Diagnostic Protocol for the detection of the Tomato Potato Psyllid, *Bactericera cockerelli* (Šulc)

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Contents

1. Introduction ... 4
   1.1 Hosts ... 4
2. Taxonomy ... 5
3. Detection ... 6
   3.1 Organisms not in Australia with which *Bactericera cockerelli* might be confused .. 10
   3.2 Symptoms on plant hosts caused by Tomato potato psyllids ... 10
      3.2.1. Symptoms on tomato ... 10
      3.2.2. Symptoms on capsicum ... 11
      3.2.3. Symptoms on potato ... 11
   3.3 Sampling ... 11
4. Identification ... 12
   4.1 Morphological identification of psyllids ... 12
      4.1.1. Features of Tomato potato psyllid: ... 12
      4.1.2 Key to distinguish adults of the exotic species from closely related Australian species ... 22
      4.1.2. Organisms in Australia with which *Bactericera cockerelli* might be confused. 23
      4.1.3. Key to distinguish nymphs of the exotic species from known Australian species associated with Solanaceae ... 23
   4.2 Molecular diagnostic tests for adults and nymphs ... 23
5. Acknowledgements ... 24
6. Contacts ... 24
7. References ... 25
   7.1 Other useful references ... 27
8. APPENDIX ... 29
   8.1 Biology ... 29
   8.2 Host table ... 31

1. INTRODUCTION

The Tomato potato psyllid is a sap sucking insect that is responsible for economic losses to tomato and potato crops as well as other solanaceous crops. It was originally described as *Trioza cockerelli* by Šulc (1909). It has been more commonly referred to as *Paratrioza cockerelli* (Šulc) in the literature until it was renamed *Bactericera cockerelli* (Šulc) by Burckhardt and Lauterer (1997). While feeding by the psyllid may adversely affect the hosts, the main issue with this species is that it can be a vector of the bacterium *Candidatus* Liberibacter solanacearum (Lieftling *et al* 2008).

This protocol has been prepared to distinguish *Bactericera cockerelli* (Šulc) from other Australian psyllid species. Australia has several hundred endemic psyllid species (Hollis 2004) but the genus *Bactericera* does not occur naturally. Consequently this protocol has been designed to be as simple and quick to use as possible and provides a key to identify *Bactericera*. Information is provided on two other exotic species that are of economic concern: *Bactericera trigona* (Hodkinson) and *Trioza apicalis* Foerster. Both these species are vectors of plant diseases, the latter recently shown to transmit *Candidatus* Liberibacter solanacearum to carrots in northern Europe. Neither of these species have been found in Australia, but reference to them is included. The protocol is based on adults because nymphal descriptions for most psyllids are inadequate for identification at the species level.

1.1 Hosts

B. cockerelli has been a pest on tomatoes since 1894 and a pest of potatoes since approximately 1927, although severe potato losses in 1911-1912 may have been due to it (Daniels 1941). Martin (2008) provides a cautionary warning about host plant records for *B. cockerelli*. A literature review indicates that it has been recorded from over 160 plant species (Davidson *et al.* 2008) and here are claims that adults have been found on plants from 20 families (Al-Jabr 1999). These large numbers of host plants are generally based on the presence of adults, and the number is reduced considerably if only plants with all life history stages (eggs, nymphs and adults), preferably under field conditions, are considered breeding hosts. In North America, 46 plant species from three plant families in the field have been identified as breeding hosts (Pletsch 1947; Wallis 1955; Davidson *et al.* 2008). The three families are Solanaceae (42 species), Convolvulaceae (3 species) and Labiatae (formerly Menthaceae) (one species), although the last record is doubtful because it is a glasshouse record where the psyllid was also on other plant species (Knowlton and Thomas 1934). To complicate the issue of host plants, the psyllid may breed on a particular plant species in one country but not in another, presumably due to genetic differences in either the host plant or the psyllid, e.g. *B. cockerelli* breeds on *Solanum nigrum* in the USA but not in New Zealand (Martin 2008). Besides plant species of economic importance (tomato, potato, capsicum, sweet potato, egg plant), it utilizes many other hosts that are ornamentals or weeds (Pletsch 1947; Wallis 1955; Davidson *et al.* 2008). Daniels (1934, 1941) listed wild native ground cherry (*Physalis lanceolata*, *P. longifolia* and *Qunicula lobata*), buffalo burr (*Androscra rostrata*), night shade and most wild solanaceae (wild tomato, *Solanum triflorum*) as breeding host plants, as well as some evergreens (pine, spruce or cedar), but the latter were not utilised if solanaceous species were present. Knowlton (1933) reported adults surviving on Douglas fir (*Pseudotsuga taxifolia*) for 96 days. Crawford (1914) lists *Medicago sativa* (alfalfa or lucerne) as a host plant, but this record is unsubstantiated and none were collected from alfalfa in Montana (Pletsch 1947). Yang and Liu (2009) studied the life history and life tables of *B. cockerelli* on bell peppers and egg plants.

In New Zealand, it has been found mainly on Solanaceous plants. It breeds on the commercial plant species such as *Capsicum annuum* L. (capsicums), *Solanum lycopersicum* L. (tomato), *Solanum tuberosum* L. (potato), *Capsicum frutescens* (chilli), *Solanum betaceum* (tamarillo) and *Solanum melongena* L. (egg plant), *Ipomoea batatas* (sweet potato - kumara) but also on non commercial plant species such as *Datura stramonium* L. (thorn apple), *Nicandra physalodes* (L.) Gaertn. (apple of Peru), black nightshade (*Solanum nigrum*), cape gooseberry (*Physalis sp*), common morning glory (*Ipomoea purpurea*) and field bind weed (*Convulvulus arvensis*), and the New Zealand *Solanum aviculare* G.Forst. and *Solanum laciniatum* (poroporo); *Ipomoea batatas*, *Solanum aviculare, Solanum laciniatum, Solanum betaceum, Datura stramonium* and *Nicandra physalodes* are considered poor hosts with low psyllid numbers (Martin 2008; Martin and Workman n.d.).

The total number of host plant species for *B. cockerelli* (defined as plant species that the psyllid oviposits on and the nymphs develop through to adults) is uncertain. Biosecurity Australia (2009) lists 63 host plant species using Knowlton and Thomas (1934), Wallis (1955) and Horticulture New Zealand (2008) as the sources of information (see Appendix 2). The list does not include *Solanum laciniatum* from New Zealand (Martin 2008).

If this New Zealand record is added to the list, there are 64 known host plant species; 36 of these plant species are known to occur in Australia.

2. TAXONOMY

Taxonomic position

Phylum	Arthropoda
Class	Insecta
Order	Hemiptera
Suborder	Sternorrhyncha
Superfamily	Psylloidea
Family	Triozidae
Genus	*Bactericera*

Species *Bactericera cockerelli* (Šulc)

Synonyms *Trioza cockerelli* Šulc; *Paratrioza cockerelli* (Šulc)

Common names

Potato and tomato psyllid (English)
potato psyllid (North America)
Tomato-potato psyllid (New Zealand)
Psilido del tomate (Spanish)
Psilido de la papa (Spanish)
Psylle de la pomme de terre/tomate (French)

3. DETECTION

B. cockerelli are found on the foliage of plants. Eggs are attached by a long pedicel to leaves and new shoots (Figures 1, 2). Nymphs (Figures 3-6) and adults (Figures 7-9) feed on leaves but can be found amongst flowers and fruit. The disease(s) vectored by *B. cockerelli* can affect foliage, stems, fruit and tubers and the bacterium can be found in all plant parts (including seed).

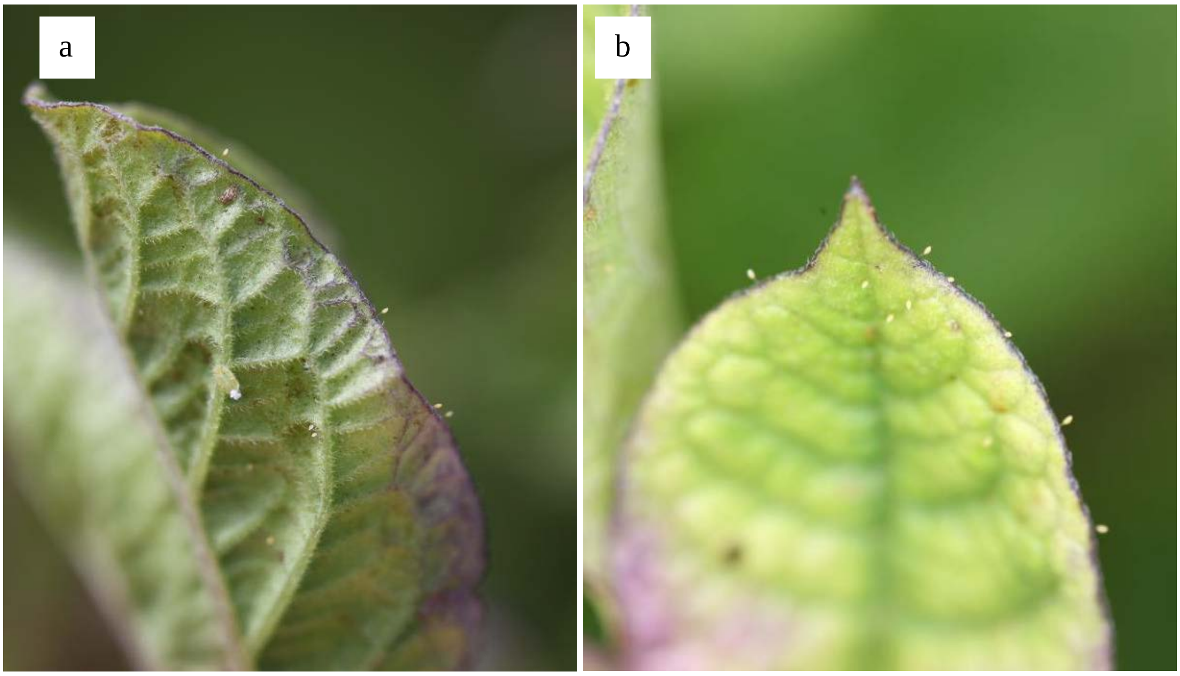


Figure 1. Eggs of *Bactericera cockerelli* (a) attached to the surface of a leaf and (b) laid along the edge of the leaf; New Zealand [Photos: A. L. Yen].

