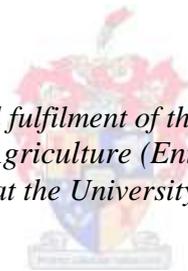


# **Morphology and taxonomy of tortricid moth pests attacking fruit crops in South Africa**

by  
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*Thesis presented in partial fulfilment of the requirements for the degree  
Master of Sciences in Agriculture (Entomology) in the Faculty of  
AgriScience at the University of Stellenbosch*



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Entomology) and  
Dr J. W. Brown (United States Department of Agriculture)

March 2013

## **Declaration**

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By submitting this thesis/dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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## Abstract

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*Cydia pomonella* (codling moth), *Thaumatotibia leucotreta* (False codling moth), *Thaumatotibia batrachopa* (Macadamia nut borer), *Grapholita molesta* (Oriental fruit moth), *Cryptophlebia peltastica* (Litchi moth), *Epichoristodes acerbella* (Pear leafroller/Carnation worm) and *Lozotaenia capensana* (Apple leafroller) are the most economically important tortricids affecting various crops in South Africa. The correct identification of these species, especially of the larval stage, is of great importance in pest management. Using available literature, augmented by additional morphological studies, an interactive identification key (Lucid key) for larval and adult stages of the seven species was developed. The colour and markings of the head, characteristics of the prothoracic and anal shields, the position of the prespiracular setae (L-group) relative to the spiracle on the prothoracic segment, the position of the spiracle on the eighth abdominal segment and L-group on the ninth abdominal segment, as well as the presence or absence of the anal comb are key characteristics for larval identification. For adult identification, wing pattern and genitalia are the most important features. However, the use of genitalia for moth identification might be difficult for the lay user, as the dissection and mounting of these structures requires certain skills and specialized equipment. Thus, genitalia have not been included in the Lucid Key. Differences in the morphological characteristics of most pupae were so minute that this stage was also not included in the Lucid key. However, the pupae of *E. acerbella* and *L. capensana* are easily distinguished from those of the other species by the presence of cremaster. This study also included the first morphological description of the pupa of *L. capensana*, which can be distinguished from that of *E. acerbella* by various features of the cremaster, antennae, spiracle shape, number of setae on abdominal segments A5-7, the size of spines on A3-7, and the presence/absence of spines on A9. A previous study by Timm (2005) indicated that geographically isolated populations of *T. leucotreta* tend to be genetically distinct. This raised the question of whether speciation/subspeciation has occurred or is occurring. Male moth genitalia are thought to evolve rapidly and are often the only features that can reliably distinguish similar species. Hence, variation in the shape of the valvae of *T. leucotreta* was used to determine whether divergence has occurred between populations of *T. leucotreta*. Elliptical Fourier analysis was used to analyze the valvar variation in three different populations. Although some variation in valvar shape was detected among mean population values for certain traits, no clear pattern emerged. Principle component analysis also showed no distinct clustering of valvae shape among populations, providing no evidence for divergence in male genitalia and therefore no morphological evidence of incipient speciation.

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## Opsomming

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*Cydia pomonella* (Kodlingmot), *Thaumatotibia leucotreta* (Valkodlingmot), *T. batrachopa* (Makadamianeutboorder), *Grapholita molesta* (Oosterse vrugtemot), *Cryptophlebia peltastica* (Lietsjiemot), *Epichoristodes acerbella* (Peerbladroller/Angelierrusper) en *Lozotaenia capensana* (Appelbladroller) is die mees ekonomies belangrike tortrisiede van die vrugtebedryf in Suid-Afrika. Die juiste identifikasie van hierdie spesies, veral van hulle larwale stadium, is van groot belang by plaagbestuur. Deur gebruik te maak van beskikbare literatuur, aangevul deur bykomstige morfologiese studies, is 'n interaktiewe uitkenningssleutel ("Lucid key") vir die larwale en volwasse stadia van die sewe spesies ontwikkel. Die kleur en tekening van die kop, kenmerke van die prothorakale en anale skild, die ligging van die prespirakulêre setae (L-groep) relatief tot die spiraculum op die prothorakale segment, die ligging van die spiraculum op die agste abdominale segment en L-groep op die negende abdominale segment, asook die aan- of afwesigheid van die anale kam is sleutel kenmerke vir larwale uitkenning. Vir die volwassenes is die vlerktekening en genitalia die mees belangrike kenmerke. Die gebruik van die genitalia vir motuutkenning kan egter vir die leek gebruiker moeilik wees omdat die disseksie en montering van hierdie strukture bepaalde vaardighede en gespesialiseerde toerusting vereis. Vir die rede is die genitalia nie in die Lucid-sleutel ingesluit nie. Verskille in die morfologiese kenmerke van meeste papies is klein en die stadium is gevolglik ook nie in die sleutel ingesluit nie. Die papies van *E. acerbella* en *L. capensana* kan egter maklik van die ander spesies onderskei word deur die aanwesigheid van 'n cremaster. Hierdie studie sluit ook die eerste morfologiese beskrywing van die papie van *L. capensana* in, wat van dié van *E. acerbella* onderskei kan word deur gebruik te maak van kenmerke van die cremaster, antennae, spirakulêre vorm, aantal setae op abdominale segmente A5-7, die grootte van stekels op A3-7, en die aan- of afwesigheid van stekels op A9. 'n Vroeëre studie (Timm 2005) het aangedui dat geografies geïsoleerde bevolkings van *T. leucotreta* neig om geneties verskillend te wees. Dit het die vraag laat ontstaan of spesiasie/subspesiasie moontlik plaasgevind het of steeds plaasvind. Manlike mot genitalië word geag om vinnig te ontwikkel en is dikwels die enigste kenmerke wat betroubaar tussen soortgelyke spesies kan onderskei. Dus is die variasie in die vorm van die valvae van *T. leucotreta* gebruik om te bepaal of divergensie wel tussen bevolkings van *T. leucotreta* plaasgevind het. Elliptiese Fourier ontleding is gebruik om die valvae se variasie by drie verskillende bevolkings te ontleed. Alhoewel enkele variasie in die vorm van die valvae bespeur is by die gemiddelde bevolkingswaardes vir bepaalde eienskappe, kon geen duidelike patroon bespeur word nie. Hoofkomponentontleding het ook geen duidelike groepering van valvae se vorm tussen bevolkings getoon nie, wat geen bewys lewer van divergensie in die manlike genitalia en dus geen morfologiese bewys van beginnende spesiasie.

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## Acknowledgements

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I wish to express my sincere appreciation to the following person and institutions:

My supervisors, Dr P. Addison, Prof. H. Geertsema and Dr J. W. Brown for their guidance, interest and constructive criticism during this research.

Citrus Research Industry (CRI), the Deciduous Fruit Producers Trust, trading as FruitGro Science and THRIP for funding this research project. Stellenbosch University for awarding me the Merit Bursary for 2011 and 2012.

S. Moore (CRI), T.M Gilligan (Colorado State University), M.F Addison, Dr K. Mitchell and L. Boardman for advice and guidance throughout the research.

Dr J. W. Brown and T.M. Gilligan and their families for taking me up in their homes during my stay in the USA.

Dr. D. Mazzi (Eidgenössische Technische Hochschule, Zürich, Switzerland), Dr. M. Botton (Embrapa Grape and Wine, Brazil), Dr D. Steenkamp (Entomon), Dr K.L. Pringle, Dr. J.M. Heunis, J. K. Opoku-Debrah, R. Stotter (XSIT), C. Chambers (River Bioscience), A. Burger, G. Nel (Wynkelderberg), F. Chidawanyika, J. Groenewald, G. Morland, R. Schoombie, M. Strydom, R. Rentel, G. Wilckens, J. Liebenberg, Z.M de Jager, S. Faure, A.J. Bam, A. Brinkhuis, S. Rosenberg and Plant Quarantine (Department of Agriculture, Forestry and Fisheries) for assistance in obtaining specimens or technical assistance.

T.W. Walters and his team (USDA, Fort Collins) for hosting me and for valuable knowledge exchange.

The landowners of the following farms for allowing me to set up traps and provide infested fruit material: Wynkelderberg, De Hoof, Frankenhof, Brandrivier, Nietvoorby (ARC Elgin), Killkewyn, Excelsior Boerdery, The Grange, Wolwehoek Boerdery, Somerslus, Glen Oak, Goosen Bourdery, Rooihogte, Timberlea, Vergenoegd, Upotn farm and The Rest 38.

My family and friends for their support throughout.

### Presentations at conferences:

Rentel, M., De Wet, PPH., Addison, P. & Geertsema, H. (2011). Morphology of two frequently confused moth pests of citrus and pomegranates: a quick identification guide. Poster, Entomological Society of southern Africa Conference, Bloemfontein.

Rentel, M., Addison, P., Geertsema, H. & Brown, J.W. (2012). Improved taxonomic understanding and the development of a LUCID key for tortricid moth pests in South Africa. 7th Citrus Research Symposium, Drakensberge.

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## CHAPTER 1

### Introduction

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Tortricidae, commonly known as leafrollers or leaftwisters, are the largest family of microlepidoptera with more than 5000 species (Powell, 1964; Pinhey, 1975; Horak & Brown, 1991). The family includes some of the most economically important pests of agriculture, forest trees, and ornamental plants (Powell, 1964; MacKay 1959; Holloway *et al.*, 1987; Razowski, 2002; Timm, 2005). The family is worldwide in distribution but reaches its greatest species-richness in temperate and tropical regions (Common, 1990; Horak & Brown, 1991; Scoble, 1992). The common name, leafrollers, originates from the larval behaviour of spinning and/or rolling leaves of the host plant upon which they feed and develop (Pinhey, 1975; Timm, 2005). Seven major economically important tortricid species can be found in South Africa, all of which have great impact on the local fruit industry: *Cydia pomonella* (Linnaeus, 1758) (Codling moth), *Thaumatotibia leucotreta* (Meyrick, 1913) (False codling moth), *Grapholita molesta* (Busck, 1916) (Oriental fruit moth), *Cryptophlebia peltastica* (Meyrick, 1921) (litchi moth), *Thaumatotibia batrachopa* (Meyrick, 1908) (Macadamia nut borer), *Epichoristodes acerbella* (Walker, 1864) (Pear leafroller/Carnation worm) and *Lozotaenia capensana* (Walker, 1863) (Apple leafroller) (Table 1). The larvae of all these species feed on a range of cultivated crops causing extensive damage and losses to the fruit industry (Powell, 1964; Timm, 2005).

Correct identification, especially of the immature stages, is important because misidentifications can lead to ineffective pest management. Current keys for tortricid species in South Africa are unsatisfactory because they are mostly incomplete. McGeoch & Krüger (1994) developed a key for identifying moth larvae associated with *Ravenelia* galls on *Acacia karroo*. One important tortricid larval species, *C. peltastica*, found on *Acacia karroo* galls, was included in their study. Krüger (1998) subsequently developed a key for identifying adult moths associated with *Ravenelia* galls on *Acacia karroo*, which included larvae of two economically important tortricid species, *C. peltastica* and *T. leucotreta*. Yet, in both McGeoch & Krüger (1994) and Krüger (1998), no description is provided for either *C. peltastica* or *T. leucotreta*. Timm *et al.* (2007, 2008) produced a dichotomous key to distinguish among six economically important tortricid larvae and their pupae present in South Africa, but for some of these species, especially *L. capensana*, a complete description for the immature life stages is lacking.

Species identification is the basis of traditional taxonomy, also known as alpha taxonomy, which relies on subjective visual evaluations (Mutanen & Pretorius 2007). Traditional taxonomy, which also included the describing of species based on morphology, is facing a serious challenge in that there is a lack of time, funding, and expertise (taxonomist have become a dying breed), and that relevant information available is often inaccessible (Walters & Winterton, 2007). This principle could be assisted by using more integrative taxonomy. Integrative taxonomy combines the use of traditional taxonomy together with multiple disciplines and modern identification techniques such as DNA barcoding, interactive identification keys, and morphometrics.

Walter & Winterton (2007) discussed how searches on “identification keys” and “insects keys” increased dramatically based on the number of “hits” on Google over a one-year period from March 2005 to March 2006. The search “Identification keys” increased over the one year period by almost 100 000 hits and “insects keys” by 19 000 hits.

Dichotomous keys have been, and are still used for identification purposes (Osborne, 1963). In dichotomous keys, each “question” has a couplet with two possible contrasting characters (Osborne, 1963; Amante & Norton, 2003; Walters & Winterton, 2007). Depending on the answer chosen, the user is either redirected to another couplet or to an endpoint providing an identity (Amante & Norton, 2003; Walters & Winterton, 2007). Dichotomous keys frequently present one major problem, the unanswerable couplet, for which a user is not able to decide on one statement, and hence, is unable to continue with the key (Amante & Norton, 2003; Walters & Winterton, 2007). Matrix keys, such as LUCID keys, are more interactive and enable the user to select more than one character to examine or to skip characters which are not conspicuous to them, and still reach a possible identification (Amante & Norton, 2003; Walters & Winterton, 2007).

