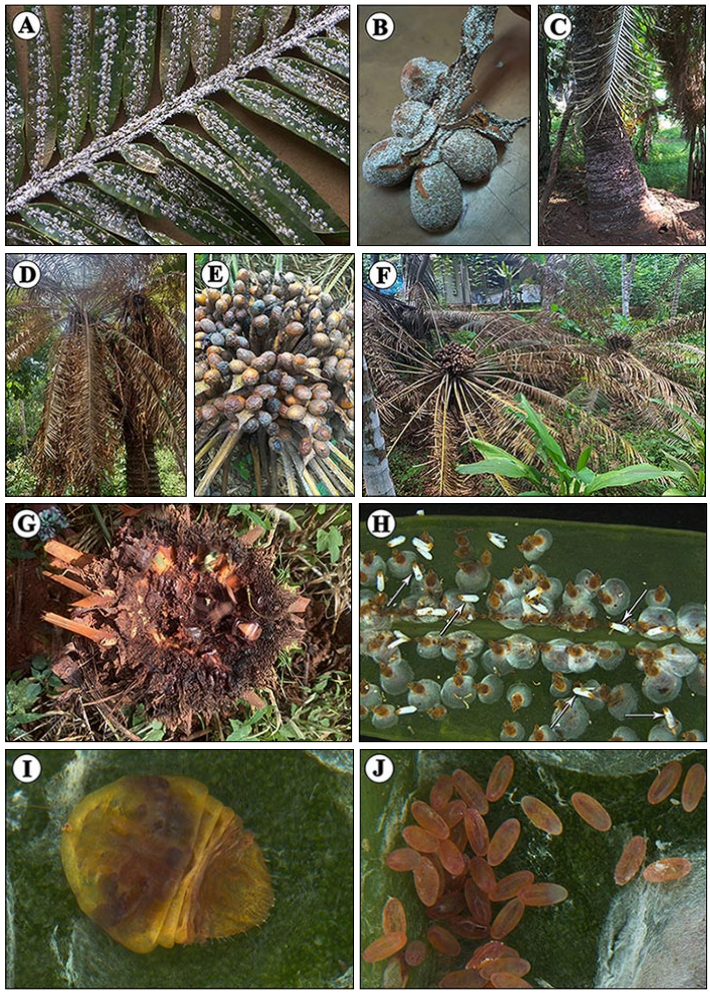

Fig 1. Damage caused by *Aulacaspis madiunensis* (Zehntner): A, Heavily infested leaf; B, infestation on megasporophyll and nuts; C, pest-ridden tree trunk; D, dried foliage; E, dried and shrunken nuts; F, field showing withered trees due to the pest; G, dead crown; H, close-up of females and males; I, mature female with scale cover overturned; J, eggs of the scale insect

Fig 2. Diagnostic features of *Aulacaspis madiunensis* (Zehntner): A, Female derm; B, dorsal macroducts associated with pygidial margin; C, apex of the pygidium showing lobes and gland spines; D, microducts; E, antenna; F, anterior spiracle; G, close-up of trilocular pores associated with spiracles; H, posterior spiracle; I, perivulvar pores in five groups; J. close-up of perivulvar pores; K. lateral macroducts; L, dorsal boss; M. peribuccal sclerosis