Figure 2. Eggs of *Bactericera cockerelli* attached to the leaf by a short pedicel (a) initially light in colour then (b) becoming orange as the embryo develops; New Zealand [Photos: Ministry of Primary Industries (MPI), New Zealand].

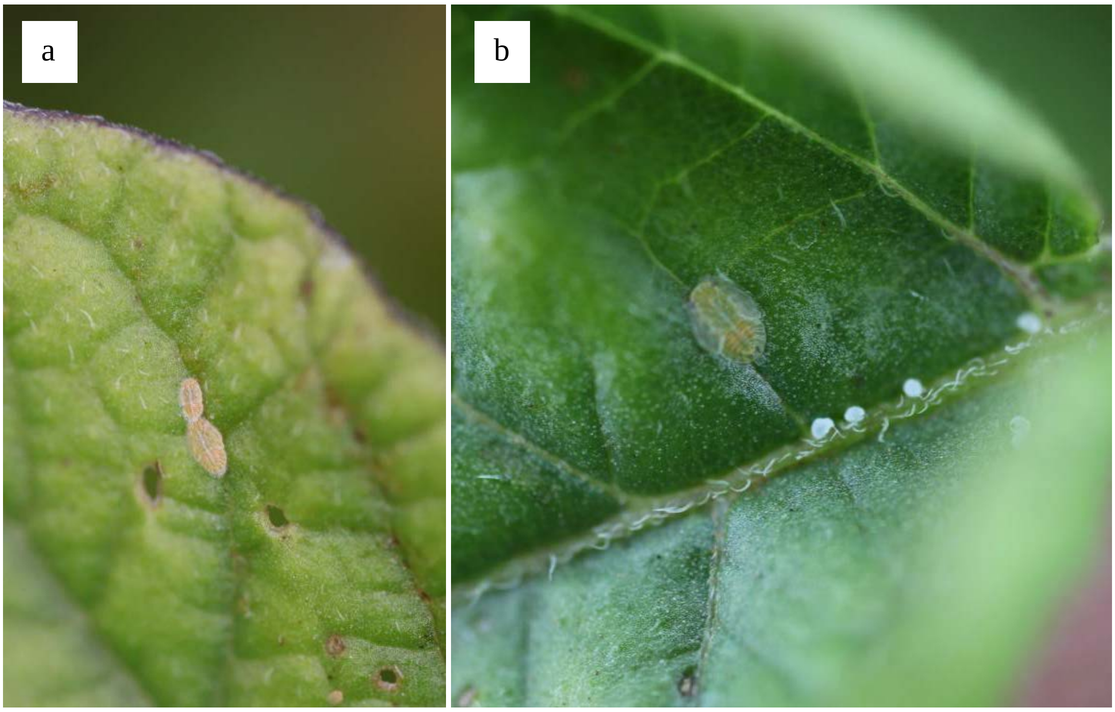


Figure 3. (a) Earlier instar nymphs of *Bactericera cockerelli*, (b) Later instar nymphs of *Bactericera cockerelli*; New Zealand [Photos: A. L. Yen]

Figure 4. *Bactericera cockerelli* nymph [Photo: Ministry of Primary Industries (MPI), New Zealand].

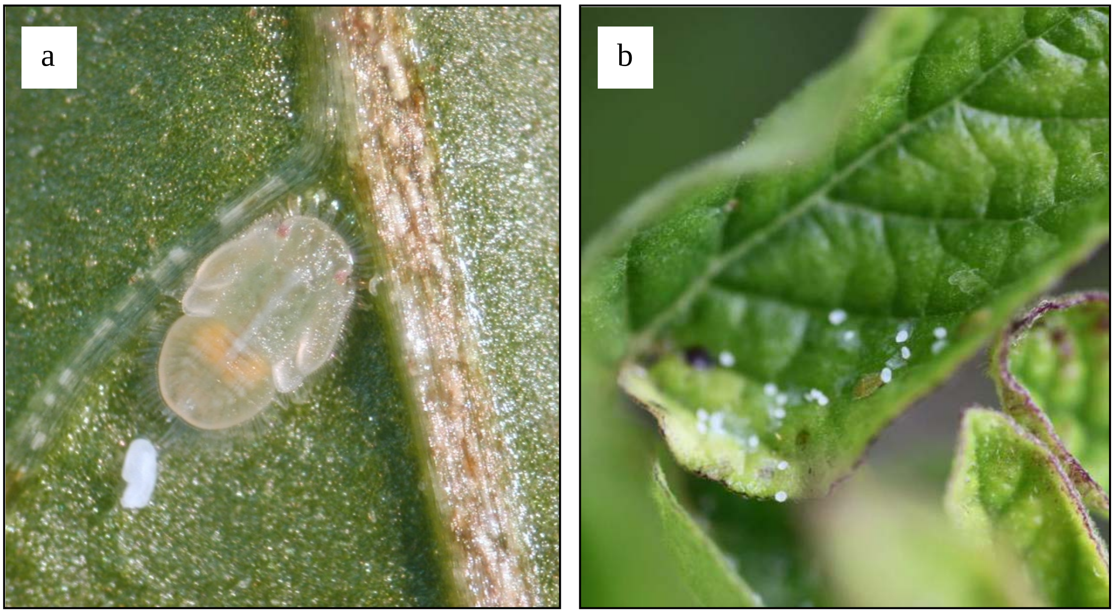


Figure 5. (a) *Bactericera cockerelli* nymph [Photo: Shaun Bennet, Ministry for Primary Industries**,** New Zealand (MPI)] and (b) honeydew produced by nymphs of *Bactericera cockerelli*; New Zealand [Photo: A. L. Yen].

Figure 6. (a) Recently emerged adult and (b) adult of *Bactericera cockerelli*; New Zealand [Photos: A. L. Yen].

Figure 7. Adult *Bactericera cockerelli*; New Zealand [Photo: A. L. Yen]

Figure 8. Adult *Bactericera cockerelli*; New Zealand [Photo: A. L. Yen]

3.1 Organisms not in Australia with which *Bactericera cockerelli* might be confused

Information about two species of Palaearctic psyllids is included because of recent reports that they transmit diseases in carrots that have relevance to the Tomato potato psyllid.

- *Trioza apicalis* Foerster. Carrots were observed exhibiting symptoms of damage, leaf curling, yellow and purple discoloration of leaves, stunted growth of shoots and roots, and proliferation of secondary roots. DNA testing of the carrots and psyllids found it was *Ca*. L. solanacearum which is the same bacterium transmitted by *Bactericera cockerelli* primarily on solanaceous plants (Munyaneza *et al.* 2010).

- *Bactericera trigona* (Hodkinson) allegedly transmitted a stolbur phytoplasma to carrots (Font *et al.* 1999). The Stolbur phytoplasma and *Candidatus* Phytoplasma australiense are most closely related to each other and it may be possible *Bactericera cockerelli* could also vector *Ca*. P. australiense (Fiona Constable, pers. comm. 2010).

Both *Trioza apicalis* and *Bactericera trigonica* are members of the family Triozidae and can be recognised by their male and female terminalia (Appendix Fig. 25). For their separation from Central European species the identification key of Burckhardt and Freuler (2000) can be used. A taxonomic revision of *Bactericera trigonica* and related species is by Hodkinson (1981) and one of the *Trioza apicalis* complex by Burckhardt (1986).

3.2 Symptoms on plant hosts caused by Tomato potato psyllids

As a sap-sucking insect, there is a considerable body of literature on the presumed effects of psyllid feeding on host plants (psyllid yellows) and possible transmission of diseases. Since the development of DNA technology, the role of the species in disease transfer is considered more significant. There is still some confusion on what diseases *B. cockerelli* vectors. It is implicated in psyllid yellows and zebra chip in potatoes, psyllid yellows in tomatoes and capsicum, and may be associated with potato purple top and phyotoplasmas. Psyllid yellows in potatoes has been reported without zebra chip symptoms in the tubers (Sengoda *et al*. 2010), but there is a possibility that the zebra chip symptoms are not expressed in the tubers due to the timing of infection and differences in symptom expression between potato varieties. The main disease vectored by *B. cockerelli* is caused by the bacterium *Candidatus* Liberibacter solanacearum (Liefting *et al.* 2008), synonymous with *Candidatus* Liberibacter psyllaurous (Hansen) (Constable 2010). A separate National Diagnostic Protocol has been developed for this disease.