Morphometrics is the “measurement and analysis of a form” (Daly, 1985) and was traditionally based on size, ratios, and linear measurements (Daly, 1985; Mutanen & Pretorius, 2007). Geometric morphometrics has become more and more popular; enabling users to quantify shapes (Mutanen & Pretorius, 2007).

Timm *et al.* (2010) found no evidence of specific host races in a population of *T. leucotreta* population, but evidence was presented for population structure on a fine-scale, indicating that populations of different geographic origins were genetically distinct. Timm *et al.* (2010) suggested that the reason for this divergence could be due to limited dispersal. This begs the question of whether speciation within *T. leucotreta* has occurred. To answer this question, the male genitalia were studied and analyzed using shape morphometrics. Meyrick (1895), the first person to introduce the use of genitalia in tortricid taxonomy, however, later opposed their use and Kennel (1908), although receiving criticism, concluded that “genitalia are so strongly diverse” that they may be useful for separating related taxa but should not be used in higher classification (Horak, 1984). Dampf (1908) proved Kennel (1908) wrong in a comparative study analyzing the genitalia of *Rhopobota naevana* (Hübner, 1817) (Horak, 1984). Pierce & Metcalfe (1922) were the first to carry out a comparative study of tortricid male and female genitalia of the British Islands. Powell (1964) mentioned that the “male genitalia in tortricids form the basis for classifications,” and that genitalia alone can be used to determine the identity of a species. Various other authors have proven the importance and taxonomic value of genitalia (Horak, 1984). The shape and size of the genitalia play an important role in identification, and by using geometric morphometrics one can identify quantitative evidence of the difference between different species.

### **1.1. Classification and systematics**

The classification of the seven important tortricids in South Africa is presented in Table 1.

**Table 1:** Classification of the seven important tortricid species in South Africa (Pinhey, 1975; Karisch, 2003; Brown, 2005)

	Codling moth	False codling moth	Macadamia nut borer	Oriental fruit moth	Litchi moth	Pear leafroller	Apple leafroller
<b>Order</b>	Lepidoptera						
<b>Family</b>	Tortricidae						
<b>Subfamily</b>	Olethreutinae					Tortricinae	
<b>Tribe</b>	Grapholitini					Archipinif	
<b>Genus</b>	<i>Cydia</i>	<i>Thaumatotibia</i>		<i>Grapholita</i>	<i>Cryptophlebia</i>	<i>Epichoristodes</i>	<i>Lozotaenia</i>
<b>Species</b>	<i>pomonella</i>	<i>leucotreta</i>	<i>batrachopa</i>	<i>molesta</i>	<i>peltastica</i>	<i>acerbella</i>	<i>capensana</i>
<b>Synonyms</b>	<i>Phalaena</i> (Tortrix) <i>pomonella</i> (Linnaeus, 1758) <i>Phalaena nitens</i> (Fourcroy, 1785) <i>Pyralis pomona</i> (Fabricius, 1775) <i>Phalaena</i> (Tortrix) <i>aeneana</i> (Villers, 1789) <i>Tortrix pomonana</i> (Denis & Schiffermüller, 1775) <i>Laspeyresia pomonella</i> (Hübner, 1825) <i>Carpocasca putaminana</i> (Staudinger, 1859) <i>Carpocasca glaphyrana</i> (Rebel, 1941)	Natal codling moth <i>Carpocapsa</i> sp. (Fuller, 1901) Orange codling moth <i>Enarmonia batrachopa</i> (Howard, 1909) <i>Agryroploce leucotreta</i> (Meyrick, 1913) <i>Cryptophlebia leucotreta</i> <i>Thaumatotibia roerigii</i> (Zacher, 1915)	<i>Cryptophlebia batrachopa</i> <i>Enarmonia batrachopa</i> (Meyrick, 1908) <i>Agryroploce colivora</i> (Meyrick, 1932)	<i>Cydia molesta</i> <i>Laspeyresia molesta</i> (Busck, 1916)	<i>Agryroploce peltastica</i> (Meyrick, 1921)	<i>Depressaria acerbella</i> (Walker, 1864) <i>Epichorista galeata</i> (Meyrick, 1921) <i>Tortrix iocoma</i> (Meyrick, 1908) <i>Proselena ionephela</i> (Meyrick, 1905) <i>Epichorista ionephela</i> (Meyrick, 1909)	<i>Teras capensana</i> (Walker, 1863) <i>Teras</i> (Tortrix) <i>meridionana</i> (Walker, 1863) <i>Teras reciprocana</i> (Walker, 1863) <i>Parapandemis capensana</i> (Walker, 1863) <i>Tortrix capitana</i> (Felder, 1875) <i>Cacoeia adustana</i> (Walsingham, 1881) <i>Tortrix adustana</i> (Walsingham, 1881) <i>Cacoeia</i> (Tortrix) <i>dorsiplagana</i> (Walsingham, 1881) <i>Tortrix capensana</i> (Meyrick, 1937)

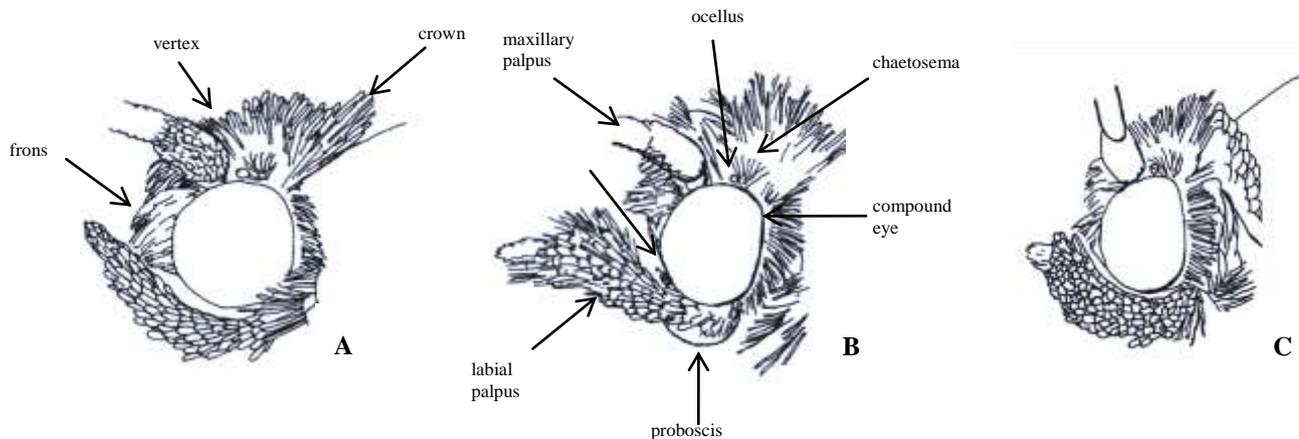
## 1.2. General morphology and characteristics of Tortricidae

Tortricids are small to medium-sized (wingspan 8-35mm) moths, generally with dull or cryptic colours; however, a few species have spectacular colours and patterns (Common, 1990; Scoble, 1992). When the moths are at rest, the forewings form a somewhat bell shape, and many species possess tufts of scales on the forewings and thorax (Scoble, 1992). The following is a summary of available literature describing tortricid characteristics of all life stages.

### 1.2.1. Adult

#### *Head*

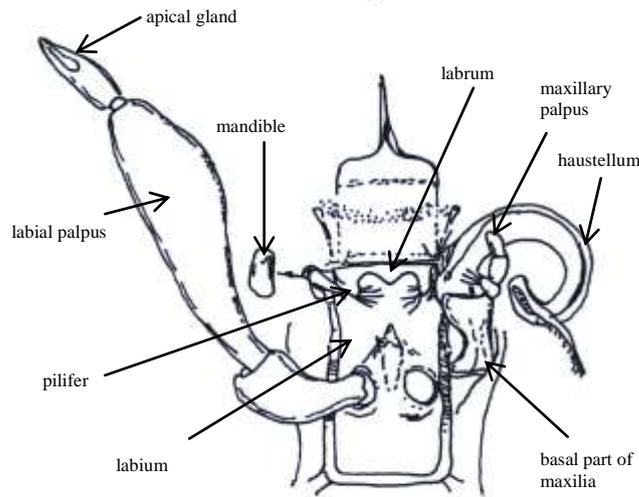
Head anteriorly covered with rough, broad, long scales on vertex and upper frons, usually downward orientated and appressed, and with short, upwards orientated scales on lower frons (Bradley *et al.*, 1973; Common, 1990; Horak, 1991, 1999, 2006; Razowski, 2002; Gilligan *et al.*, 2008). Head capsule sutures reduced or absent (Horak, 1999; Razowski, 2002). Ocellus above each compound eye usually well developed, chaetosemata well-developed, pin-bristle-like, domed, adjacent to ocellus (Fig. 1) (Common, 1990; Horak, 1991, 1999, 2006; Scoble, 1992; Gilligan *et al.*, 2008). Compound eyes spherical with marginal band of microtrichia (Fig. 1) (Common, 1990; Horak, 1991, 1999, 2006; Scoble, 1992).



**Figure 1:** Head of Tortricid moths, a) Tortricinae: Archipini; b) Tortricinae: Tortricini; c) Olethreutinae: Grapholitini – *Cydia pomonella* (Redrawn from Bradley *et al.*, 1973; Figs 8, 11, 14)

Scape and pedicel of antenna densely covered with scales with small intercalary sclerite between basal two antennal segments (Horak, 1991, 2006). Scales on flagellum across dorsal surface, ventral surface unscaled with many sensilla (Common, 1990; Horak, 1991; Gilligan *et al.*, 2008). Scales arranged ventrally as interrupting rings, with one (Olethreutinae) or two (Tortricinae) rings per segment (Horak, 1991, 1999, 2006; Razowski, 2002; Gilligan *et al.*, 2008). Sensory setae (often referred to as cilia) either evenly distributed and short or grouped and longer, varying in size, usually more well developed in males (Horak, 1991, 2006; Razowski, 2002). Males of certain groups with secondary sexual modifications, e.g., a notched or expanded and flattened base of flagellum forming scent organ (Horak, 1991, 1999; Scoble, 1992; Razowski, 2002). Pilifers present and well developed (Horak, 1999; Razowski, 2002).

Proboscis well-developed and naked (unscaled) (Common, 1990; Scoble, 1992; Horak, 2006; Gilligan *et al.*, 2008). Maxillary palpi very small, varying from well-developed, scaled, with one to four segments, to reduced, naked and unsegmented remnants (Fig. 2) (Horak, 1991, 2006). Labial palpi three-segmented, varying in length from short (ca. equal to diameter of compound eye) to very long (ca. 3 times diameter of compound eye), porrect, or ascending (Fig. 2) (Bradley, 1973; Common, 1992; Razowski, 2002). First second (basal) short; second segment long, sinuate and distally widened; third segment short and angled forward and downwards, containing Rath's organ (Horak, 1991, 2006; Razowski, 2002), and frequently concealed by the expanded distal scaling of the second segment.



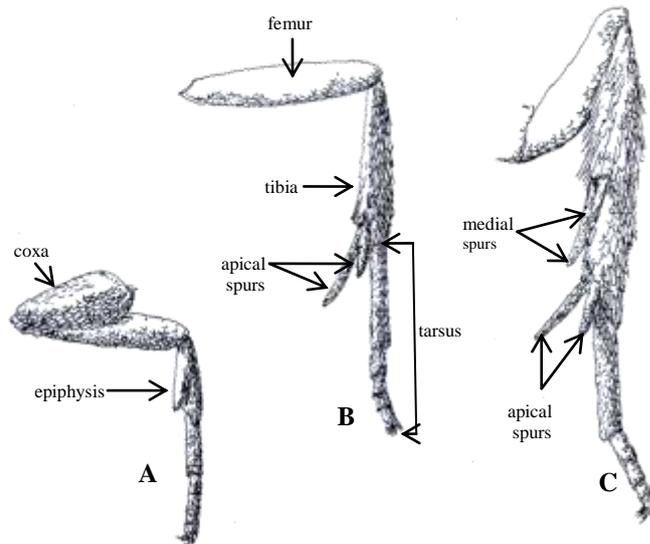
**Figure 2:** Mouthparts of the Tortricini (Redrawn from Razowski, 2002; Fig 1 – Mouth parts).

### ***Thorax***

Thorax mostly smooth scaled, sometimes with single or bipartite posterior crest of raised scales (Common, 1992; Razowski, 2002; Horak, 2006). Patagia (flap-like scales) present on prothorax, well-developed, parapatagia absent (Common, 1991; Horak, 1999).

### ***Legs***

Legs well-developed, densely covered with scales, characteristic for ditrysian Lepidoptera (Horak, 1991, 2006). Forecoxa free and undivided, tibia with epiphysis bristled along inner surface, comb-shaped (Bradley *et al.*, 1973; Horak, 1991; 2006; Razowski, 2002). Tibial spur formula 0-2-4 (Common, 1991; Scoble, 1992). Mid and hind coxae firmly fused to thorax, subdivided into anterior eucoxa and posterior meron (Horak, 1991). Apical spurs and specialized spiny scales present on mid tibia (Horak, 1999; Razowski 2002). Hind tibia with two types of spurs (Fig. 3), apical spurs and an additional median spur, scent scales present (Bradley *et al.*, 1973; Horak, 1991, 2006; Razowski, 2002). Males from various Olethreutine groups with modified hind tibiae with various scale modifications (Horak, 2006). Tarsus divided into five segments with spines near apex of segments 1-4, but reduced in some groups, pretarsus complete with two simple claws (Horak, 1991, 2006; Razowski, 2002).