of the second lobe well developed, the lateral a little smaller than the mesal; third lobe with broader lobules Gland spines singly between median and second lobes, between second and third lobes, singly on segment 5 and 6 and numerous around edges of segments 2 to 4. Gland spine formula 1–1–1 (Fig. 1b). Pore prominence (Fig. 2c) on abdominal segment VI produced nearly the same as mesal lobules of third lobe; pore prominence on VII hardly produced to level of apex of mesal lobule of second lobe. Marginal processes occurring laterad of pore prominence on abdominal segment IV and those on V broad, flattish, and serrate. Prepygidial gland spines slender. Dorsal ducts in submedian and submarginal rows (Fig. 1c – marked with arrows) on segments 3 to 5, and in a submarginal group of 3-4 on segment 6 (Fig. 2d). A few smaller ducts on margins of segments 2 and 3. Minute ducts present anteriorly on margins to head (Fig. 2e). Lateral bosses present in some specimens on segments 1 and only in two specimens on segment 6 (Fig. 2f). Anterior spiracle with compact group of 18 – 32 disc pores (Fig. 2g); posterior spiracle with relatively smaller group consisting of 7 – 17 pores (Fig. 2h). Spiracular pores trilocular (Fig. 2i). Perivulvar pores in five groups (Fig. 2j): 21 – 37 in anterolateral group, 20 – 32 in posterolateral group and 14 – 24 in the medial group. Perispiracular pores quinquelocular (Fig. 2k). Microducts in rows on pygidium and on margins of free abdominal segments. Minute ducts present near margins of thorax. Antenna each with a single seta (Fig. 2l). Prebuccal sclerosis well developed (Fig. 2m). Ventral side of abdominal segments II–V with flower-shaped segmental scars for muscle attachment.

In general, characters observed in the material collected from India agree well with the description of the species by Williams and Watson (1988), however, they could observe lateral dorsal bosses on segments 1, 4 and 6, while in the specimens examined by us, dorsal boss was observed mainly on abdominal segment 1 and only in two specimens on abdominal segment 6. In several specimens, bosses were present only on one side of the specimens, indicating this character to be of highly irregular occurrence.

This species can be separated from highly invasive cycad scale *A. yasumatsui* by (characters of *A. yasumatsui* given in the parentheses) (i) two or three macroducts on abdominal segment 6 (1 or 2 with mean 1.1); (ii) well developed peribuccal sclerosis (absent); (iii) anterior

and posterior spiracle with 18-32 and 7-17 perispiracular pores (corresponding number – 10-14 and 6-15); (iv) median, anterolateral and posterolateral groups of perispiracular pores with 14-24, 21-37 and 20-32 pores (corresponding numbers – 12-17, 14-26 and 14-25).

Cycas circinalis L. is attacked by 17 scale insect species throughout the world, of which 12 belong to Diaspididae family, and from India, the soft scale *Saissetia coffeae* (Walker) (Coccidae) and an armoured scale *Poliaspis media* Maskell have been reported earlier (table 1). Table 1 also indicates that, though *C. circinalis* is considered an endemic species to India, the records of natural enemies of scale insects infesting *C. circinalis* have been recorded throughout the world. Either there is erroneous identification of the host plant in those studies or *C. circinalis* should not be considered as an endemic species to India.

No natural enemies were reported in the present study, however, Rao and Sankaran (1969) have reported *Rhyzobius pulchellus* (Montrouzier) (Coccinellidae) as an important predator of this pest from India on sugarcane. Apart from this, seven parasitoids belonging to Aphelinidae and Encyrtidae and a predator belonging to Coccinellidae have been recorded from different parts of the world (García Morales *et al*., 2016). No information on the life cycle of this scale insect is available in the

Table 1. Scale insect species recorded from *Cycas circinalis* from different countries

Scale insect species	Family	Country	Reference
Aulacaspis yasumatsui Takagi	Diaspididae	Britain	Malumphy & Marquart, 2012
Ceroplastes floridensis Comstock	Coccidae	Cuba	Ballou, 1926
Ceroplastes rubens Maskell	Coccidae	Sri Lanka	Vithana, *et al*., 2018
Chrysomphalus aonidum (Linnaeus)	Diaspididae	República Dominicana	Gómez-Menor Ortega, 1941
Chrysomphalus dictyospermi (Morgan)	Diaspididae	República Dominicana	Gómez-Menor Ortega, 1941
		Spain	Martín, 1983
Crypticerya multicicatrices Kondo & Unruh	Monophlebidae	Ecuador	Arias de López *et al*., 2022
Furchadaspis zamiae (Morgan)	Diaspididae	Switzerland	Kozár & Hippe, 1996
Hemiberlesia palmae (Cockerell)	Diaspididae	Tropical South Pacific Region	Williams and Watson, 1988
Lepidosaphes cocculi (Green)	Diaspididae	Micronesia	Takahashi, 1939
Lepidosaphes laterochitinosa Green	Diaspididae	Micronesia	Beardsley, 1966
		Japan	Takagi, 1970
Lindingaspis misrae (Laing)	Diaspididae	California	McKenzie, 1943
Parlatoria proteus (Curtis)	Diaspididae	Hawaii	Nakahara, 1981
Poliaspis media Maskell	Diaspididae	India	Rao and Kumar, 1952
Prococcus acutissimus (Green)	Coccidae	Hawaii	Nakahara, 1981
Pseudaulacaspis cockerelli (Cooley)	Diaspididae	Florida	Dekle, 1965
Saissetia coffeae (Walker)	Coccidae	India	Ali, 1968; Ali, 1971
		Cuba	Ballou, 1926
		Netherlands	Jansen, 1995
		Denmark	Kozarshevskaya & Reitzel, 1975
Selenaspidus articulatus (Morgan)	Diaspidiae	California	McKenzie, 1956