Symptoms vary according to the infected host plant species and sometimes cultivar (Biosecurity Australia 2009). *Candidatus* Liberibacter solanacearum displays similar symptoms, especially on potato. As there are other potential insect vectors of the disease, need to note these symptoms are not specific to *Bactericera cockerelli*.

3.2.1. Symptoms on tomato

Foliage symptoms include spiky, chlorotic apical growth with purpling of the midveins, general mottling of the leaves, curling of the midveins, and overall stunting of the plants; fruit may be misshapen, with a strawberry-like appearance, and uneven development of fruit locules; in some cases, there is no fruit set at all.

3.2.2. Symptoms on capsicum

Chlorotic or pale green leaves, sharp tapering of leaf apex (spiky appearance) leading to leaf cupping, short internodes and petioles and apical meristem necrosis and/or flower abortion and an overall stunting.

3.2.3. Symptoms on potato

Stunting, chlorosis, and swollen nodes causing a “zig-zag” appearance of the upper growth, proliferated auxiliary buds, aerial tubers and leaf scorching leading to early dieback; below-ground symptoms include enlarged lenticels of the underground stem, collapsed stolons, brown discoloration of the vascular ring and necrotic flecking of internal tuber tissues (Gudmestad and Secor 2007). Symptoms also include smaller tubers, an increase in the number of tubers and shorter stolons. Furthermore, tubers tend to be misshapen, have a rough skin and suffer a loss of dormancy resulting in premature sprouting. Therefore, tuber chaining and internal sprouting are common. Sprouts are spindly, hairy and very weak. Zebra chip is the name given to symptoms of psyllid yellows in fried potato chips, a stripped pattern of discolouration in fried cross-sections of potato tubers (Munyaneza *et al*. 2007).

3.3 Sampling

a. **Preferred stage to be collected**
   Of the three life stages (egg, nymph and adult) only adults are identifiable to species using morphological features.

b. **How to collect**
   Adult psyllids can be hand collected into glass vials or vacuum collected either with vacuum sampler, or swept from foliage with a hand net. Adult psyllids are normally found on the leaves and young shoots. A practical and reliable method for associating nymphs with adults as well as with host plants is the collection of infested leaves and shoots containing nymphs and rearing them in a constant temperature room / laboratory to obtain adults. Adult psyllids are easily collected by sticky traps and water traps. However host plant information can only be inferred if these traps are adjacent to known host species.

c. **How to collect and preserve plant sample if required**
   Leaves and young shoots with suspect feeding damage can be stored between sheets of dry newspaper to permit slow drying. For laboratory rearing of psyllids, infested plant material containing mature nymphs can be collected in a large jar and kept in a constant temperature room for regular checking. It is recommended that a plant sample be collected for plant identification if there is either any question about the identity of the host plant or if the host plant is suspected of being a new record. It is important to record if only adult psyllids are found on the plant or if immature stages (eggs and nymphs) are present to distinguish between chance visitation by adult psyllids or actual use of the plant for breeding.

d. **How to preserve psyllids**
   Adults and nymphs can be placed in 70% ethanol and stored indefinitely, although their colour fades gradually with time. Adults can be dry mounted, these should be collected, killed by freezing and stored frozen until they are dry mounted. Specimens required for molecular diagnostic work should be killed / preserved in 100% ethanol and stored at -20° to - 80° C).

4. IDENTIFICATION

Definitive diagnosis of *Bactericera cockerelli* requires examination of adult specimens, in particular the male terminalia, as well as nymphs, and comparison with validated voucher specimens.

Proposed methodology for diagnosis:

1. Examine adult psyllid specimens under dissecting microscope to assess whether or not they belong to family Triozidae using external morphological characters listed under sections 4.1.2 and 4.1.3.
2. If they are Triozidae, then continue to key through the identification key given under section 4.1.2 to distinguish them from the Australian species of this family.
3. If the specimens key to *B. cockerelli*, select male specimen and carefully detach abdomen from specimen. If only female specimens are available, it is not possible to identify them to the species level if all *Bactericera* species are considered; however, any detection of *Bactericera* in Australia is of biosecurity concern and female specimens should be sent to a psyllid specialist.
4. Soak abdomen in 10% KOH for several hours until it becomes soft and cleared. Wash in water.
5. Transfer cleared abdomen into 70% ethanol and glycerine
6. Carefully stretch the aedeagus when folded and examine terminalia in a strict lateral view on an excavated slide covered with a cover slip. After examination store terminalia in a microvial together with the remainder of the specimen.
7. Label the specimen.

4.1 Morphological identification of psyllids

All figures referenced in the keys are replicated in the Appendix.

4.1.1. Features of Tomato potato psyllid:

***Eggs*: (Figure 9).**

Dirty whitish or light yellowish, semitransparent. Before emergence of nymph myzetome becomes visible as yellow or orange spot in basal half. Average size of each egg 0.32 mm long and 0.18 mm wide, petiole 0.30 mm long. Eggs are almond-shaped, elongate with a broadly rounded base, attached to the long, thin petiole, and narrowed towards apex which is narrowly curved at the end.

Figure 9. Eggs of *Bactericera cockerelli* attached to the leaf by a short pedicel (a) initially light in colour then (b) becoming orange as the embryo develops; New Zealand [Photos: Ministry of Primary Industries (MPI), New Zealand].

***Nymphs*: (Figures 10-12).**

There are five nymphal instars which are all strongly dorso-ventrally flattened. All instars bear marginal sectasetae surrounding the entire body. Dorsal surface lacking macroscopic setae. Before emergence of next instar the yellow orange myzetome is well-visible, particularly in ventral view.

1st instar – around 0.40 mm long by 0.21 mm wide. Body whitish or yellowish, dorsal sclerites greyish with a pair of red compound eyes. Antennae 1-segmented, legs 3-segmented. Forewing pad indistinct, visible as square sclerites separated from mesonotal sclerite.

2nd instar – 0.52 mm long and 0.33 mm wide. Body whitish or yellowish, with four longitudinal rows of grey dots on thorax and abdomen dorsally; with a pair of red compound eyes. Antennae indistinctly 3-segmented, legs 3-segmented. Forewing pad distinct, fused to mesonotal sclerite, humeral lobe small.

3rd instar – 0.80 mm long and 0.48 mm wide. Body whitish or yellowish, with four longitudinal rows of grey dots on thorax and abdomen dorsally; with a pair of red compound eyes. Antennae indistinctly 3-segmented, legs 3-segmented. Forewing pad distinct, fused to mesonotal sclerite, humeral lobe small.

4th instar – 1.18 mm long and 0.75 mm wide. Body whitish or yellowish, with two grey longitudinal bands bearing brown dots on thorax and abdomen dorsally; with a pair of red compound eyes. Antennae indistinctly 3-segmented, legs 3-segmented. Forewing pad distinct, fused to mesonotal sclerite, humeral lobe large.

5th instar – 1.65 mm long and 1.23 mm wide. Body whitish or yellowish, with scattered brown dots on thorax and on wing pads dorsally, and two grey longitudinal bands bearing brown dots on abdomen dorsally; with a pair of red compound eyes. Antennae indistinctly 5-segmented, legs 4-segmented. Forewing pad distinct, fused to mesonotal sclerite, humeral lobe large.

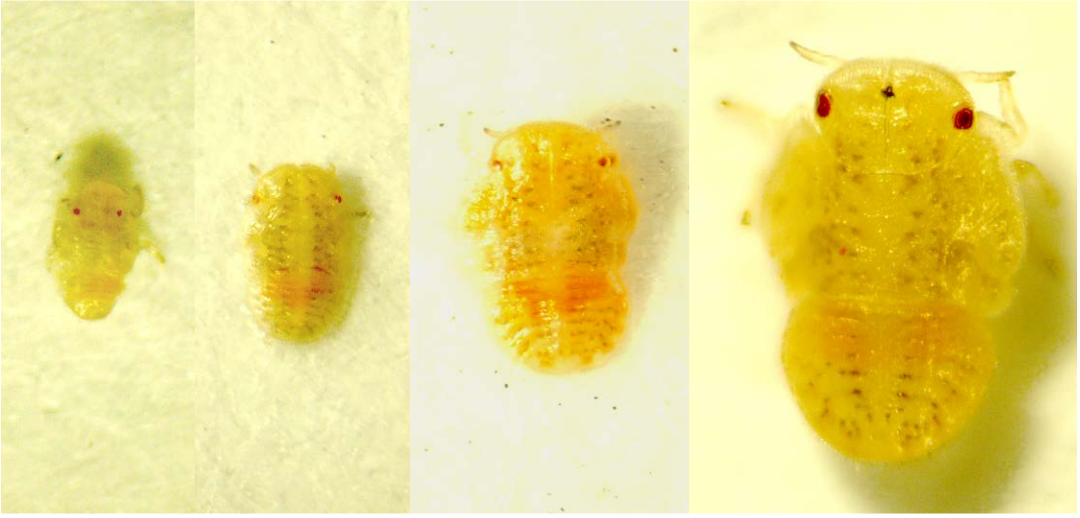


Figure 10. *Bactericera cockerelli*, first to forth nymphal instars, dorsal view; New Zealand [photo: A. L. Yen and D. Burckhardt].

Figure 11. *Bactericera cockerelli*, the fifth nymphal instar, dorsal view; New Zealand [photo: A. L. Yen and D. Burckhardt].