**Figure 3:** Legs of Tortricini: A) fore leg, B) middle leg, C) hind leg (Redrawn from Bradley *et al.*, 1973; Figs 15-17).

### **Wings**

Wings well-developed (with some exceptions), shape of wings differing occasionally between sexes of conspecifics as a result of sexual modifications (Horak, 1991; Razowski, 2002). Fore and hind wings of males sometimes with folds associated with scent scales that distribute chemicals that presumably function in short-range courtship behaviour (Common, 1990; Scoble, 1992; Horak 1999, 2006; Razowski, 2002).

Fore wing shape variable: broadly triangular, fairly narrow-triangular, subrectangular, or subovate (Horak, 1999, 2006). Termen varying from nearly right-angled to costa to strongly oblique, sometimes more or less straight or variably sinuate with an indentation beneath apex (Horak, 2006). Pterostigma mostly absent, but with microtrichia, however, only in small dorso-basal area (Common, 1990; Horak, 1999; Razowski, 2002). Most olethreutine groups with smooth, flattened scales on fore wing, but in some groups with raised scale tufts of taxonomic significance (Horak, 2006).

Hind wings usually as broad as fore wing, slightly broader or narrower in different groups (Common, 1990; Horak, 1999). Olethreutinae (and some Tortricinae: Sparganothini) with cubital pecten, a row or tuft of hair scales, on base of hind wings (Common, 1990; Scoble, 1992; Horak, 1999, 2006). Males sometimes with modified anal margin on hind wing, often containing scent-producing scales (Horak, 1999, 2006). Infrequently with small, broad scales on anal margin, causing hind wing to be semi-translucent with areas of melanic scales and scale pencils (Horak, 2006). Cubital pecten, fine row of hair-like scales, present on hindwings of most Oletreutinae (Gilligan *et al.*, 2008).

Wing coupling is accomplished by a frenular-retinacular system, with frenular bristles present at base of hind wing (Fig. 4) locking into a retinaculum (in males as a small membranous hook from subcosta, and in females as erect scales in a row behind base of cubitus) beneath forewing (Common, 1990; Scoble, 1992; Horak, 2006). Frenulum of males a single acanthus, that of females with multiple acanthi, variable from 2-6

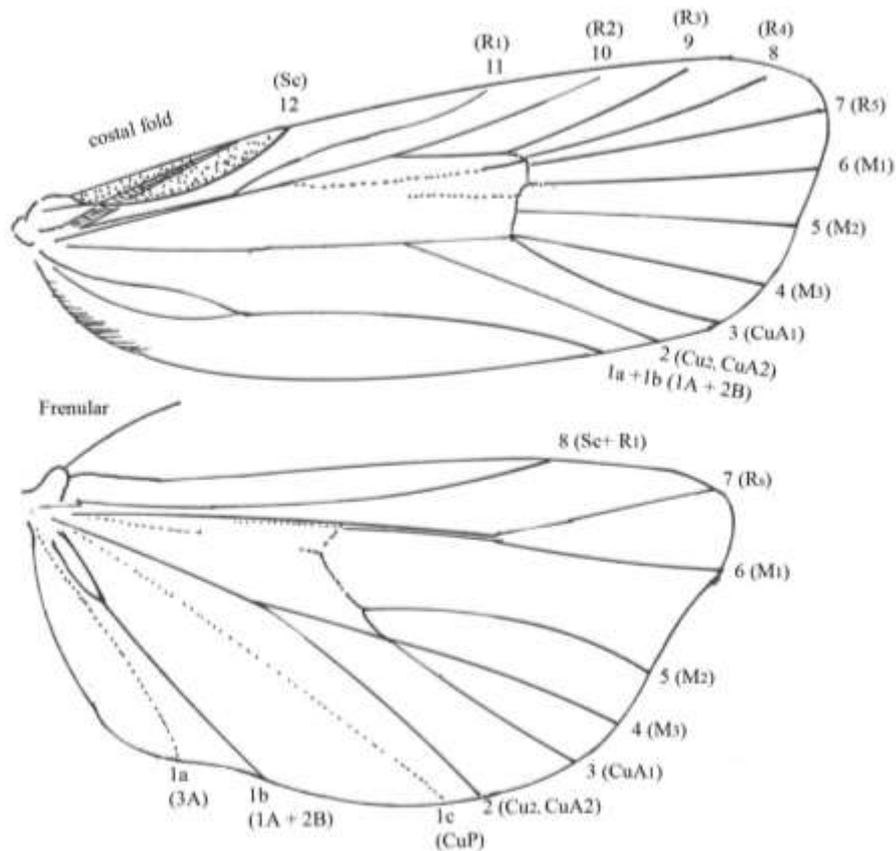
(or more), frequently asymmetrical on the same individual (Fig. 4) (Bradley *et al.*, 1973; Common, 1999, Horak, 2006; Monsalve *et al.*, 2011).



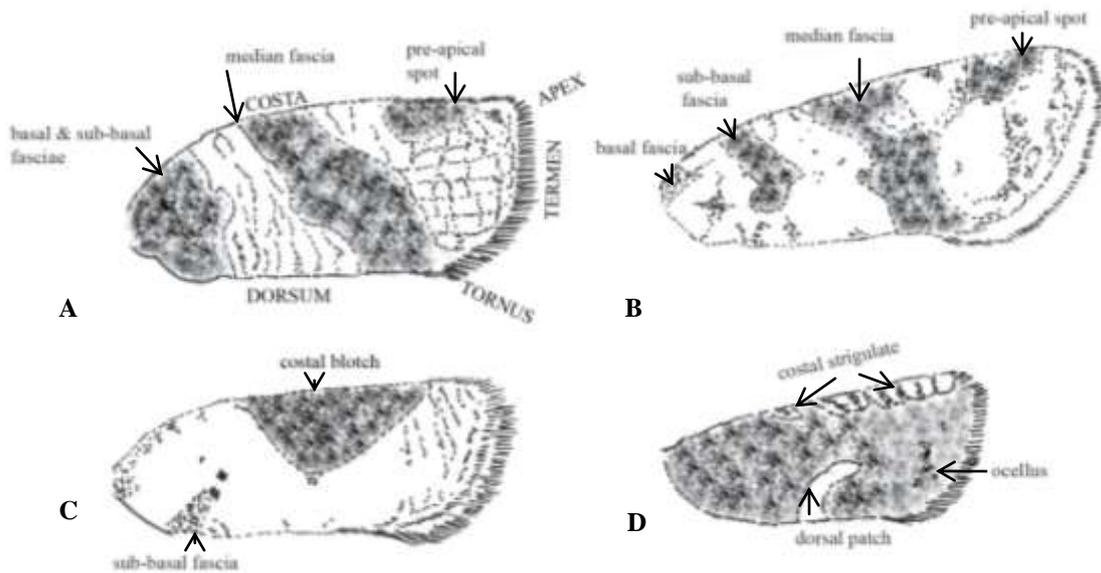
**Figure 4:** Frenular bristles at base of hind wing, A) males, B) females (Redrawn from Bradley *et al.*, 1973; Figs 18, 19).

Wing venation of tortricids typically heteroneurous with hind wing venation reduced to eight veins or radial branches (R-branch) compared to the 12 veins in the fore wing (Fig. 5) (Bradley *et al.*, 1973; Horak, 1991, 2006). Cryptically coloured forewings in most species, bright-coloured in species active during the day (Razowski, 2002). Hindwings usually unicolourous (Bradley *et al.* 1973).

Detailed descriptions and illustrations of wing venation and patterns are provided by Bradley *et al.*, 1973, Common, 1990; Horak, 1991; Scoble, 1992 and Razowski, 2002 (Figs 5-6, Table 2).



**Figure 5:** Wing venation of Tortricidae (Redrawn from Razowski, 2002; Fig. 2 Venation of *Tortricidae*)



**Figure 6:** Wing pattern of Tortricidae: A) & B) Tortricini, C) & D) Archipini (Redrawn and adjusted from Bradley *et al.* 1973; Figs 3-5)

**Table 2:** Wing venation systems according to Razowski (2002) (MS) and Hampson's system (HS) (Bradley *et al.*, 1973).

		Fore wing		Hind wing	
Terminology		MS	HS	MS	HS
<b>Subcosta</b>	Sc	M <sub>2</sub>	5	M <sub>3</sub>	4
		M <sub>1</sub>	6	M <sub>2</sub>	5
		R <sub>5</sub>	7	M <sub>1</sub>	6
		R <sub>4</sub>	8	R <sub>s</sub>	7
		R <sub>3</sub>	9	Sc+ R <sub>1</sub>	8
		R <sub>2</sub>	10		
		R <sub>1</sub>	11		
		Sc	12		
<b>Radial branches</b>	R	M <sub>3</sub>	4	CuA <sub>1</sub>	3
<b>Media stem</b>	M	CuA <sub>1</sub>	3	CuA <sub>2</sub>	2
<b>Cubitus anterior</b>	CuA	CuA <sub>2</sub>	2	CuP	1c
<b>Cubitus posterior</b>	CuP	CuP		1A+1B	1b
<b>Anal veins</b>	A	1A+1B	1a+1b	3A	1a

### Abdomen

Sternum of first segment absent, S2 with well-developed ventral tortricoid apodemes (Common, 1990; Horak, 1999; Razowski, 2002). Some genera with dorsal pits present on A2 or A3, either singly (fused) or in pairs (Common, 1990, Horak, 1991; Scoble, 1992; Brown & Miller, 1999; Razowski, 2002; Powell & Brown, 2012). Subgenital segments sometimes strongly modified to accommodate secondary sexual scales in males and specialized oviposition scales in females (Horak, 1991; Razowski, 2002). In males, segment A8 often supporting genitalia with distinct scent organs, e.g., coremata (Common, 1992. Horak, 1991,

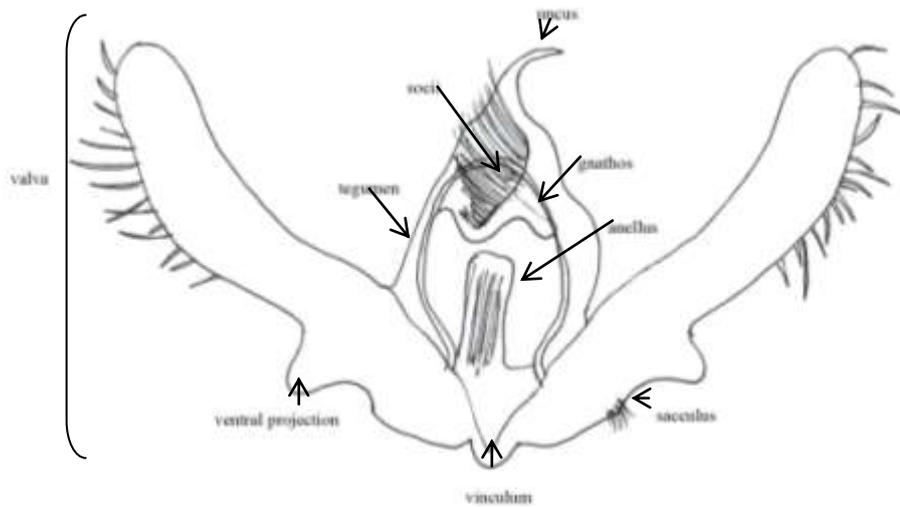
1999; Razowski, 2002). In females, modified scales form the corethrogyne, a tuft of densely set scales that on segment A7 covers the eggs (Powell, 1976; Common, 1990; Horak, 1991; Razowski, 2002). Pheromone glands are situated in the intersegmental membrane as a dorsal invagination between terga 8-9 (Horak, 1999; Razowski, 2002). Dorsally unspined on segments A9-A11 in males and A8-11 in females (Horak, 1999; Razowski, 2002).

### ***Genitalia***

Male and female genitalia (Figs 7-8) are critically important for the identification of tortricids (Horak, 1991).