literature. This scale insect has been reported to infest 16 host plants belonging to five families and 12 genera with plants belonging to Poaceae as major host plants (García Morales *et al*., 2016). *Cycas circinalis*, is a new host, however, we could not observe any other host plants with its infestation, in the areas surveyed.

CONCLUSION

Operating a conservation action plan for an endemic *Cycas* population that has become threatened by this new pest attack requires an understanding of a combination of phenomena. Also, it is necessary to know the exact distribution of *C. circinalis* in India and elsewhere in the world. Way back in 1996, the causes of the rapid decline in the population of cycads were enlisted and their conservation strategies were proposed (Pant, 1996), which are valid even today. Apart from *A. madiunensis*, highly invasive *A. yasmatsui* is associated with cycads in several parts of the world, and invasion of this species to different parts of the world is the greatest concern amongst quarantine and plant protection officers, hence rapid identification of armoured scales in every newly infested location should be conducted by an expert taxonomist to rule out additional species involved in the damage caused to various species of cycads. Several pesticides are being recommended for the containment of this pest, however, farmers are hesitant due to the expenditure involved. Because of the immense seriousness of this pest in cycad-growing areas of India, it would be desirable to conduct surveys, record natural enemies, and study the life cycle for future use in the fields to develop an appropriate management action plan. Publicizing new outbreaks is essential to enable the most effective response from the plant protection agencies.

Characters of the scale insect in the field and the mounted condition described, and key to the Indian species of *Aulacaspis* discussed herein will be helpful in quick diagnosis of the pest, monitoring its spread to different geographical areas, and generation of awareness about the pest species to avoid further economic loss.

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Key to adult females of the Indian species of *Aulacaspis*

Key to the species of *Aulacaspis* from India has recently been published by Joshi *et al.* (2023). As this paper is not easily accessible to Indian researchers, we are reproducing the key with the permission of the copyright holder ©Magnolia Press, Auckland, New Zealand.

Note: Although recorded from India, *A. malayala* Varshney has not been included in this key because, in his checklist of South Asian scale insects, Varshney (2002) named this 'sp. nov.' based on a brief comment added by Takagi & Williams (1998) to their notes on *A. vitis* and related forms. He designated no specimen as the holotype, nor any specimens as a type series, and since there was no indication of where his material was deposited, the species is considered a *nomen nudum* (García Morales *et al*., 2016). The key below is derived from keys to the species of *Aulacaspis* in Wei *et al.* (2016) and Tian & Xing (2022). In the present key, *A. yasmatsui* has been classified under the species with swollen prosoma as per the original description by Takagi (1977), however, later Takagi and Faveri (2009) discussed variation in this species and illustrated *A. yasmatsui* without swollen prosoma.