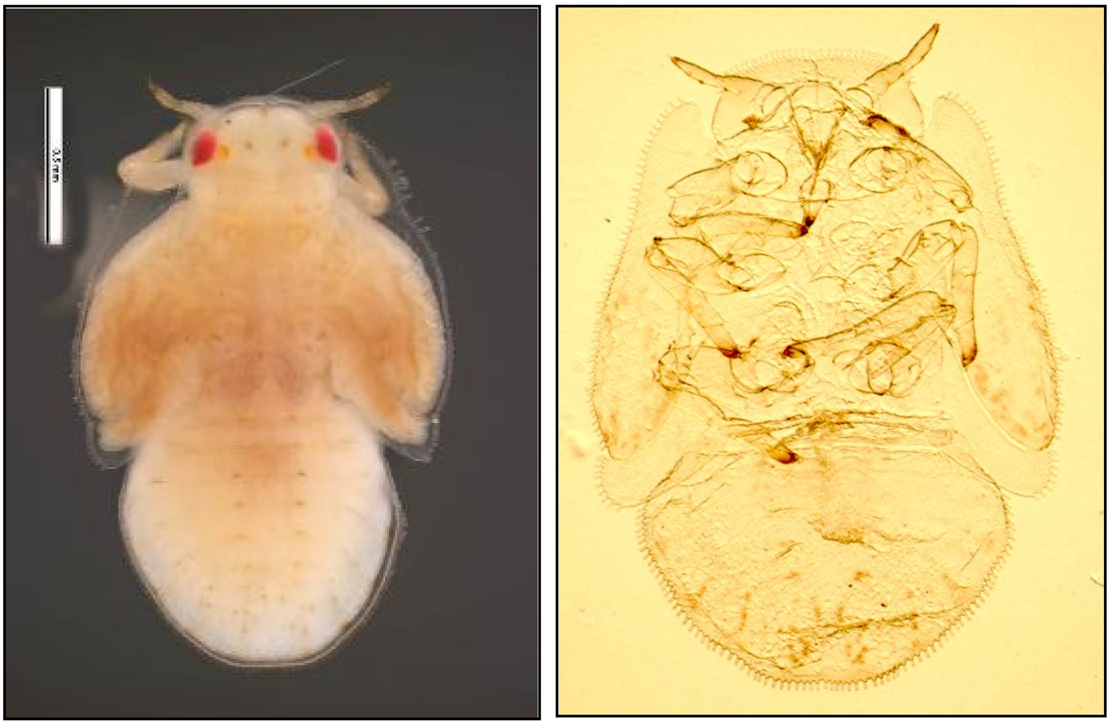


Figure 12. *Bactericera cockerelli*. Fifth instar nymph. (a) Dorsal view, (b) view of cleared specimen [photo: Simon Hinkley and Ken Walker, Museum Victoria ; A. L. Yen and D. Burckhardt].

***Adult*: (Figures 13-23).**
Body length (including forewings) of male around 2.8–2.9 mm, female around 2.8–3.2 mm; body width (across metathorax) of male and female around 0.6 mm.

Body of mature specimens almost black with following lighter elements: vertex surrounded by whitish margin and bearing whitish transverse stripe in the middle. Posteroventral eye margin whitish as well as an oval spot on each side. Basal two thirds of antennal segments 3–8 yellowish. Clypeus dirty yellowish. Pronotum medially and mesonotum along narrow longitudinal stripes pale reddish. Tibiae and basal tarsal segments ochreous, apical tarsal segments brown. Forewing with ochreous to brown veins and transparent, more or less colourless membrane. Parameres and parts of male and female proctiger ochreous to light brown. Younger specimens lighter with more extended light pattern. Head hardly inclined from longitudinal body axis, including eyes slightly narrower than mesothorax. Forewings are 2.6 x as long as wide, subacute at apex, widest in apical third.

Previous morphological studies and descriptive comments on *B. cockerelli* include nymphs (Ferris 1925), adults (Crawford 1911; Daniels 1934; Rowe and Knowlton 1935; Caldwell 1941; Pletsch 1947). Carter (1961) outlined a method to differentiate instar IV-V nymphs on the basis of the structure of the mycetome. Dale and Nielsen (2009) outline characteristics to distinguish adult *B. cockerelli* from other species of psyllids in New Zealand.

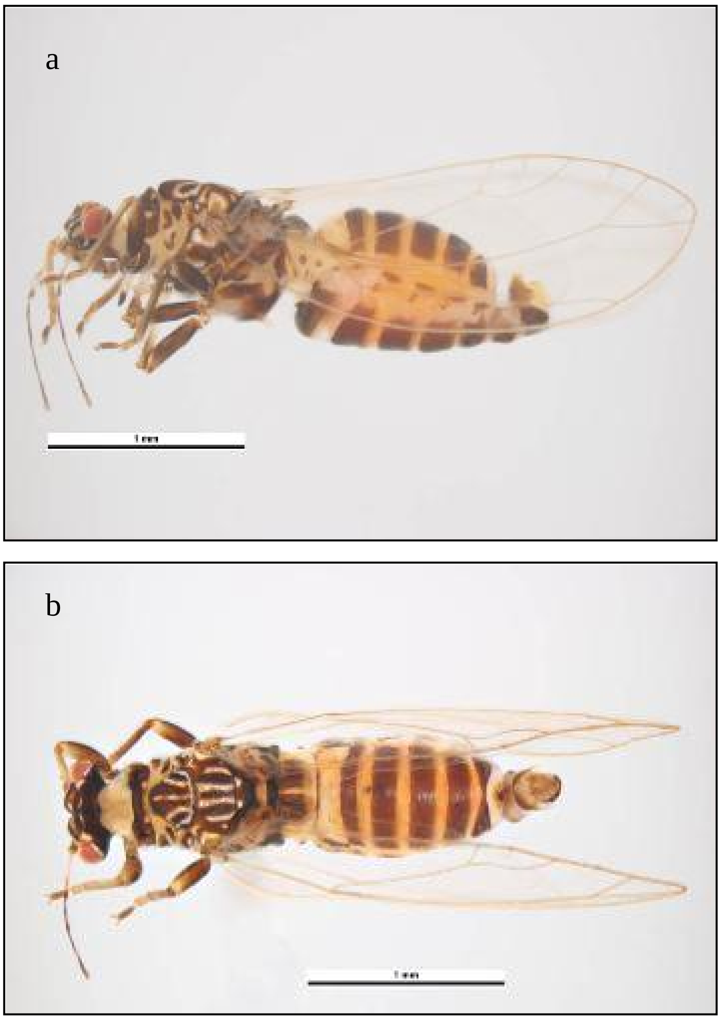
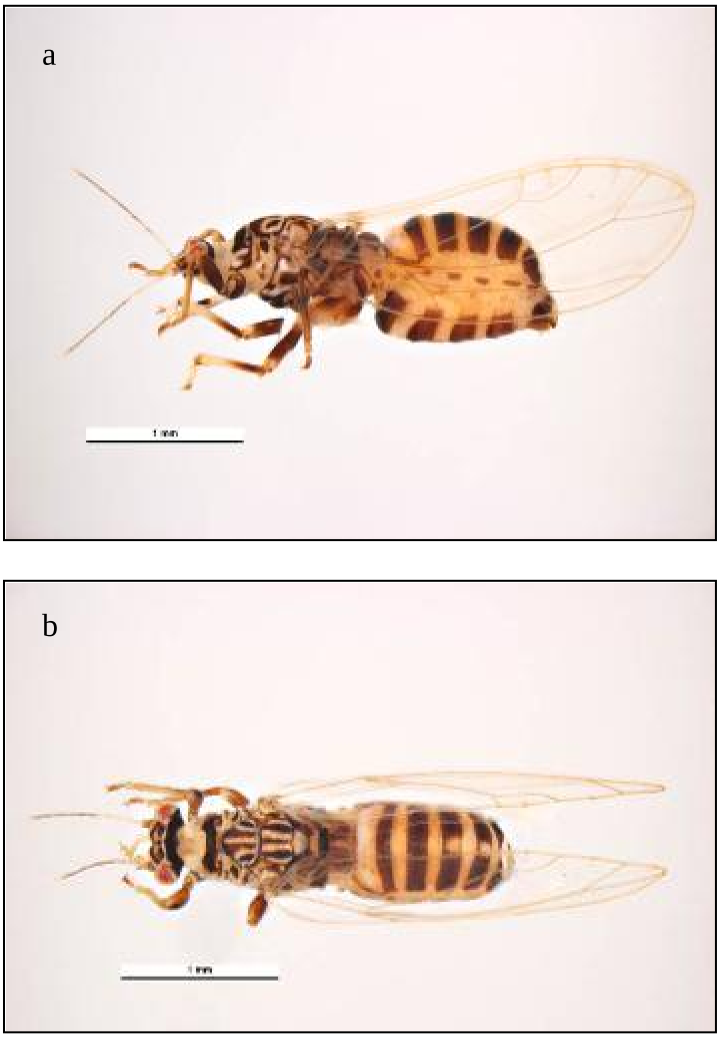


Figure 13. *Bactericera cockerelli*, adult habitus Male (a) lateral view (b) dorsal view [photo: Simon Hinkley and Ken Walker, Museum Victoria].



Figures 14. *Bactericera cockerelli*, adult habitus Female (a) lateral view; (b) dorsal view [photo: Simon Hinkley and Ken Walker, Museum Victoria].