#### *Male genitalia* (Fig.7)

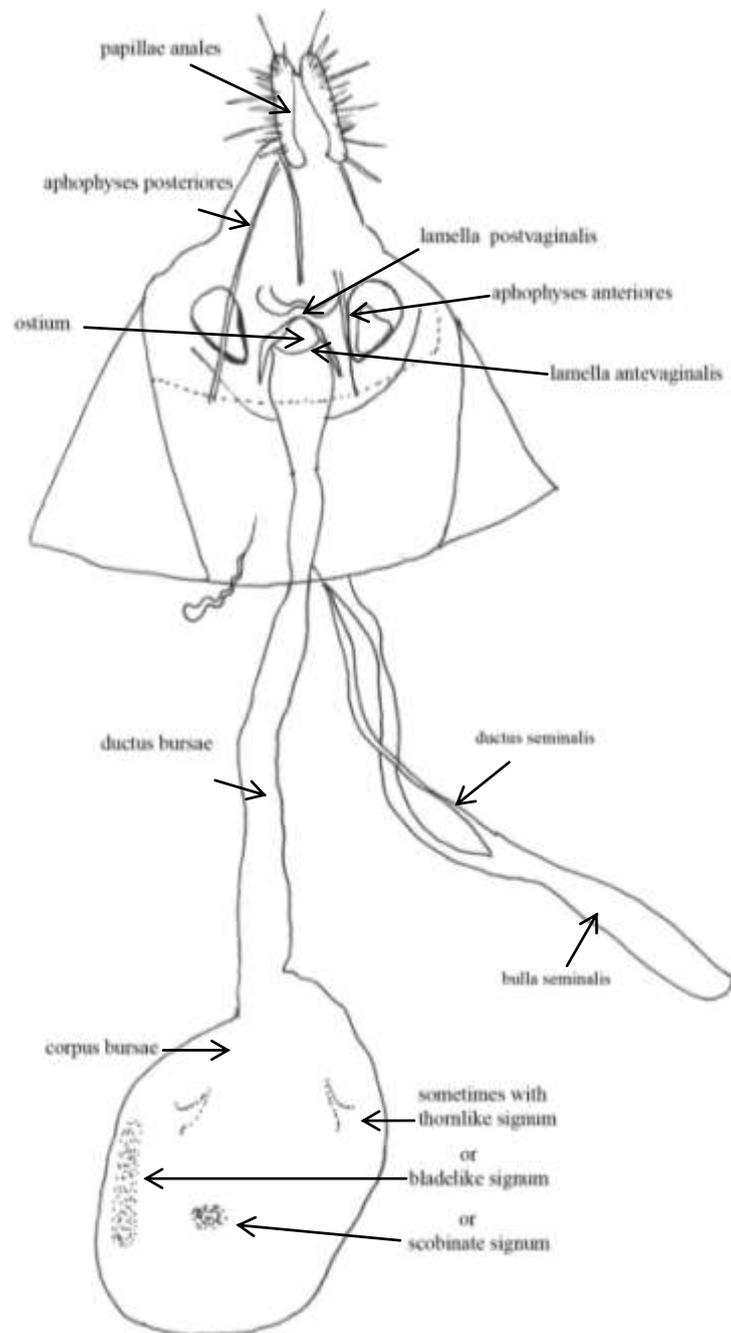
Dorsal tegumen and ventral vinculum originate from tergum and sternum of A9 to form a ring from which different paired processes of the genitalia arise (Horak, 1991; Gilligan *et al.*, 2008). Pedunculi, the base of the tegumen, usually long, with subterminal, inner attachment points of tergal flexors of valva ( $m_4$ ) (Horak, 1999; Razowski, 2002). Uncus, if present, slender and elongated, with or without processes, or bifid, well-developed ventral tuft or brush of setae in some groups (e.g., Archipini), modified by reduction or completely absent in others (Holloway *et al.*, 1987; Common, 1990; Horak, 1991; Razowski, 2002). Socii, membranous to sclerotized setose, drooping (pendulous) lobes or sacs, often reduced, sometimes fused with gnathos, usually with dense setae; more specialized socii partially distinctly sclerotized and erect (Holloway *et al.*, 1987; Common, 1990; Horak, 1999; Razowski, 2002; Gilligan *et al.*, 2008). Gnathos, if present, a pair of lateral arms or bands fused distally, supporting the distal terminus of the anal tube; frequently reduced or absent (e.g. Tortricini), in latter, lobes formed by a distinct subscaphium (Common, 1990; Horak, 1999; Razowski, 2002; Gilligan *et al.*, 2007). Valvae variable in shape, usually simple and symmetrical. Sclerotized costal margin (dorsal edge) and sacculus (ventral edge), in Olethreutinae distal part of valve specialized, densely hairy or spiny (=cucullus), in some groups with membranous pulvinus at inner base of valve (Holloway *et al.*, 1987; Common, 1990; Razowski, 2002). Anellus as folded convex membrane forming transtilla dorsally and a sclerotized juxta ventrally (Razowski, 2002; Gilligan *et al.*, 2008). Transtilla absent in Olethreutinae, present in Tortricinae as sclerotized, spined or membranous band connecting costal parts of valvae (Holloway *et al.*, 1987; Horak, 1999; Razowski, 2002). Vinculum either U- or V-shaped, attached or fused to pedunculi, saccus developed in most Chlidanotini and Hilarographini, absent in most other groups, in Archipini broad flaps formed by laterally emarginated ventral part (Holloway *et al.*, 1987; Horak, 1991; Razowski, 2002). Aedeagus variable, frequently short, curved, loosely attached to juxta by membrane and usually with well-developed coecum penis (lost in Olethreutinae) (Holloway *et al.*, 1987; Common, 1990; Horak, 1999). Juxta a simple shield-shaped plate, aedeagus in Tortricinae attached to juxta by membrane and folded perpendicularly, in Olethreutinae juxta firmly folded and fused with anellus and aedeagus (Common, 1990; Horak, 1991, 1999; Razowski 2002). Vesica or endophallus variably shaped, often minutely spinose, frequently with fixed or deciduous internal spine-like or plate-like cornuti (Holloway *et al.*, 1987; Horak, 1999; Razowski, 2002; Gilligan *et al.*, 2008).



**Figure 7:** Male genitalia of Oletreutinae (Redrawn from Gilligan *et al.*, 2008; Fig. 11).

#### *Female genitalia* (Fig. 8)

Ovipositor short or only slightly telescopic. Papillae anales soft, fleshy, setose (with papillate setae), flattened, lobe-like, more slender in groups adapted to deposit eggs into various crevices (Razowski, 2002); in a few groups (e.g. Tortricini and Cnephasiini) with nail-like setae (i.e. floricomous ovipositor) used to scrape debris over eggs (Holloway *et al.*, 1987; Common, 1990; Scoble, 1992; Horak, 1999; Razowski, 2002, Gilligan *et al.*, 2008). Apophyses ranging from short to very long, one pair connected to papillae anales (apophyses posteriors) and one pair to latero-posterior part of sterigma (Tortricinae) and tergum VIII (apophyses anteriores) (Common, 1990; Horak, 1999; Razowski, 2002, Gilligan *et al.*, 2008). Connection between apophyses and sterigma well sclerotized in almost all Tortricinae (Horak, 1991). Sterigma simple, variously sclerotized, occasionally asymmetrical (anteostial part short and ventral or forming cup and tube with dorsal part), surrounding ostium bursae of sternum 8 (S8) (Common, 1999; Horak, 1999; Razowski, 2002). Sterigma rarely fused to S7 in modified ovipositor of Oletreutinae and membranous junctures with eighth tergite (Horak, 1999; Razowski, 2002, Gilligan *et al.*, 2008). Ostium bursae opening in bursa copulatrix (important taxonomic characteristic) separated into slender ductus bursae and corpus bursae (Horak, 1991, 1999; Razowski, 2002). Corpus bursae usually with sclerotized signum (or signa): a single slender horn with prominent capitulum in Archipini (Tortricinae), a pair of thorn-like spines in Eucosmini and Grapholitini or absent in some Oletreutinae; ductus bursae with colliculum (distal part of ductus bursae, a sclerotized ring) below ostium, sometimes with cestum (inner part of ductus bursae, sclerotized ribbon) (Holloway *et al.*, 1987; Horak, 1991, 1999; Common, 1999; Razowski, 2002). Ductus seminalis, with diverticulum (bulla seminalis, very distinct), connecting bursa to vagina and accessory bursa (corpus bursae with a variously developed diverticulum) variably situated (anterior or posterior, dorsal or ventral) (Horak, 1991; Razowski, 2002 Gilligan *et al.*, 2008). Paired ovaries with four ovarioles (Horak, 1991). Spermatheca and accessory glands structure and arrangement as in higher Lepidoptera (Horak, 1991).



**Figure 8:** Female genitalia of Oletreutinae (Redrawn from Gilligan *et al.*, 2008; Fig. 13)

### 1.2.2. Egg

Eggs oval or circular in outline and flat, scale-like, or sometimes slightly convex (Fig. 9) (Common, 1990), with a long horizontal axis and micropyle terminal (Common, 1990; Horak, 1991; Razowski, 2002). Surface reticulated with ridges or finely sculptured chorion (Common, 1990; Horak, 1999; Razowski, 2002). Eggs laid singly, in pairs, groups or overlapping, forming large imbricate masses (Archipini) (Bradley *et al.*, 1973; Powell & Common, 1985; Common, 1990). Eggs sometimes covered with female accessory gland secretion and/or scales from anal tuft or wings (Bradley *et al.*, 1973).



**Figure 9:** *Thaumatotibia leucotreta* eggs

### 1.2.3. Larva

External feeders generally slender, internal feeders stout, three pairs of thoracic legs, and pairs of prolegs each on abdominal segments 3-6 and 10 (Bradley *et al.*, 1973; Horak, 1991). Head semi-prognathous, dark in initial instars, lighter in later instars (Bradley *et al.*, 1973; Common, 1991). Adfrontals extending to epicranial notch (Common, 1990; Horak, 1999). Coronal suture short; six stemmata (often incorrectly referred to as ocelli) on each lateral side (Bradley *et al.*, 1973; Common, 1990; Horak., 1991, 1999; Scoble, 1992; Razowski, 2002). Stemmatal area rounded in most internal feeders (fruit borers), angular in most external feeders (leaf rollers) (Bradley *et al.*, 1973). Darker pigmentation around lateral indentation or towards stemmatal area (Dugdale *et al.*, 2007). Pinacula, anal and prothoracic shield well sclerotized (Bradley *et al.*, 1973; Common, 1990). Cuticle spinulose or granulose with only primary and subprimary setae (Common, 1990; Razowski, 2002).

Prothorax lateral (L-) group trisetose, with three prespiracular setae (Bradley *et al.*, 1973; Common, 1991; Scoble, 1992; Horak, 1999; Razowski, 2002). Subventral group (SV) on T1-3 usually 2:1:1 with two SV setae on prothorax, one on meso- and metathorax (Brown, 1987; Common, 1990; Horak, 1999; Razowski, 2002). Well-developed thoracic legs (Razowski, 2002).

Abdominal integument granulated, usually without markings and secondary setae and usually with strongly sclerotized pinacula (Bradley *et al.*, 1973). Spiracles round to oval, peritreme sclerite well-defined (Bradley *et al.*, 1973). Eight abdominal segments with  $L^1$  and  $L^2$  setae adjacent, arranged vertically or at an angle on single pinaculum (Bradley *et al.*, 1973; Common, 1990; Scoble, 1992; Horak, 1999; Razowski, 2002). Anal shield sclerotized; anal comb or fork (3-8 straight prongs) on the last abdominal segment (A10) dorsal to anus, lost in a few internal feeders (Bradley *et al.*, 1973; Common, 1990; Scoble 1992; Razowski, 2002). Four pairs of ventral (A3-6) and one pair of anal prolegs (Razowski, 2002). Crotchets of prolegs either circular or elliptical shaped; uni-, bi-, or triordinal (Bradley *et al.*, 1973; Common, 1990; Scoble, 1992; Razowski, 2002). Crotchets on anal prolegs in semi-circle (Scoble, 1992). SV-group trisetose on A3-6

(Horak, 1999). Subdorsal seta ( $SD^1$ ) directly anterior to spiracle on A8 (Bradley *et al.*, 1973, Common, 1990; Horak, 1999; Razowski, 2002). Dorsal setae  $D^2$  on A9 usually sharing a single pinaculum forming a “saddle” (Common, 1990; Horak, 1999; Razowski, 2002).  $D^1$  closer to  $SD^1$  (often found on same pinaculum) than  $D^2$  (Horak, 1999; Dugdale *et al.*, 2005).  $SD^2$  absent on A9 (Dugdale *et al.*, 2005). According to Dugdale *et al.* (2005), “Anal shield with  $D^2$  usually anterior to level of  $SD^1$ , or at the same level in endophytic larvae with shortened anal shield and with setae  $D^2$  directed horizontally, not strongly directed dorsally or ventrally with anal combs sclerotized structure present above anus and secondary setae absent.”