1(0) Abdominal segment VI without dorsal macroducts 2
- Abdominal segment VI with dorsal macroducts 3

2(1) Abdominal segment II with dorsal macroducts and segment III with submedian macroducts ..... *A. australis* Brimblecombe
- Abdominal segment II without dorsal macroducts and segment III without submedian macroducts ..... *A. litzeae* (Green)

3(1) Prosoma not swollen 4
- Prosoma swollen 9

4(3) Body shape unique, narrowly oblong, with an incompletely formed prosoma in which mesothorax is clearly demarcated from fused head and prothorax ..... *A. loranthi* (Green)
- Body shape not as above 5

5(4) Abdominal segment III with only 1 submedial macroduct on each side ..... *A. hedyotidis* (Green)
- Abdominal segment III with 3 or more submedial macroducts on each side ……..... 6

6(5) Posterior spiracle associated with disc pores encircling anterior, lateral and posterior parts of peritreme. Abdominal segment II with dorsal macroducts ..... *A. elettaria* Joshi & Nafeesa

- Posterior spiracular pores present only anteriorly or laterally or anterolaterally to peritreme 7

7(6) Posterior spiracle with 1–4 associated disc-pores situated anterior to spiracle. Median lobes (L1) rounded, with basal zygosis represented by a pair of small sclerotizations ..... *A. anaimala* Takagi
- Posterior spiracle with associated pores situated lateral to spiracle. Shapes of median lobes and their basal zygoses various 8

8(7) Posterior spiracle with 6–20 associated disc-pores in a compact lateral group. Median lobes (L1) slender, narrowly separated, with basal zygosis horseshoe shaped and produced anteriorly beyond bases of L1 ..... *A. malabarica* Takagi
- Posterior spiracle with only 5–8 associated disc-pores in a lateral group. Median lobes widely separated; specimens from twigs with basal zygosis horseshoe shaped but specimens from leaves with basal zygosis represented by a pair of small sclerotized patches ..... *A. nilagirica* Takagi

9(3) Posterior spiracle without associated disc-pores .. *A. vitis* (Green)
- Posterior spiracle with associated disc-pores 10

10(9) Prosoma without lateral tubercles 11
- Prosoma with lateral tubercles 16

11(10) Pygidial margin with pore prominences poorly developed. Short dorsal microducts present in submarginal band around free abdominal segments and on prothorax ..... *A. tegalensis* (Zehntner)
- Pygidial margin with pore prominences well developed. Dorsal microducts not distributed as above 12

12(11) Abdominal segment II with submedial macroducts ..... *A. litseae* Tang
- Abdominal segment II without submedial macroducts 13

13(12) Submedial macroducts numbering fewer than 3 on abdominal segment III ..... *A. herbae* (Green)
- Submedial macroducts numbering more than 3 on abdominal segment III 14

14(13) Lateral macroducts on abdominal segment II numbering more than 4 ..... *A. rosae* (Bouché)
- Lateral macroducts on abdominal segment II numbering fewer than 4 15

15(14) Derm remaining membranous except for pygidium and small patches on cephalothorax, even in very mature specimens. Perivulvar pores numbering 37–57 on each side of body ..... *A. yasumatsui* Takagi
- Complete prosoma tending to be sclerotized with maturity, with many small patches. Perivulvar pores numbering 35–77 on each side ..... *A. litsearum* Takagi

16(10) Submedian macroducts absent from abdominal segment II 17
- Submedian macroducts present on abdominal segment II 19

17(16) Posterior spiracle associated with up to 25 spiracular pores ..... *A. gudalura* (Green)
- Posterior spiracle associated with no more than 12 spiracular pores 18

18 (17) Peribuccal scleroses not formed ..... *A. ferrisi* Scott
- Peribuccal scleroses well developed ..... *A. madiunensis* (Zehntner)

19(16) With 4 or more macroducts on abdominal segment VI 20
- With 1 or 2 macroducts on abdominal segment VI 21

20(19) Abdominal segment VI with about 8 macroducts. Total number of perivulvar disc-pores 136–245 . ..... *A. crawii* (Cockerell)
- Abdominal segment VI with about 4 macroducts. Total number of perivulvar disc-pores 95–125 ... . *A. rosarum* Borschsenius

21(20) Median lobes (L1) robust and produced but sunken into pygidium, strongly divergent from bases linked by a strong zygosis; lobes with mesad margins parallel sided ..... *A. tubercularis* Newstead
- Median lobes (L1) small, partly recessed, divergent and bluntly pointed [further details not available] ..... *A. orientalis* (Green)

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