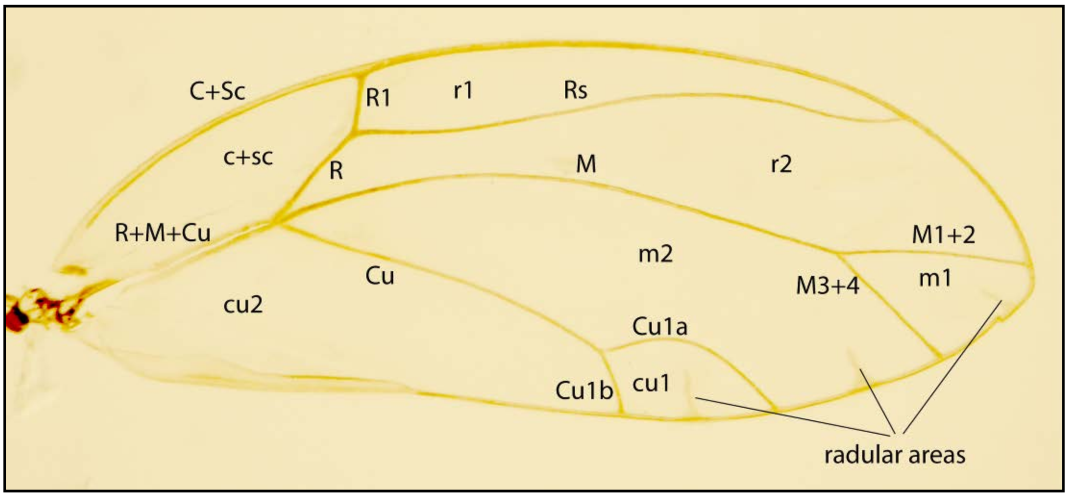


Figure 15. *Bactericera cockerelli*, forewing venation; New Zealand [photo: A. L. Yen and D. Burckhardt].

Figure 16. *Bactericera cockerelli*, hind leg; arrows indicating apical spurs; New Zealand [photo: A. L. Yen and D. Burckhardt].

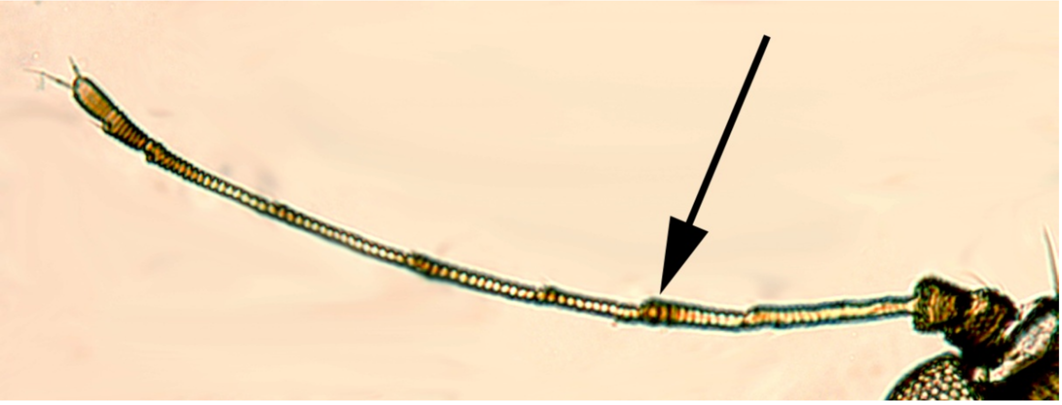


Figure 17. *Bactericera cockerelli*, antenna; arrow indicating position of modified rhinarium on segment 4; New Zealand [photo: A. L. Yen and D. Burckhardt].

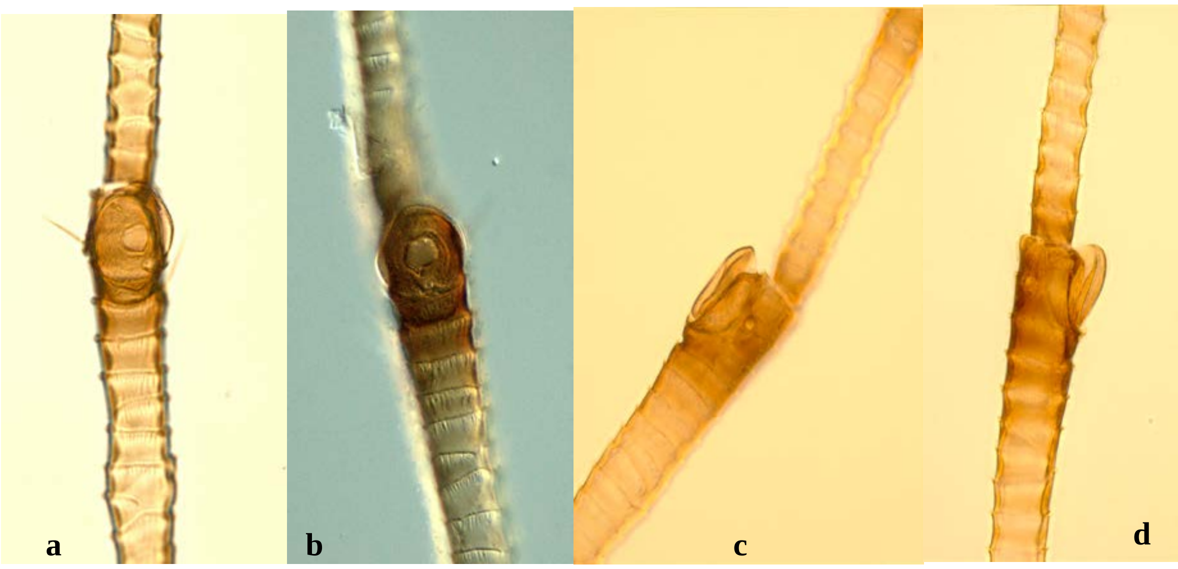


Figure 18. *Bactericera cockerelli*, disk-shaped rhinarium on antennal segment 4. (a, b). Dorsal view; (c, d). lateral view; New Zealand [photo: A. L. Yen and D. Burckhardt].

Figure 19. *Bactericera cockerelli*, head, dorsal view. **(L).** Dry mounted specimen [photo: Simon Hinkley and Ken Walker, Museum Victoria]; **(R).** cleared specimen; New Zealand [photo: A. L. Yen and D. Burckhardt].

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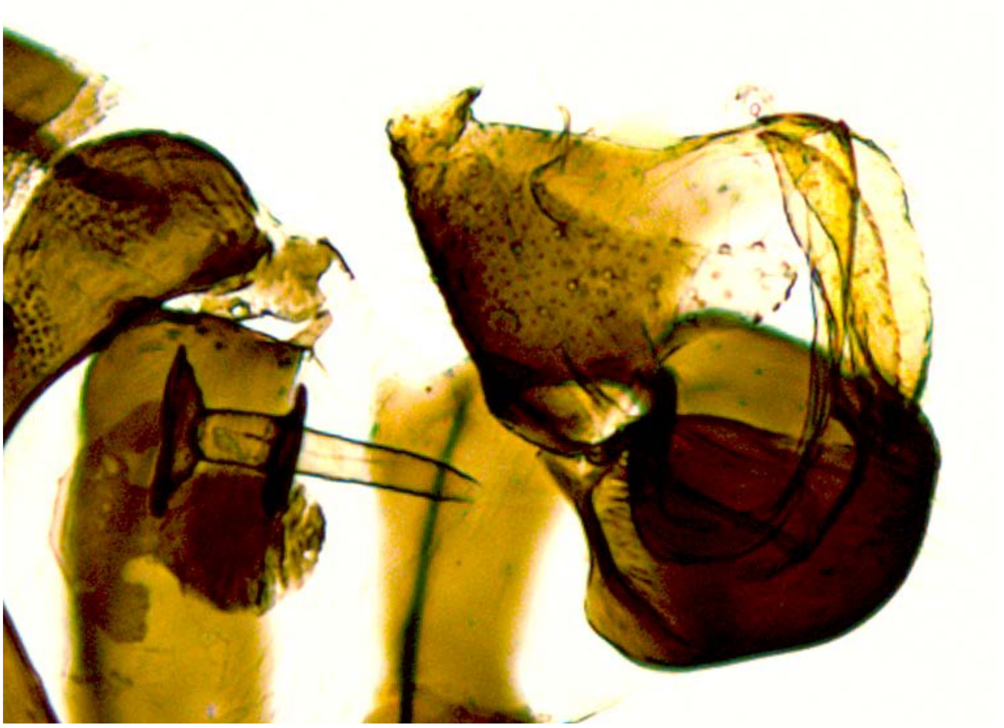


Figure 20. *Bactericera cockerelli*, male terminalia, lateral view; New Zealand [photo: A. L. Yen and D. Burckhardt].