#### **1.2.4. Pupa**

Small to medium in size (length 4-15 mm), cylindrical, somewhat rounded-blunt anteriorly, tapered caudad (Patočka & Turčáni, 2005). Distinct setae on clypeus and frons. Hook-shaped caudal and perianal setae on A10 (Patočka & Turčáni, 2005). Aedeagus, obteet, well sclerotized, fused appendages (wings, legs, etc.), with some moveable abdominal segments (Common, 1990; Scoble, 1992; Horak, 1991, 1999; Gilligan *et al.*, 2008). Head rounded apically and produced to anterior point, or rarely with large spine on frons (Common, 1990; Horak, 1999; Razowski, 2002). Vertex short (Patočka & Turčáni, 2005). Proboscis half as long as distance to wing tips, maxillary palpi present, but alar furrows rarely present (Common, 1990; Horak, 1999; Dugdale *et al.*, 2005). Labial palpi, prothoracic femora and sometimes mesothoracic coxae exposed (Common, 1990; Patočka & Turčáni, 2005). Antenna tapered, shorter than wings, reaching nearly to apices of the forewings (Bradley *et al.*, 1973; Common, 1990; Patočka & Turčáni, 2005). Forewings broad, rounded, extending to A4, and hindwings extending slightly past forewings (Bradley *et al.*, 1973; Common, 1990; Patočka & Turčáni, 2005). Metatarsus visible slightly (Patočka & Turčáni, 2005). Pronotum short, mesonotum sometime with subdorsal longitudinal furrow or dorsal ridge (alar furrow) (Patočka & Turčáni, 2005). Two transverse rows of spines on mid-abdominal segments, the basal uni- or multiseriate and the caudal uniseriate (Patočka & Turčáni, 2005). Abdominal segments (A) fused: A1 and A2 in both male and female, A8-10 in males, and A7-10 in females (Bradley *et al.*, 1973; Horak, 1999; Razowski, 2002; Gilligan *et al.*, 2008). Abdominal segments A4-7 movable in males and A4-6 in females (Komai, 1999; Razowski, 2002). Two rows of dorsal transverse spines on tergites A3-7, variably developed on A2 and A8-10 (Bradley *et al.*, 1973; Common, 1990; Scoble, 1992; Komai, 1999; Razowski, 2002). Along anterior margin of A2 and A3 paired dorsal pits between the anterior dorsal row of spines and anterior margin segments A2 and A3 in a few Archipini and Sparganothini (function unknown) (Scoble, 1992; Horak, 1991, 1999). Terminal segments A7–A10 on ventral side hold the genital pore (on A8 or A9) and anal opening (on A10) (Gilligan *et al.*, 2008). The genital pore is located on A8 in females and A9 in males (Gilligan *et al.*, 2008). A10 often with dorsal spines or transverse row (Patočka & Turčáni, 2005). Cremaster (caudal end) variably developed, short, round or extended with hooked setae or bristles in Tortricinae, usually reduced or absent in Oletreutinae (Bradley *et al.*, 1973; Common, 1991; Scoble, 1992; Komai, 1999; Razowski, 2002).

### 1.3. Pest status

The main cultivated host plants for the seven tortricid pests that are the focus of this study are listed in Table 3. Basic information on each tortricid pest species is summarized below.

**Table 3:** Main cultivated host plants for seven tortricid pests damaging fruit crops in South Africa (Summer, 1966; Annecke & Moran, 1982; Barnes, 1991; Victor *et al.*, 1991; Begemann *et al.*, 1998; Newton, 1998; Van den Berg, 2001; Timm *et al.*, 2007, 2008; Stotter 2009).

<i>Host Plants</i>	CM	FCM	MNB	OFM	LM	PLR**	ALR**
Acorn		✓					✓
Almond	✓			✓			
Apple	✓	?		✓		✓	✓
Apricot	✓	✓		✓		✓	✓
Avocado		✓					
Banana		✓					
Bean		✓					
Cherry				✓			
Coffee		✓					
Cotton		✓					
Flowers						✓	
Grape		✓				✓	
Grapefruit		✓					
Guava		✓					
Lemon		✓					
Litchi		✓	✓		✓		
Macadamia		✓	✓		✓		✓*
Maize		✓					
Mandarin		✓					
Mango		✓			✓		
Nectarine	✓			✓			
Olive		✓					
Orange		✓					✓
Peach	✓	✓		✓		✓	✓
Pear	✓	✓		✓		✓	
Pea							✓
Persimmon		✓		✓			
Pineapple		✓					
Plum	✓	✓		✓		✓	✓
Pomegranate	✓	✓					
Quince	✓			✓	✓		
Sweet Cherry	✓						
Tangelo		✓					
Tangerine		✓					
Tea		✓					
Walnut	✓	✓					

\* Unpublished data from van den Berg, 1999, in van den Berg, 2001

\*\* Leafroller feeding mainly on foliage and sometimes on fruit

**False codling moth, *Thaumatotibia leucotreta***

Fuller (1901) was the first to describe the false codling moth (FCM) as a pest of citrus, and he referred to it as the “Natal codling moth” (Gunn, 1921; Aschenborn, 1978; Catling & Aschenborn, 1978; Schwartz, 1981). FCM is indigenous to southern Africa (Stofberg, 1954; Annecke & Moran, 1982). Although initially absent from the Western Cape, it appeared in 1974 in the Clanwilliam district (Newton, 1998). FCM has an extensive host plant range that includes more than 50 cultivated and wild host plants (Gunn, 1921; Aschenborn, 1978; Catling & Aschenborn, 1978; Van der Geest *et al.*, 1991; Bloem *et al.*, 2003; Stotter, 2009). FCM attacks citrus, deciduous subtropical and tropical fruit, and is known as a pest of acorns, walnuts, olives, tea, almonds, and cotton (Table 3) (Gunn, 1921; Catling & Aschenborn, 1978; Bloem *et al.*, 2003; Stotter, 2009). In 1996, Bell & McGeoch (1996) ranked FCM as the ninth worst agricultural pest compared to Moran’s (1983) ranking of 14<sup>th</sup> most damaging pest. The USA regards an accidental introduction by FCM as the “worst of the worst” threats to the agricultural industry of the United States (ESA, 2003).

**Codling moth, *Cydia pomonella***

Codling moth (CM), an invasive fruit pest to South Africa, originated most likely from Eurasia and was first recorded in Graaff-Reinet around 1885 (Lounsbury, 1898; Newman, 1912; Annecke & Moran, 1982; Barnes, 1991). CM is an important pest to the pome fruit industry not only within South Africa but in temperate regions worldwide (Anonymous, 1906; Barnes, 1980; Phillips & Barnes, 1974; Nel, 1983; Addison, 2005). It has also been recorded as a pest on walnuts and occasionally on almonds, wild almonds, pecan nuts, pomegranates, apricots, peaches, and plums (Table 3) (Phillips & Barnes, 1974; Nel, 1983; Barnes, 1991; Blomefield, 1994). In 1983, CM rated fifth in the 101 most important plant-feeding pests in South Africa (Moran, 1983); in 1996 it was changed to third (Bell & McGeoch 1996). In the 1980’s its infestation potential in South Africa was one of the highest in the world (Myburgh, 1980).

**Oriental fruit moth, *Grapholita molesta***

The oriental fruit moth (OFM) is originally from the Orient, Siberia, China, Korea, and Japan, hence the vernacular name (Collins, 1933; Summer, 1966, Rothschild & Vickers, 1991; Alford, 2007). It was positively identified in 1990 in South Africa (Blomefield & Geertsema, 1990; Victor *et al.*, 1991). It has become an important pest on peaches, nectarines, apricots, apples, pears, plums, almonds, and persimmons and some ornamental flowering plants (Collins, 1933; Victor *et al.*, 1991; Alford, 2007). In the season 1990/1991 OFM caused over R1 million rand losses to the peach industry in the Western Cape with some farmers recording up to 70% fruit loss due to damage caused by OFM (Anonymous, 1991; Viljoen, 1992).

**Litchi Moth, *Cryptophlebia peltastica***

The litchi moth (LM) is native to the African continent and has been found in South Africa, Madagascar, Seychelles, and Mauritius (Bradley, 1963; McGeoch, 1993; Krüger, 1998; Timm *et al.*, 2006). Larvae of LM are often found in pods of indigenous trees such as karooboerboon (*Schotia cafra*) and flamboyant

(*Poinciana regia*) (Annecke & Moran, 1982) and also in galls of *Ravenlia macowania* (Uredinales), on *Acacia karoo* and *Uromycladium tepperianum* (Uredinales) on the Port Jackson willow (*Acacia saligna*). In the case of the last host, LM may be considered a biological control agent against this weed pest (McGeoch, 1993; Krüger, 1998; Timm *et al.*, 2006). LM is a pest on litchi and macadamia (Annecke & Moran, 1982; de Villiers, 2001b). In 1996, Bell & McGeoch (1996) ranked it 19th worst pest compared to Moran's ranking in 1983 where it had no pest-status ranking. In Friedenheim, South Africa, an infestation of 8.9% and in other areas up to 15% was recorded on litchi fruit (de Villiers & Stander, 1989; Newton & Crause, 1990).

#### **Macadamia nut borer, *Thaumatotibia batrachopa***

The macadamia nut borer (MNB) is an Afrotropical moth not yet recorded beyond the African continent (Timm *et al.*, 2006). MNB only has two known host plants in South Africa, macadamia and litchi, but it is the dominant pest on macadamia in South Africa (Timm *et al.*, 2006). The first official record of MNB as a macadamia pest in South Africa was in 1999. However in 1972, an individual of MNB was reared from citrus by E.C.G. Bedford from a larvae found in an unusual infestation in this crop (de Villiers, 2001a). However, since then no further occurrence of MNB on citrus has been reported (Newton, 1998). In Malawi, MNB is a major pest of macadamia and litchi, but it is also found on snot apple (*Azanza garckeana*), Mauritius thorn (*Caesalpinea decapetala*), and feijoa (*Feijoa sellwiana*) (de Villiers, 2001a). A 20% crop loss has been recorded in Malawi on macadamia (de Villiers, 2001a).

#### **Pear leafroller/ Carnation worm, *Epichoristodes acerbella***

The pear leafroller (PLR), also known as the carnation worm, is also native to South Africa but was accidentally introduced with cuttings to Denmark in the 1960s from where it subsequently spread to various European countries (Thygesen, 1965, quoted in Nuzzaci, 1973; Allen, 1980; Timm *et al.*, 2008). The damage that PLR causes to crops and flowers make it one of the most important pests in South Africa and it is a notorious carnation pest worldwide (Bolton, 1979; Timm *et al.*, 2008). It attacks stone fruit, pome fruit, and grapes, but also feeds on weeds such as false dandelion (*Hypochoeris radiacata*), wild radish (*Raphanus raphanistrum*), sheep sorrel (*Rumex angiocarpous*), and *Arctotheca* sp. (Myburgh & Basson, 1961; Bolton, 1979; Timm *et al.*, 2008). In 1924, 75% of carnation shoots were found to be infested at a local florist in the Eastern Cape (Gunn, 1926).

#### **Apple leafroller, *Lozotaenia capensana***

The apple leafroller (ALR) is an African insect that is polyphagous; it has been recorded from apples, pears, citrus, peaches, plums, apricots, avocados, granadilla, marula, sometimes garden roses, but also on weeds such as *Arctotheca* sp., false dandelion (*Hypochoeris radiacata*), wild radish (*Raphanus raphanistrum*), *Rumex acetocella*, and *Tacsonia nollissima* (Myburgh & Basson, 1961; Borrow, 1977; Annecke & Moran, 1982; Begemann *et al.*, 1998; van den Berg, 2001). It has also been reared on *Pinus radiata* (Geertsema, pers. comm), and unpublished data from van den Berg showed ALR infestation in macadamia (van den

Berg, 2001). In 1996, Bell & McGeoch (1996) determined the pest status for ALR, ranking it 11<sup>th</sup> compared to Moran's (1983) ranking where it was placed 22<sup>nd</sup>. In 1976, in the Zebediela area the total amount of citrus fruit lost due to ALR was 32.4% and of the Valencia's cultivar 43.4% (Begemann *et al.*, 1998).

#### 1.4. Aims and objectives

The aim of the present study was to establish an easy identification system for tortricid moth pests of fruit, including the construction of interactive taxonomic keys of all life stages with associated morphological information.

Objectives:

- i) To collate and analyse all available literature on seven major species of economic importance and to compile more comprehensive morphological descriptions;
- ii) to develop an interactive key based on LUCID software using morphological data (published and own study) of local and potential invasive tortricid moth species for use by fruit industry stakeholders; and
- iii) to determine the species status of *T. leucotreta*, using male genitalia and shape morphometrics.

The chapters of this thesis are structured as individual papers and therefore some repetition is unavoidable.

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## CHAPTER 2

### Morphological study and development of a taxonomic key for the larval stages of economic importance tortricids in South Africa

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#### 2.1. Abstract

*Cydia pomonella*, *Thaumatotibia leucotreta*, *Grapholita molesta*, *Cryptophlebia peltastica*, *Thaumatotibia batrachopa*, *Epichoristodes acerbella* and *Lozotaenia capensana* are the seven most economically important tortricids in South Africa, causing extensive damage and losses to the fruit industry. The correct identification of these species in the larval stage is important as misidentifications could lead to ineffective pest management. In South Africa no comprehensive, accurate or user-friendly key exists to distinguish between these species. Thus the aim was to compile, from an extensive literature study and own morphological analyses of the larvae, descriptions of the larval stages of each species and to develop an interactive LUCID key.