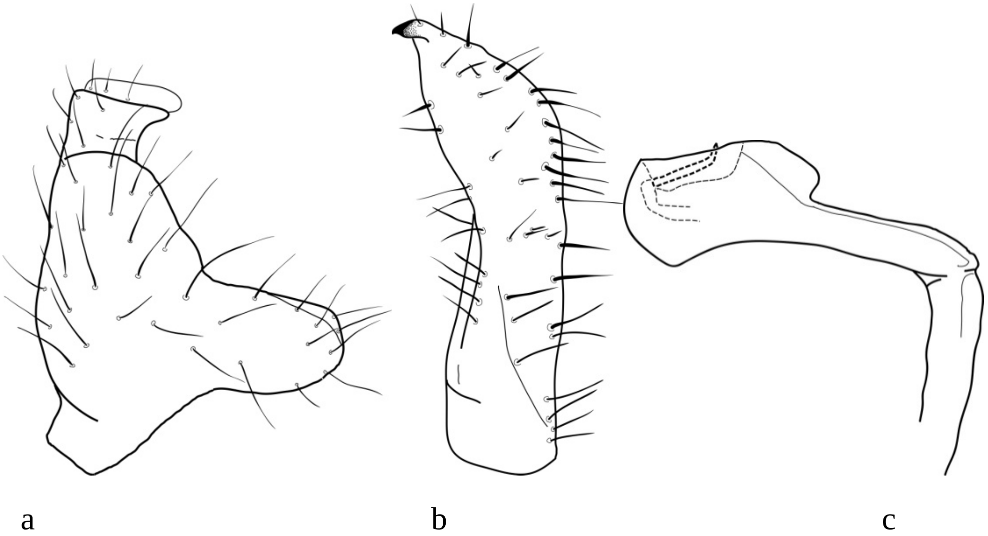


Figure 21. *Bactericera cockerelli*, male terminalia. (a) Proctiger, lateral, view; (b) paramere, inner surface; (c) distal portion of aedeagus, lateral view [illustration: A. L. Yen and D. Burckhardt].

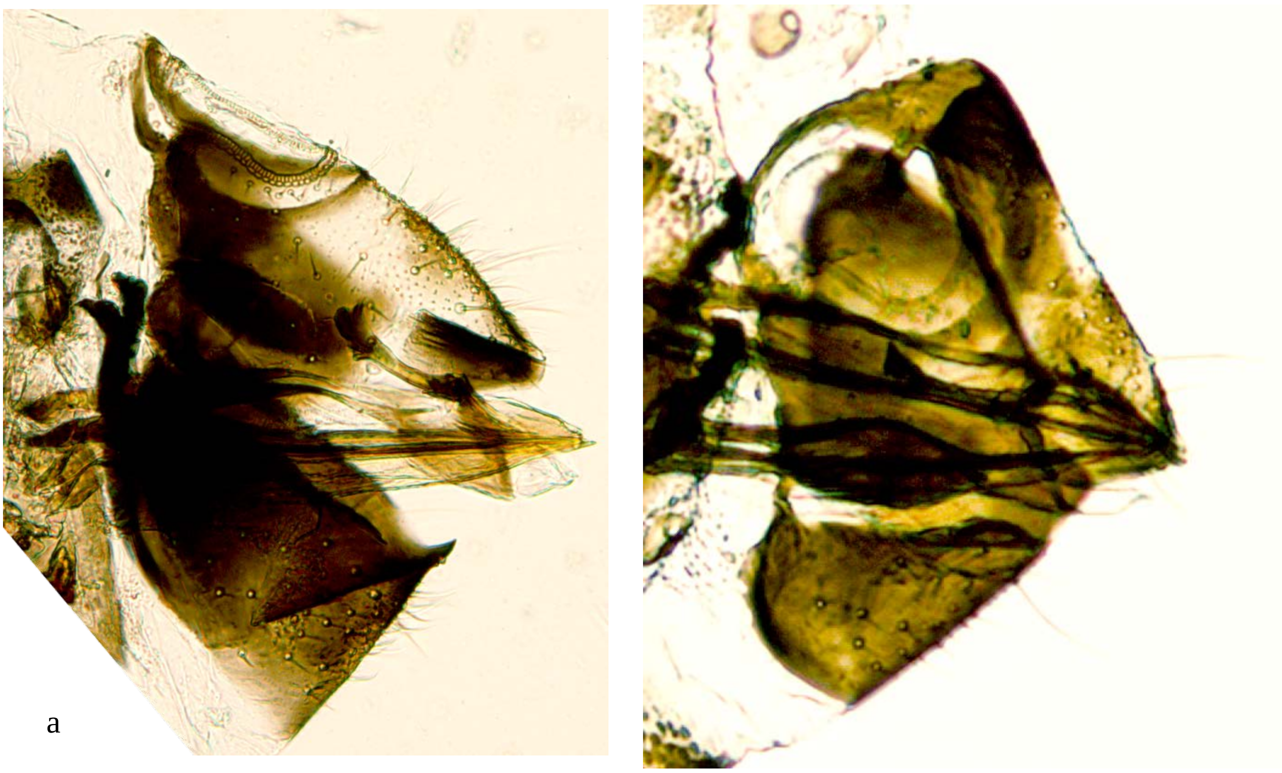
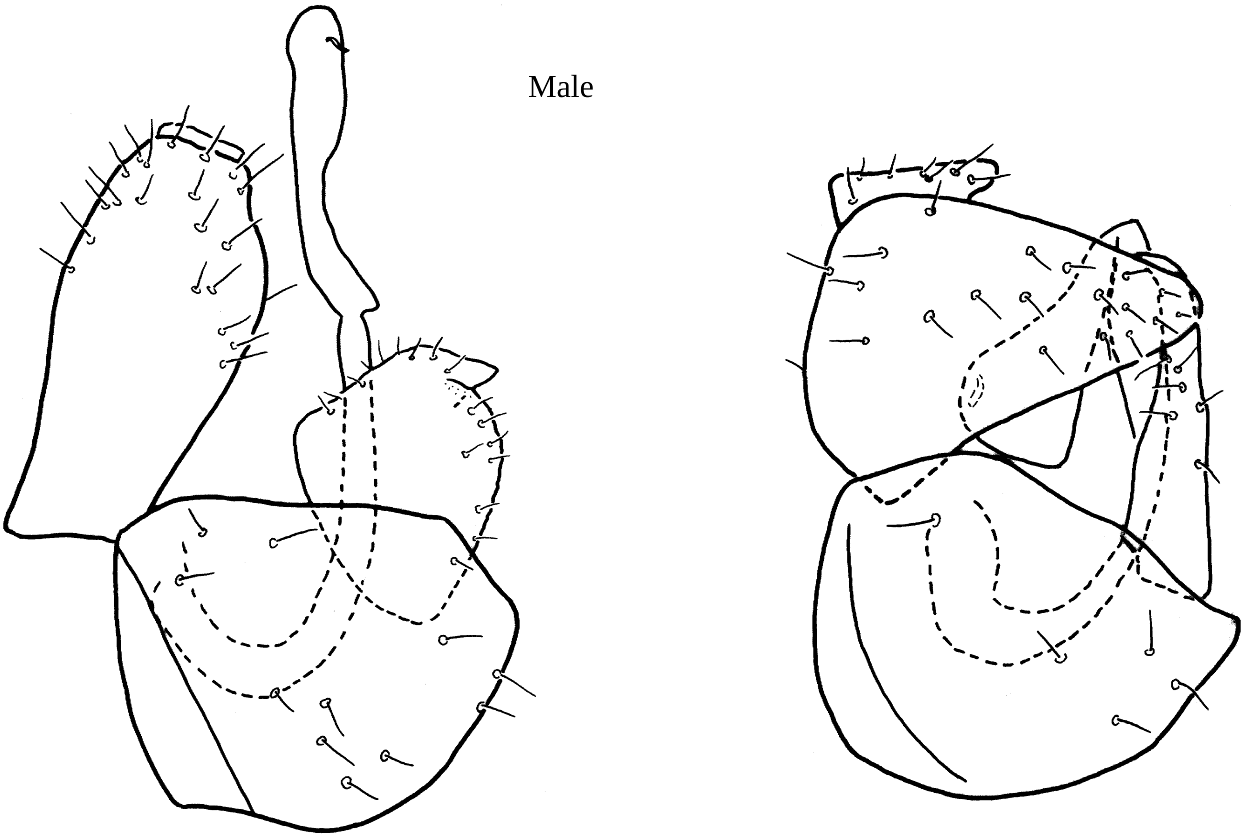


Figure 22. *Bactericera cockerelli,* female genitalia; New Zealand. (a) Lateral view; (b) Dorsal view [photo: A. L. Yen and D. Burckhardt].

Male



Female

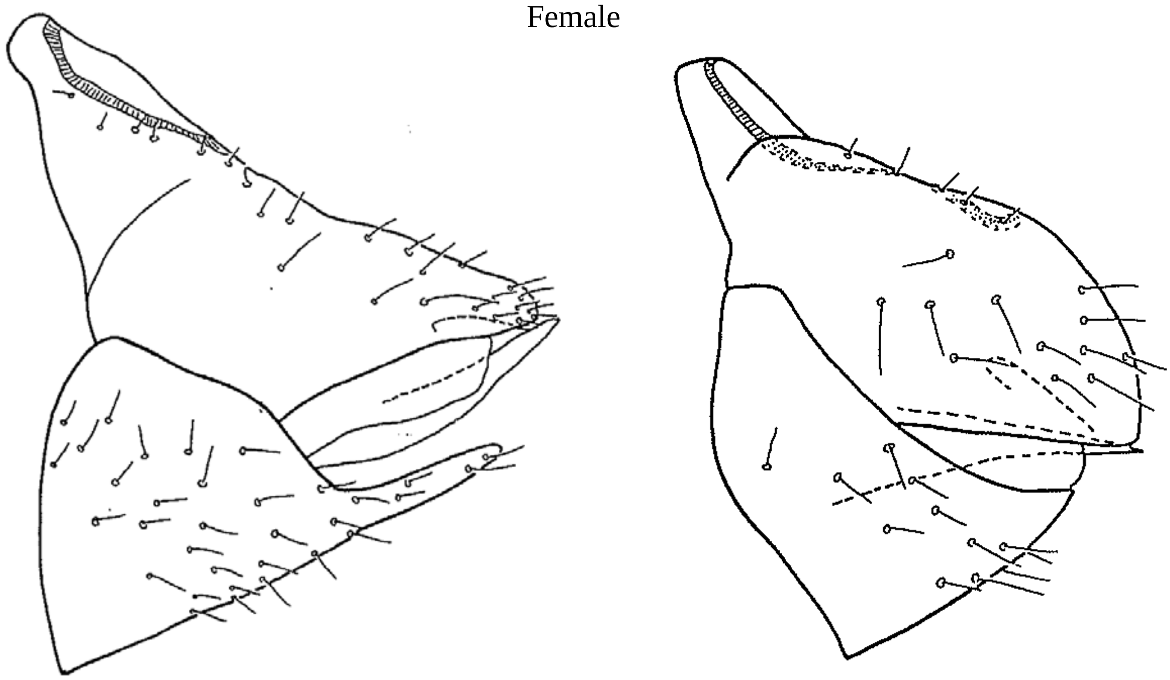


Figure 23. Male (above) and female (below) terminalia of *Bactericera cockerelli* (left) and *Bactericera trigonica* (right) [source: Burckhardt, D. and Freuler, J. 2000. Jumping plant-lice (Hemiptera, Psylloidae) from sticky traps in carrot fields in Valais, Switzerland. *Mitteilungen der Schweizerischen Entomologischen Gesellschaft* 73: 191-209].

4.1.2 Key to distinguish adults of the exotic species from closely related Australian species

1 Forewing with veins Rs and M_{1+2} confluent at some point along their lengths or connected by a crossvein ....NOT *Bactericera*

\- Forewing with veins Rs and M_{1+2} not confluent or not in contact at all, nor connected by a crossvein..2

2 Forewing with R+M+Cu stem trifurcating into R stem, M stem and Cu stem (occasionally a very short R+M stem present); costal break absent, pterostigma absent, metabasitarsal spurs absent (Figure 15); Triozidae 3

\- Forewing with R+M+Cu stem bifurcating into R stem and M+Cu stem ....NOT *Bactericera*

3 Metatibia with 1+2 apical spurs (Figure 16)...4

\- Metatibial spurs absent (*Aacanthocnema*) or in different numbers and arrangements (1+3 in *Cerotrioza*, *Leptynoptera* and *Schedotrioza*; 2+2 or more in some *Pauropsylla*) ....NOT *Bactericera*

4 Forewing with vein Rs sinuous; vein Cu longer than 3 times vein Cu_{1b}; membrane colourless; forewing about 2.7 times as long as wide. Male proctiger with short posterior lobes. Female terminalia short. Genal processes less than half vertex length 5

\- Combination of characters different. Forewing with vein Rs generally concave with respect to foremargin. Sometimes Cu as long as or shorther than Cu_{1b}. Membrane sometimes with dark wing pattern. Forewing rarely very broad, length : width ratio about 2.0. Male proctiger often without posterior lobes. Female terminalia short or long. Genal processes variable...NOT *Bactericera*

5 Antennal segments 4–8 light basally, dark apically (Figure 17); rhinarium of antennal segment 4 with covering (Figure 18). Vertex dark with light margin and light interior transverse band. Male proctiger with apically narrow posterior lobes. Paramere wide in apical half. Apical dilatation of distal segment of aedeagus subrectangular (Figure 21). Dorsal margin of female proctiger almost straight (Figure 22) …..*Bactericera cockerelli*

\- Antennal segments 4–8 entirely dark; rhinarium of antennal segment 4 simple pit. Vertex light in younger specimens, becoming irregularly darker with age; mature specimens almost black. Male proctiger with apically relatively wide posterior lobes (Figure 23). Paramere slender in apical half. Apical dilatation of distal segment of aedeagus subtriangular. Dorsal margin of female proctiger distinctly evenly curved .. ..*Bactericera trigonica*

4.1.2. Organisms in Australia with which *Bactericera cockerelli* might be confused

Family Triozidae

Adults of the family Triozidae can be separated from the other psylloid families Calophyidae, Carsidaridae, Homotomidae, Phacopteronidae and Psyllidae with the following combination of characters: Forewing without a costal break; pterostigma absent; Rs not fused to M at any point; vein M+Cu absent or very short, or very short vein R+M develped, so that R+M+Cu stem branches into its component veins at approximately one point (Figure 16); anal break in distance of apex of vein Cu_{1b}. Fifth instar nymphs may be recognised by the fusion of the mesonotal sclerites with the forewing pads, and the metanotal sclerites with the hindwing pads, respectively. Many triozid nymphs, including those of *Bactericera*, are characterised by the presence of a complete fringe of wax-producing sectasetae.

Bactericera cockerelli and trigonica

Within Australian Triozidae *Bactericera cockerelli* (and *B. trigonica*) can be recognised by the following combination of characters: Vertex and thorax with very short, indistinct setosity dorsally (magnification 100 times). Genal processes less than half vertex length. Forewing membrane colourless lacking dark pattern. forewing about 2.7 times as long as wide, subacute apically. Forewing venation comprising sinuous vein Rs; vein Cu longer than 3 times vein Cu_{1b}. Metatibia with 1+2 apical spurs. Male proctiger with short posterior lobes. Parameres simple, lamellar or digitiform. Female terminalia short.

As psyllids are generally very host specific the nymphs can be best identified by their host plant. The only known psyllids in Australia associated with Solanaceae are two *Acizzia* spp. (Psyllidae, Acizziinae). They have been reported from *Solanum mauritianum* and *S. melongena* (Kent and Taylor 2010) and differ from *Bactericera cockerelli* and *trigonica* in the 9-segmented antennae (rather than 3–5-segmented), the distinct thoracic sclerites, the absence of humeral lobes on the forewing pads, the presence of long capitate setae and the lack of marginal sectasetae on the head, wing pads and abdomen.

4.1.3. Key to distinguish nymphs of the exotic species from known Australian species associated with Solanaceae

1 Body completely surrounded by marginal sectasetae; dorsal surface lacking long capitate setae. Forewing pads with well-developed humeral lobes. Antenna indistinctly 3-5-segmented .... *Bactericera cockerelli*

\- Body lacking fringe of marginal sectasetae; long dorsal capitate setae present. Forewing pads lacking humeral lobes. Antenna distinctly 9-segmented (*Acizzia* cf. Kent and Taylor 2010) .... NOT *Bactericera*

4.2 Molecular diagnostic tests for adults and nymphs

Molecular diagnostic tests were used to differentiate two biotypes of *B. cockerelli* (Liu *et al.* 2006).

However adults of *B. cockerelli* can be differentiated from other Australian psyllid species on the basis of morphological characters. Nymphs of Australian psyllid species are unlikely to be found on the likely hosts of *B. cockerelli*; the possible exceptions are the nymphs of the *Acizzia* species found on egg plants (Kent and Taylor 2010). However the nymphs of *Acizzia* and *Bacticera* are quite different and can be distinguished on morphological characters.

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John Thompson (BioForce) provided specimens of *Bactericera cockerelli* from New Zealand and Gary Taylor (University of Adelaide) Australian triozid specimens. Isabelle Zürcher (Basel Natural History Museum) provided technical assistance.

The protocol was reviewed and verified by Diane C. Jones (Entomologist), Plant Health and Environment Laboratory, Ministry for Primary Industries (MPI), Christchurch, New Zealand.

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The Victorian Agricultural Insect Collection of the DPI Victoria has acquired adult and nymphal specimens of *B. cockerelli* for comparison and has copies of the major taxonomic literature enabling positive identification of both these species to be made. A set of verified adult specimens will be lodged at the ANIC in Canberra.

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8. APPENDIX

8.1 Biology

General
Psyllids are sap-sucking insects that use their stylet to feed on phloem. All psyllid species have six immature life history stages (eggs and five nymphal instars) before the adult stage. The nymphs are naked (no waxy or sugary covering or inside galls). Eggs are always oviposited on fresh plant tissue and are embedded by a petiole. Nymphs are wingless and develop into winged adults.

Life cycle
Oviposition. Eggs are laid on both surfaces of potato leaves (especially young apical growth), along margins of leaves, and also on petioles or stems. There may be a preference by nymphs for underside of leaves (Knowlton and Janes 1931).