#### 2.2. Introduction

Worldwide, many tortricid species are of economic importance as the family includes some of the most significant agricultural pests (Powell, 1964; MacKay 1959; Holloway *et al.*, 1987; Razowski, 2002; Timm, 2005). In South Africa, seven tortricid species are of economic significance, primarily to the fruit industry (Timm, 2005): *Cydia pomonella* (Linnaeus, 1758) (Codling moth), *Thaumatotibia leucotreta* (Meyrick, 1913) (False codling moth), *Grapholita molesta* (Busck, 1916) (Oriental fruit moth), *Cryptophlebia peltastica* (Meyrick, 1921) (Litchi moth), *Thaumatotibia batrachopa* (Meyrick, 1908) (Macadamia nut borer), *Epichoristodes acerbella* (Walker, 1864) (Pear leafroller/Carnation worm), and *Lozotaenia capensana* (Walker, 1863) (Apple leafroller) (Brown, 2005). The larvae of all these species feed on a range of cultivated crops causing extensive damage and loss to fruit production (Powell, 1964; Timm, 2005). MacKay (1959) mentioned larvae of North America Olethreutinae are rather similar in appearance and are thus often confused or misidentified. Identification keys for tortricid species in South Africa are currently unsatisfactory because they are incomplete. McGeoch & Krüger (1994) developed a key for identifying moth larvae associated with *Ravenelia* galls on *Acacia karroo*, and that study included one economically important tortricid species, *C. peltastica*. Unfortunately, McGeoch & Krüger (1994) provided no morphological description for *C. peltastica*. Timm (2005) produced a dichotomous key to distinguish among the larvae of six economically important tortricid species in South Africa, but for some of these species a complete description for all the life stages is lacking. Although dichotomous keys continue to play a major role for the identification of species (Osborne, 1962), they often leave the user without a satisfactory identification. In a dichotomous key each couplet addresses a feature for which there are two possible answers of contrasting characters (Osborne, 1962; Amante & Norton, 2003; Walters & Winterton, 2007). The answer chosen directs the user to either another couplet or to an end point (Amante & Norton, 2003; Walters & Winterton, 2007). A major problem with dichotomous keys is the “unanswerable couplet.” An unanswerable couplet is that for which the user is unable to choose among the two options provided and

thus cannot continue with the key (Amante & Norton, 2003; Walters & Winterton, 2007). Matrix keys, such as LUCID key, are interactive and allow the user to select more than one character or skip characters and still get an end solution (Amante & Norton, 2003; Walters & Winterton, 2007). The main objective of this study was to develop descriptions of the larval stages of each species so that they can be compared and distinguished, and then to develop an interactive key, using the LUCID Key program, for use by workers in the fruit industry.

### **2.3. Material and methods**

Literature of various authors were studied, summarized (Table 4; Appendix 2.1), and compared for descriptions of the larval stages of *T. leucotreta*, *C. pomonella*, *T. batrachopa*, *G. molesta*, *C. peltastica* and *E. acerbella*. The descriptions were then compared with specimens of larvae in an effort to fill in gaps in the various descriptions based on own morphological studies (see Results). The morphological characteristics described in this chapter may be less than comprehensive for internal or inconspicuous features, the goal, being the development of a Lucid key for the specific use by personnel in the fruit industry.

#### **2.3.1. Insect material**

Final instar larvae of *T. leucotreta*, *C. pomonella*, *C. peltastica*, and *G. molesta* were obtained from established laboratory colonies: *T. leucotreta* from XSIT, Citrusdal, South Africa and Rhodes University, Grahamstown, South Africa; *C. pomonella* from Entomon, Stellenbosch, South Africa; *C. peltastica* from Bioriver Science, Addo, South Africa; *G. molesta* from Embrapa Grape and Wine, Bento Gonçalves, Brazil and the Applied Entomology Department in the Institute of Agricultural Research, Eidgenössische Technische Hochschule Zürich, Switzerland; and *T. batrachopa* from Upotn farm, Umhlali, South Africa. Additional larvae were collected locally from *Acacia saligna* and *A. pygnantha* galls. Unfortunately, no larvae of *L. capensana* were obtained. Voucher specimens were deposited in the Entomological Museum of the Stellenbosch University, South Africa.

#### **2.3.2. Preparation of specimens**

Larvae were killed in boiling water so as to extend the specimens, injected with Kahle's Fluid as a preservative, and stored as reference material. Kahle's fluid was selected for its better colour retention of specimens.

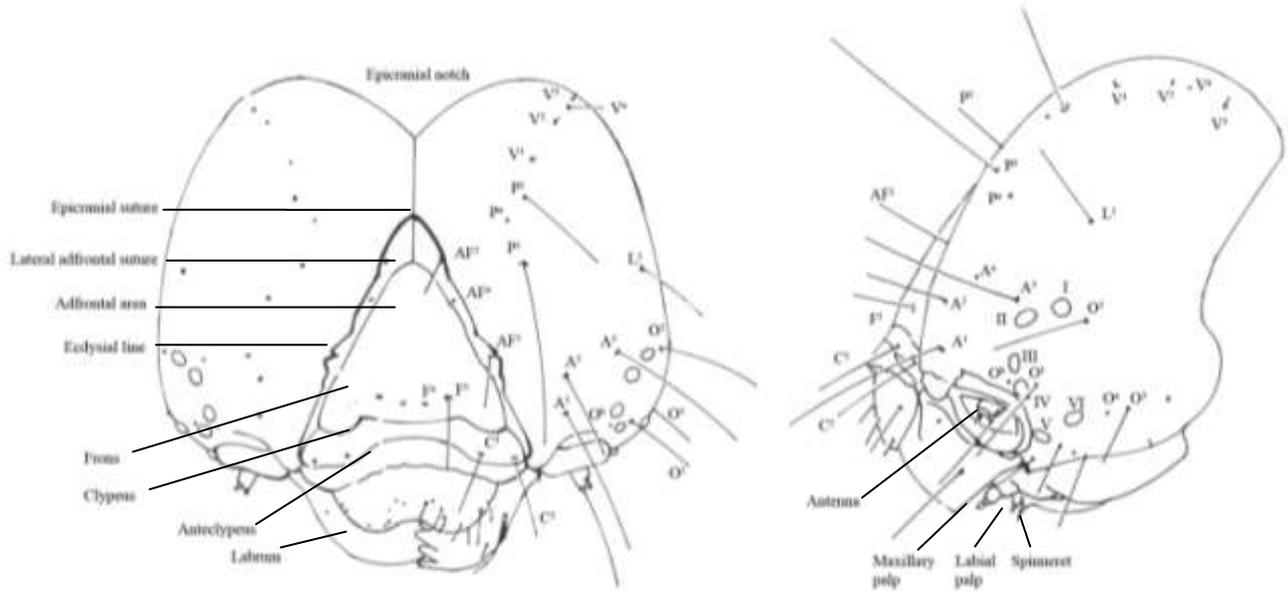
#### **2.3.3. Preparation of images**

Photos of larvae were taken with a Leica MZ 16A automontage microscope for two dimensional image analysis with a Leica DFC 290 fixed digital camera and Leica Application Suite (LAS) v.2.7. software. Photos were edited in Adobe Photoshop Element v.9.0.0 (Adobe System Incorporated).

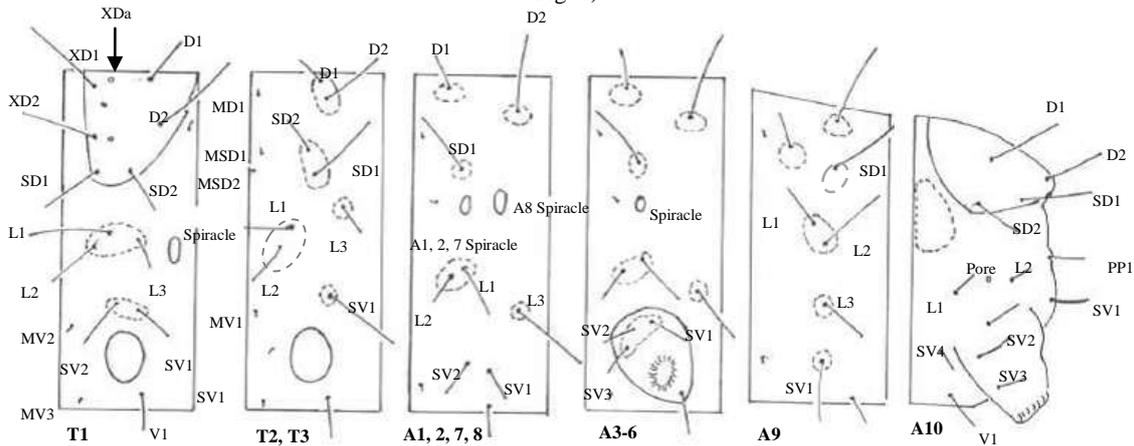
**2.3.4. Nomenclature**

Nomenclature for the setal arrangements of the head capsule follows Heinrich (1916 (in Stehr, 1987)) and Swatschek (1958) (Fig. 10), that of the thorax and abdomen follows Hinton (1946; in Stehr, 1987) (Fig. 11), and that of the anal shield follows MacKay (1959) (Fig. 12). Figure 2 is adapted from MacKay (1959) and Stehr (1987). The style and format of the descriptions follows Timm *et al.* (2007, 2008) for uniformity.

Diagnostic characteristics for this study are based on MacKay (1959). However, MacKay did not include the chaetotaxy of the mandibles, which was included by Timm *et al.* (2007, 2008) and in this study.



**Figure 10:** Head capsule, frontal and lateral view (Redrawn from Stehr, 1958; Figs 26.1, 26.2, adjusted with Swatschek, 1958; Fig. 1).



**Figure 11:** Lepidoptera setal maps (Redrawn from Stehr, 1958; Figs 26.20-26.25, and adapted from MacKay, 1959; Fig. 1).

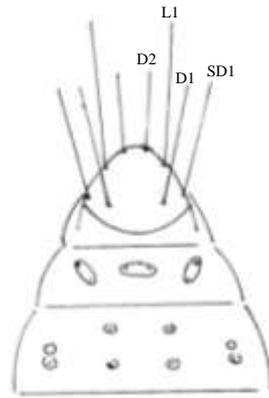


Figure 12: A8-A10 dorsal view (Redrawn from MacKay, 1959; Fig. 1).

### 2.3.5. Key development

A diagnostic key was developed using LUCID key 3.5.2 (Lucid, The University of Queensland), based on a key developed by Gilligan & Epstein (2012).

## 2.4. Results

### 2.4.1. *Thaumatotibia leucotreta* (Figure 13)

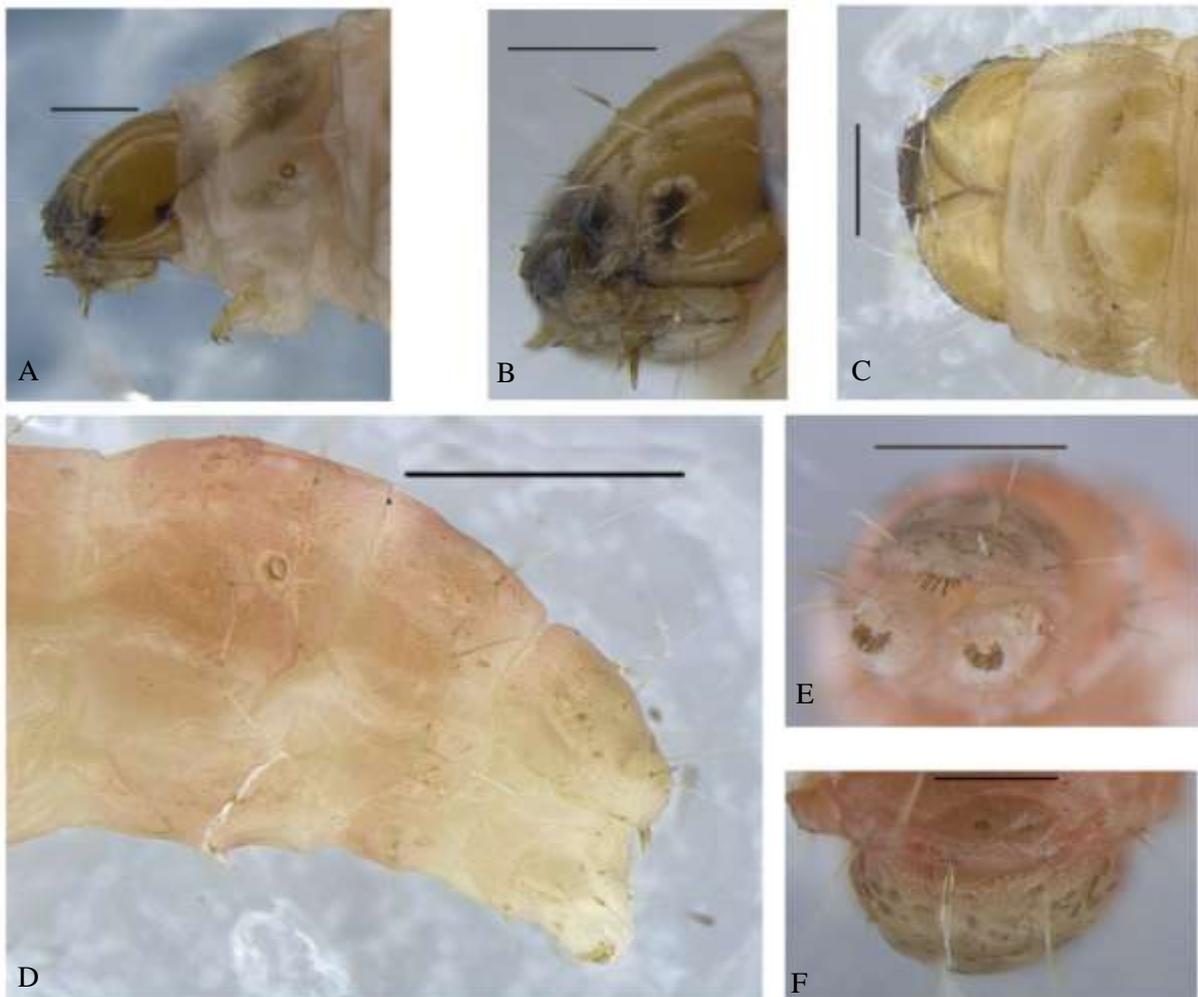
*General:* Setal bases medium to dark brown. Pinacula convex and distinct.

*Head: Chaetotaxy:* Stemma II closer to stemma I than III by approximately half the diameter of II. Distance between stemma II and III more than half the diameter of II. Stemma IV much closer to III than to V.  $O^2$  anteroventral to stemma I. Line joining  $O^1$  and  $A^2$  closer to stemma II than to III. Line joining  $O^1$  and  $A^1$  and  $O^1$  and  $A^3$  nearly at a right angle.

*Thorax: Prothorax:* Spiracle rounded, larger than those on A1-8. **Prothoracic shield:** Pale brown to brown, either unicolorous or with posterior shading. Peritreme of spiraculum large, medium to dark brown. L-group pinaculum darker than other pinacula. **Chaetotaxy:**  $XD^1$  and  $XD^2$  similar in length, in line with  $SD^1$ .  $D^1$  very short,  $D^2$  equal or slightly longer than  $SD^1$  and longer than  $XD^1$  and  $XD^2$ .  $SD^2$  approximately half length of  $SD^1$ , situated at an upwards angle posterior to  $SD^1$ .  $L^1$  longest,  $L^2$  shortest,  $L^3$  less than half as long as  $L^1$ , longer than  $L^2$ .  $SV^1$  long,  $SV^2$  half length of  $SV^1$ .  $V^1$ 's tiny; close together, slightly medial to coxa. Distance between coxa and  $V^1$  greater than between  $V^1$ 's. **Meso- and metathorax: Chaetotaxy:** D-group pinaculum in line with SD group.  $D^1$  short, less than half length of  $D^2$ .  $D^2$  as long as  $SD^1$ .  $SD^2$  equal in length to  $D^1$ .  $L^1$  long,  $L^2$  and  $L^3$  equal in length.  $L^3$  situated on a separate pinaculum, larger than  $L^1$  and  $L^2$  pinaculum.  $SV^1$  slightly longer than  $L^1$ .  $V^1$ 's further apart than on prothorax. **Thoracic legs:** Seven coxal setae, one minute, five medium, varying in length, and one long seta. One pair of setae situated distally on mesal part of femur. Six setae arranged around tibia; two pairs of setae, one pair longer, situated dorsally, and shorter pair ventrally on tarsus.

*Abdomen: Chaetotaxy:*  $SD^1$  on A1-7 situated dorsally to spiracle. On A8,  $SD^1$  anterior to spiracle. **A1-7:** On A3-6,  $D^1$  less than half length of  $D^2$ , in line with  $SD^1$ , spiracle, and L-group.  $D^2$  longer than  $SD^1$ .  $SD^1$

long,  $SD^2$  minute, found mostly on same pinaculum, but sometimes on separate pinaculum.  $L^1$  long,  $L^2$  short,  $L^3$  similar in length to  $L^1$ ;  $L^1$ - $L^2$  and  $L^3$  pinacula equal in size.  $V^1$ 's on A1-2 closer together than on A3-6, farther apart than on prothorax. Distance between  $V^1$ 's on A3-6 equal to distance between  $V^1$  on meso- and metathorax.  $V^1$ 's on A7 equal distance as on A1-2. A8:  $SD^1$  and  $SD^2$  situated anterior to spiracle,  $SD^1$  equal in length to  $D^1$  and  $SD^2$  minute.  $L^1$  longer than  $L^3$  but slightly shorter than  $SD^1$ .  $L^2$  shortest.  $SV^1$  long,  $SV^2$   $\frac{1}{3}$  of  $SV^1$ .  $V^1$ 's further apart than on prothorax. A9:  $D^2$ 's sharing a pinaculum forming a "saddle" across mid-dorsum of segment.  $D^2$  equal in length to  $SD^1$ .  $D^1$  on same pinaculum as  $SD^1$ , length half of  $SD^1$ .  $SD^2$  absent. L-group trisetose.  $L^1$  approximately equal in length to  $SD^1$ .  $L^2$  shortest,  $L^3$  slightly longer than  $L^2$ .  $SV^2$  absent,  $SV^1$  slightly shorter than  $L^1$ .  $V^1$ 's further apart than on A8.



**Figure 13:** *Thaumatotibia leucotreta* larvae, A) lateral view of head and T1; B) stemmata; C) dorsal view of head and prothoracic shield, D) lateral view of A8 – A10; E) anal fork; F) dorsal view of A9 and anal shield. Scale: D = 1mm, A-C, E-F = 0.5mm.

#### 2.4.2. *Cydia pomonella* (Figure 14)

*General:* Larvae slender with a rugose integument. Spiracle, rounded, light brown. Pinacula body colour to slightly dark greyish brown.

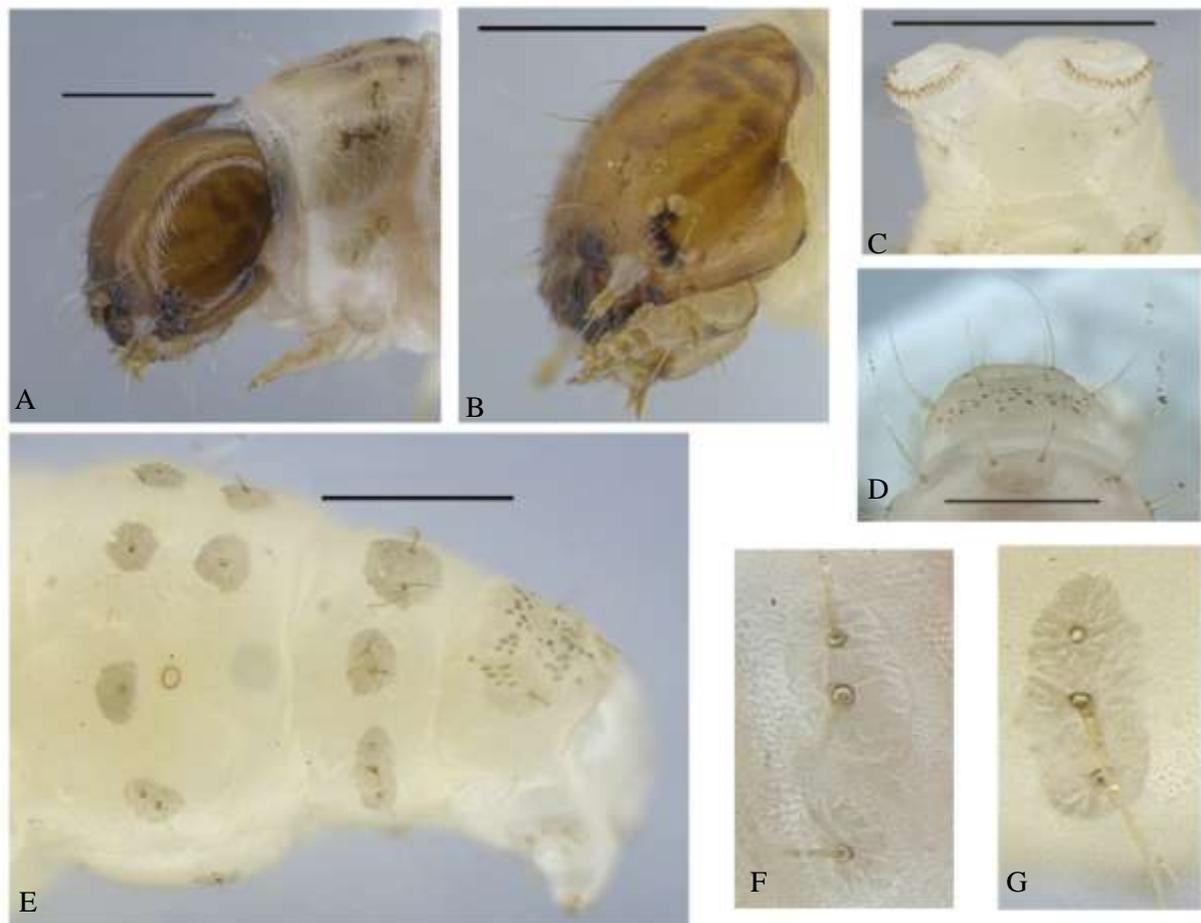
*Head:* Dark pigmented area at the postgenal juncture (posteriorly to the stemmatal area). **Chaetotaxy:** Stemma VI more oval compared to other stemmata (rounded). Stemma III closer to IV than to II. Stemma V slightly closer to IV than to VI. Stemma IV separated from stemma VI by distance nearly half diameter of IV. Stemma V separated from VI by distance slightly more than half diameter of V.  $A^3$  slightly closer to  $A^2$  than to  $L^1$ . Lines joining  $O^1$  and  $A^1$  equidistant to slightly closer to stemma III than to II. Lines joining  $O^1$  and  $L^1$  through median of stemma I. Lines joining  $O^1$  and  $A^2$  through median of stemma II. Antenna elongate, shorter, less robust than labial palps, with long terminal seta. Five mandibular teeth, outer three large and pointed, second largest, fourth smaller, fifth smallest and bluntly rounded. Mandibular teeth often appear blunt in more mature larvae.

*Thorax:* Pinacula body coloured to slightly dark greyish brown, setal bases with light brown colouration.

**Prothorax: Prothoracic shield:** Body colour to slightly darker greyish brown. **Chaetotaxy:**  $XD^1$  and  $XD^2$  equal in length.  $XD^a$  posterior to  $XD^1$  and distance between  $XD^a$  and  $XD^1$  equal to diameter of pinaculum of  $XD^1$ .  $XD^b$  posteriodorsal to  $XD^1$ , separated by four and a half times pinaculum diameter of  $XD^1$ .  $XD^1$  and  $XD^2$  equal in length.  $SD^1$  long,  $SD^2$  short,  $XD^2$  longer than  $SD^2$  but shorter than  $SD^1$ .  $D^1$  vertically posteriorly to  $D^2$  above the level of  $XD^1$ , setae equal or slightly longer than  $SD^1$ .  $D^2$  short, equal to  $SD^2$ .  $XD^1$ ,  $XD^2$  and  $SD^1$  in line. Spiracle pale brown to brown. L-group pinaculum not extending below spiracle and darker than other pinacula.  $L^1$  longer than  $SD^1$ .  $L^2$  short,  $L^3$  very short.  $SV^2$  more less than half as long as  $SV^1$ .  $V^1$ s situated between thoracic legs and closer together than on meso- and metathorax. **Meso- and metathorax:**  $D^1$  and  $D^2$  dorsal to SD-group, in vertical position,  $D^2$  longer than  $D^1$ .  $SD^1$  longer than  $SD^2$ , but shorter than  $D^2$ .  $SD^2$  and  $D^1$  equal in length.  $L^1$  and  $L^2$  on one pinaculum, anteroventral to SD-group and  $L^3$ .  $L^3$  situated posteroventral to SD-group and posteriodorsal to  $L^1$  and  $L^2$ .  $L^3$  pinaculum larger than  $L^1$  and  $L^2$ .  $L^2$  and  $L^3$  equal in length.  $SV^1$  long, posteriodorsal to thoracic legs and in line with  $L^3$  pinaculum.  $V^1$ s on meso- and metathorax equidistant, not fused to coxae. **Thoracic legs:** Seven setae, situated on coxa, one very tiny, five medium, varying in length, and one long. One pair setae situated distally on mesal part of femur. Six setae arranged around tibia; two pairs of setae. Claws curved.