Duration of life history stages. The developmental time (eggs to adults) for *B. cockerelli* is temperature related and may also be related to the host plant species. In North America, there are records of the life cycle taking 25 days for completion (temperature range 16-27ºC; Lehman 1930), 15-30 days in Utah (Knowlton and Janes 1931), 11-23 days in Colorado (Daniels 1934). In caged rearing experiments in California, the average developmental period was 31.2 days (range 19-42 days) and egg development was an average of 8.7 days (range 7-11 days in California; Davis 1937). Compere (1916) recorded 15 days for egg development and 30 days for nymphs reared in captivity in California. Abdullah (2008) found an average life cycle of 29 days at 26ºC. Egg development was 3-9 days and nymphal development period was 12-21 days in Utah (Knowlton and Janes 1931). The developmental rate for males and females was similar in California (Davis 1937). Adult longevity and female fecundity depended on the host plant (Knowlton and Thomas 1934; Pletsch 1947). Pletsch (1947) found that eggs to adults took 16-34 days on potato and 18-30 days on tomato in Montana; the pre-oviposition period was 6 days, oviposition period was 55 days, and post-oviposition was 55 days. Daniels (1934): Colorado – eggs 3-5 days, nymphs 15-20 days; adults live an average of 2 weeks. Cameron *et al.* (2009) report on the seasonality of this species on potato in New Zealand.

The number of generations/year probably varies according to temperature. Pletsch (1947) reported 3-5 generations/year in Montana. List (1939b) also reported 3-5 generation while Daniels (1941) reported up to 8-10 generations/year in Colorado. Compere (1916) reported that it was found throughout the year in California but did not give any indication on the number of generations. Overlapping summer generations were reported in Utah (Knowlton and Janes 1931).

Fecundity. Knowlton and Janes (1931) recorded females surviving in laboratory conditions for up to 189 days and laying over 1,000 eggs. Most females oviposit for an average of 21 days. The number of eggs per female ranges from 36 (Compere 1916) to 75 (Lehman 1930).

Adult behaviour. Females can mate after emergence, but mating generally occurs 2-3 days after. Eggs are generally oviposited 6 days after mating (Davis 1937). The sex ratio of adults has been recorded as 3♂:2♀ in California (Davis 1937) and 1:1 in Montana (Pletsch 1947).

Feeding. Nymphs raise their abdomen and move the tip from side to side. They secrete a spirals or droplets “honeydew” or wax which is- primarily sugar (List 1939b; Pletsch 1947). The digestive system has been examined (Cicero *et al.* 2009).

Overwintering. Overwinters as adults in cedars in southwestern Nebraska – prefer warm, dry locations near preferred host plant areas (Daniels 1941).

Temperature responses. The response of *B. cockerelli* to higher temperatures may be the main factor determining the persistence of this species. According to List (1939a), *B. cockerelli* thrives at temperatures less than 80ºF in Colorado, and can still oviposit at 90ºF. However, exposure to 100ºF for 1-2 hours can be lethal to eggs and nymphs and there is no oviposition. In the laboratory, 80ºF is the optimal temperature, and temperatures above this start to retard development (List 1939b). Higher summer temperatures cause adults to disperse (List 1939a, b). Hill (1947) reported that the absence or infrequent occurrence of hot summer temperatures permit establishment of the psyllid on small plants at a time when the foliage offers little protection from the heat. Later, however, when the leaves are dense enough to shade the lower portions of the plants and the soil surface, relatively high temperatures are important for maintenance of optimum developmental conditions in Nebraska. In North America, *B. cockerelli* spends summer in Arizona, Idaho and Utah and migrates to overwintering sites in California (Jensen 1954). Migration is inferred from the simultaneous occurrence of adults in widely scattered areas in Montana (Pletsch 1947). During these migrations large numbers could be found in mountainous areas on various non-solanaceous hosts (Jensen 1954). Daniels (1941) observed that psyllid yellows damage may be related to environmental conditions, and were more severe in association with drought and higher temperatures in Colorado, but Daniels (1941) also noted that outbreaks also occurred with moderately high temperatures and low rainfall in early spring, which may favour perennial host plants.

8.2 Host table

Host table from "Final pest risk analysis report for "*Candidatus* Liberibacter psyllaurous" in fresh fruit, potato tubers, nursery stock and its vector the tomato-potato psyllid. Biosecurity Australia, Canberra. Appendix A.

Host	**Common name**	**Host association**	**Present in Australia**
Convolvulaceae			
Convolvulus arvensis L.	Field bindweed	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**Yes** (AVH 2009)
Ipomoea batatas (L.) Lam.	Sweet potato, Kumara	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**Yes** (AVH 2009)
Ipomoea purpurea (L.) Roth	Morning glory	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**Yes** (AVH 2009)
Lamiaceae			
Mentha spicata L.	Spearmint	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**Yes** (AVH 2009)
Micromeria chamissonis (Benth.) Greene		Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**No record**
Solanaceae			
Atropa belladonna L.	Deadly nightshade, Bella Donna	Unknown	**Yes** (Randall 2007)
Capsicum annuum L.	Capsicum, Pepper	Breeding host. This species supports large populations of the psyllid (Horticulture New Zealand 2008b)	**Yes** (AVH 2009)
Capsicum frutescens L.	Chilli	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**Yes** (AVH 2009)
Datura fastuosa L.		Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**No record**
Datura inoxia Mill.		Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**Yes** (AVH 2009)
Datura stramonium L.	Jimsonweed, Thornapple	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**Yes** (AVH 2009)
Hyoscyamus albus L.		Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**Yes** (AVH 2009)
Hyoscyamus niger L.	Henbane	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**Yes** (AVH 2009)
Lycium andersonii A. Gray		Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**No record**
Lycium exsertum A. Gray		Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**No record**
Lycium fremontii A. Gray		Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**No record**
Lycium halimifolium Mill.	Matrimony vine	Breeding host (Wallis 1955)	**No record**

Host	**Common name**	**Host association**	**Present in Australia**
Lycium macrodon A. Gray		Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**No record**
Lycium pallidum Miers		Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**No record**
Lycium parishii A. Gray		Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**No record**
Lycium quadrifidum Moc. and Sessé ex		Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**No record**
Lycium torreyi A. Gray		Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**No record**
Lycopersicon esculentum Mill. [synonyms: *Solanum lycopersicum* L., *Lycopersicon lycopersicum* (L.) H. Karst.]	Tomato	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**Yes** (AVH 2009)
Lycopersicon pimpinellifolium (L.) Mill.	Currant tomato	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**Yes** (AVH 2009)
Nicandra physalodes (L.) Gaertn.	Apple of Peru	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**Yes** (AVH 2009)
Nicotiana affinis Moore	Flowering tobacco	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**No record**
Nicotiana glutinosa L.		Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**No record**
Nicotiana tabacum L.	Tobacco	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**Yes** (AVH 2009)
Nicotiana texana Maxim.		Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**No record**
Nierembergia hippomanica Miers	Cup flower	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**Yes** (AVH 2009)
Physalis angulata L.	Cut leaf ground-cherry	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**Yes** (AVH 2009)
Physalis comata Rydb.	Wild ground-cherry	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**No record**
Physalis alkekengi L.	Chinese lantern	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**Yes** (AVH 2009)
Physalis heterophylla Nees	Clammy ground-cherry	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**Yes** (AVH 2009)
Physalis ixocarpa Brot. ex Hornem. [synonym: *Physalis philadelphica* Lam.]	Tomatillo	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**Yes** (AVH 2009)
Physalis lanceolata Michx.		Breeding host (Wallis 1955)	**No record**
Physalis lobata Torr.	Purple ground-berry	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**No record**

Host	**Common name**	**Host association**	**Present in Australia**
Physalis longifolia Nutt.	Longleaf ground-cherry	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**Yes** (AVH 2009)
Physalis mollis Nutt.	Longleaf ground-cherry	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**No record**
Physalis peruviana L.	Cape gooseberry	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**Yes** (AVH 2009)
Physalis pruinosa L.	Husk tomato	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**No record**
Physalis rotundata Rydb.	Longleaf ground-cherry	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**No record**
Solanum aviculare G. Forst.	Bullibulli	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**Yes** (AVH 2009)
Solanum baylisii Geras.		Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**No record**
Solanum betaceum Cav. [synonym: *Cyphomandra betacea* (Cav.)	Tamarillo	Breeding host (Horticulture New Zealand 2008b)	**Yes** (AVH 2009)
Solanum carolinense L.	Ball nightshade, Bull nettle, Horse nettle, Devil's tomato	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**Yes** (AVH 2009)
Solanum chenopodioides Lam.	Velvety nightshade, Whitetip nightshade	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**Yes** (AVH 2009)
Solanum citrullifolium A. Braun		Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**No record**
Solanum elaeagnifolium Cav.	White horse-nettle, Silver-leaf nightshade	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**Yes** (AVH 2009)
Solanum jamesii Torr.	Wild potato	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**No record**
Solanum melongena L.	Eggplants, Aubergine	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**Yes** (AVH 2009)
Solanum mexicanum Moc. and Sessé ex		Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**No record**
Solanum nigrum L.	Wonderberry, Black nightshade, Blackberry nightshade, Garden huckleberry	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**Yes** (AVH 2009)
Solanum pseudocapsicum L.	Jerusalem cherry	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**Yes** (AVH 2009)

Host	Common name	Host association	Present in Australia
Solanum pyracanthos Lam.	Porcupine tomato	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**No record**
Solanum racemigerum Zodda		Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**No record**
Solanum rostratum Dunal	Buffalo-bur	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**Yes** (AVH 2009)
Solanum sanitwongsei Craib		Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**No record**
Solanum sisymbriifolium Lam.	Viscid nightshade, Sticky nightshade	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**Yes** (AVH 2009)
Solanum triflorum Nutt.	Wild tomato	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**Yes** (AVH 2009)
Solanum tuberosum L.	Potato	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	**Yes** (AVH 2009)
Solanum villosum Mill.	Hair nightshade	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	**Yes** (AVH 2009)

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