*Abdomen:* **Chaetotaxy:**  $SD^1$  and  $SD^2$  with common pinaculum on abdominal segments, but  $SD^2$  on A1-8 reduced or absent. **A1-7:**  $D^1$  shorter than  $D^2$ .  $SD^1$  long, sharing pinaculum with  $SD^2$ , the latter tiny, anteroventral to  $SD^1$ .  $L^1$  shorter than  $L^2$ , sharing a pinaculum,  $L^2$  and  $SV^1$  equal in length.  $L^3$  slightly shorter than  $L^2$ , closer to  $SV^1$  and in line with  $D^2$ .  $SV^2$  and  $SV^3$  equal in length.  $SV^3$  on A7 occasionally absent.  $SV^2$  anterior ventrad to  $SV^1$ .  $SV^3$  anterior-dorsad to  $SV^1$ .  $SV^1$  twice as long as  $SV^2$  or  $SV^3$ . **A8:**  $D^1$  and  $D^2$  pinaculum in line.  $D^1$  shorter than  $D^2$ .  $SD^1$  slightly shorter than  $L^2$ .  $SD^2$  ventral to  $SD^1$ , very short,  $SD^1$  anterior to spiracle. Spiracle positioned on the anterior two-thirds of segment.  $L^1$  shorter than  $L^2$ ,  $L^3$  equal in length to  $L^2$ .  $L^3$  pinaculum equal in size to  $L^1$  and  $L^2$  pinacula.  $L^3$  in line and closer to SV group

than to  $L^1$  and  $L^2$ .  $SV^1$  shorter than  $SV^2$ .  $V^1$ 's same distance apart as on A7. A9:  $D^2$ 's situated on same pinaculum forming a "saddle".  $D^2$  and  $SD^1$  equal in length.  $D^1$  much shorter than  $SD^1$  and sharing the same pinaculum.  $SV^1$  shorter than  $SV^2$ .  $V^1$ 's distance same distance apart or farther than  $V^1$ 's on A8. **Crochets** pale brown to brown.



**Figure 14:** *Cydia pomonella* larvae, A) lateral view of head and T1; B) stemmata; C) Anal comb absent; D) dorsal view of A9 and anal shield; E) lateral view of A8 – A10; F) L-group on A9 trisetose, 2 setae on 1 pinaculum and 1 on a separate pinaculum; G) L-group on A9 trisetose, all 3 setae on 1 pinaculum. Scale: A, D-E = 1mm, B = 0.5mm.

### 2.4.3. *Grapholita molesta* (Figure 15)

*General:* Pinacula concolourous with body and setal base dark brown.

*Head:* Stemmata irregularly rounded. **Chaetotaxy:** Blackened sclerotized area around stemma III–VI. A<sup>3</sup> closer to A<sup>1</sup> than to A<sup>2</sup>. Stemma III very close to IV. Stemma IV closer to III than to V. Stemma V slightly posterior to IV and closer to IV than to VI, separated by VI by nearly the diameter of V. Distance between IV and VI half the diameter of IV. Lines joining O<sup>1</sup> and A<sup>1</sup> passing through anterior ventral edge of stemma II. Lines joining O<sup>1</sup> and A<sup>1</sup> passing through median or anterior edge of stemma II. Lines joining O<sup>1</sup> and L<sup>1</sup> through edge anterior of stemma I. Five mandibular teeth, outer three large and pointed, second largest, fourth smaller, fifth smallest and blunt. Spinneret rounded.

*Thorax:* Prothorax: Spiracle brown to dark brown, larger than on abdominal segments **Prothoracic Shield:** Orange brown, without markings. **Chaetotaxy:** SD<sup>2</sup> approximately  $\frac{1}{3}$  to  $\frac{1}{4}$  length of SD<sup>1</sup>. XD<sup>a</sup> posterior ventral to XD<sup>1</sup>, separated by one and a half to two times setal base of XD<sup>1</sup>. XD<sup>b</sup> posterior-dorsad at an angle to XD<sup>2</sup>, separated by four to five times setal base of XD<sup>2</sup>. XD<sup>1</sup> half length of SD<sup>1</sup>, XD<sup>2</sup> twice as long as SD<sup>2</sup>. XD<sup>1</sup> and XD<sup>2</sup> in line with SD<sup>1</sup>. D<sup>1</sup> short, almost as long as SD<sup>2</sup>, and posterior-ventrad to D<sup>2</sup> at the same level as XD<sup>1</sup>. D<sup>2</sup> almost as long as SD<sup>1</sup>. L-group pinaculum darker than other pinacula, not extending horizontally below spiracle. L<sup>1</sup> longest, almost as long as SD<sup>1</sup>, L<sup>3</sup> short,  $\frac{1}{4}$  length of L<sup>2</sup>. SV<sup>1</sup> two and a half times longer than SV<sup>2</sup>. V<sup>1</sup> tiny, ventral to thoracic legs, close together. Meso and metathorax: **Chaetotaxy:** D<sup>1</sup> short, half as long as D<sup>2</sup>. SD<sup>1</sup> equal in length to D<sup>1</sup>. SD<sup>1</sup> longer than D<sup>2</sup>. L<sup>1</sup> and L<sup>2</sup> on the same pinaculum, equal in size as L<sup>3</sup> pinaculum. L<sup>1</sup> three times as long as L<sup>2</sup> and L<sup>3</sup>. SV<sup>1</sup> long, but shorter than L<sup>1</sup>. V<sup>1</sup> tiny, situated farther apart than on prothorax. **Thoracic legs:** Concolourous with body at coxa, with a small V-shaped sclerotized area at anterior part of leg. Seven seta, situated on coxa, one very tiny, five medium, varying in length, and one long. One pair of setae situated distally on mesal part of femur. Six setae arranged around tibia; two pairs of setae, one pair longer situated dorsally on and the shorter pair ventrally on the tarsus. Claws curved.

*Abdomen:* **Chaetotaxy:** A1-7: D<sup>2</sup> posteroventral to D<sup>1</sup>, D<sup>2</sup> longer than D<sup>1</sup>. SD<sup>1</sup> and SD<sup>2</sup> on same pinaculum, but SD<sup>2</sup> puncture-like, often inconspicuous, sometimes separated from SD<sup>1</sup>. SD<sup>1</sup> long. L<sup>1</sup> and L<sup>2</sup> on single pinaculum positioned anteroventral vertical close to spiracle. L<sup>2</sup> longer seta, L<sup>1</sup> equal in length to L<sup>3</sup>. L<sup>3</sup> on a separate pinaculum, posteroventral to spiracle, closer to SV group than the to L<sup>1</sup> and L<sup>2</sup>. SV<sup>2</sup> and SV<sup>3</sup> equal in length, SV<sup>1</sup> twice as long. SV<sup>2</sup> anterior ventrad to SV<sup>1</sup>. SV<sup>3</sup> anterior-dorsad to SV<sup>1</sup>. V<sup>1</sup> seta tiny, found on the inside of the prolegs. V<sup>1</sup>s on A7 closer together than those on A1-6, equal to V<sup>1</sup>s distance on A8. A8: Same as A1-7 except for the following: D<sup>1</sup> and D<sup>2</sup> closer together and almost in horizontal to each other. Spiracle larger, situated on the posterior two-thirds of the segment. SD<sup>1</sup> anteroventral to the spiracle. SD<sup>1</sup> in line with L-group. SD<sup>2</sup> closer to spiracle than to SD<sup>1</sup>. SV<sup>2</sup> setal length  $\frac{1}{3}$  of SV<sup>1</sup>, situated on the same pinaculum, close to L<sup>3</sup>, no SV<sup>3</sup>. V<sup>1</sup>s closer together than those on A1-A6. A9: D<sup>2</sup> on a shared dorsal “saddle”. D<sup>2</sup> longer than D<sup>1</sup>. D<sup>1</sup> and D<sup>2</sup> on shared pinaculum. SD<sup>1</sup> and D<sup>2</sup> equal in

length. L-group trisetose, all setae on same pinaculum,  $L^1$  longest and in line with  $L^2$  and  $L^3$ ,  $L^2$  setae equal in length.  $SV^1$  three times as long as  $SV^2$ .  $V^1$ 's tiny, slightly further apart than on A8.



**Figure 15:** *Grapholita molesta* larvae A) lateral view of head and T1; B) stemmata; C) dorsal view of head and prothoracic shield; D) lateral view of A8 – A10; E) dorsal view of A9 and anal shield; F) anal fork; Scale: A,C, E = 1mm, B, D, F = 0.5mm.

#### 2.4.4. *Cryptophlebia peltastica* (Figure 16)

*General:* Body pale brown to pinkish white. Setae moderately long, with dark brown bases. Pinacula large, darker than body colour.

*Head:* Head variable, pale to dark brown. Darker pigmentation at postgenal juncture. **Chaetotaxy:** Stemmata rounded. Stemma II closer to I than to III by half a diameter, Stemma IV and VI separated by distance nearly equal to diameter of IV. Stemma V closer to IV than to VI by less than half a diameter of V.  $O^2$  posterior and in a horizontal line to stemma I. Line through  $O^1$  and  $L^1$  crossing edge of stemma II.  $A^2$  closer to  $A^1$  than to  $A^3$ .  $A^3$  closer to  $L^1$  than to  $A^2$ .

*Thorax:* Prothorax: Spiracle dark brown, larger than those on A1-A7. L-group pinaculum extending horizontally below spiracle, larger and darker than other pinacula. **Prothoracic Shield:** Darker lateral margins and or posterior shading. **Chaetotaxy:**  $SD^2$  half (or slightly less than half) as long as  $SD^1$ .  $XD^1$  shorter than  $XD^2$ ,  $SD^1$  longer than  $XD^2$ .  $XD^1$  and  $XD^2$  in line with  $SD^1$ .  $XD^a$  postero-dorsad to  $XD^1$ .  $D^1$  short, almost equal in length to  $SD^2$ ,  $D^2$  and  $SD^1$  equal in length.  $D^1$  and  $D^2$  slightly posterior dorsal to  $SD^2$ .  $L^1$  longest and  $L^3$  shortest.  $SV^2$  twice as long as  $SV^1$ .  $V^1$  tiny, ventral to thoracic legs. Meso and metathorax: **Chaetotaxy:**  $D^1$  short, dorsal to  $SD^1$ ,  $D^2$  longer than  $D^1$  and about the same length as  $SD^1$ .  $SD^2$  about the same length as  $D^1$ .  $L^1$  and  $L^2$  on same pinaculum, smaller than  $L^3$  pinaculum.  $L^1$  longer than  $L^2$  and  $L^3$ .  $SV^1$  long, dorsal to thoracic legs.  $V^1$  tiny, same as on prothorax. **Thoracic legs:** Coxa concolourous with body basally, gradually darkening to brown at femur, tibia and tarsus with a dark brown claw. Small V-shaped sclerotized area at the anterior part of coxa. Seven seta on the coxa: one pair setae situated distally on mesal part of femur. Six setae arranged around tibia; two pairs of setae, one pair longer situated dorsally on and the shorter pair ventrally on the tarsus.

*Abdomen:* **Chaetotaxy:** A1-7:  $D^2$  displaced posteroventral of  $D^1$ ,  $D^2$  longer than  $D^1$ .  $SD^1$  and  $SD^2$  on same pinaculum, but  $SD^2$  puncture-like, often inconspicuous, usually separated from  $SD^1$ .  $SD^1$  long.  $L^1$  and  $L^2$  on shared pinaculum, positioned anteroventral, vertical, close to spiracle.  $L^2$  longer,  $L^1$  and  $L^3$  equal in length.  $L^3$  on separate pinaculum, posteroventral to spiracle, closer to SV-group than to  $L^1$  and  $L^2$ .  $SV^2$  and  $SV^3$  equal in length,  $SV^1$  twice as long as  $SV^2$  and  $SV^3$ .  $SV^3$  anterior-dorsad to  $SV^1$ .  $V^1$  tiny, medial to prolegs.  $V^1$ s on A7 closer together than those on A1-6, equally distant to those on A8. A8: Same as A1-7 except for:  $D^1$  and  $D^2$  closer together, almost in horizontal line. Spiracle larger, situated on posterior two-thirds of segment.  $SD^1$  anteroventral to spiracle.  $SD^1$  in line with L-group.  $SD^2$  closer to spiracle than  $SD^1$ . L-setae as on A1-7.  $SV^1$  longer than  $SV^2$ , situated on same pinaculum close to  $L^3$ .  $SV^3$  absent.  $V^1$ s closer together than those on A1-A6 or A9. A9:  $D^2$  on a shared dorsal "saddle".  $D^2$  longer than  $D^1$ .  $D^1$  and  $SD^1$  on shared pinaculum.  $SD^1$  and  $D^2$  equal long. L-group trisetose, on same pinaculum.  $L^1$  longest, in line with  $L^2$  and  $L^3$ .  $L^2$  and  $L^3$  equal in length.  $SV^1$  longer than  $SV^2$ .  $V^1$ s slightly further apart than on A8.



**Figure 16:** *Cryptophlebia peltastica* larvae A) lateral view of head and T1; B) stemmata; C) dorsal view of head and prothoracic shield; D) lateral view of A8 – A10; E) dorsal view of A9 and anal shield; F) anal fork absent. Scale: A, C - F = 1mm, B = 0.5mm.

#### 2.4.5. *Thaumatotibia batrachopa* (Figure 17)

*General:* Pinacula large, greyish brown, easily observed with naked eye, with dark brown bases. Setae moderately long and easily observed.

*Head:* Dark pigmentation at stemmatal area and at postgenal juncture. **Chaetotaxy:** Distance between stemma II and III about half the diameter of II, stemma IV closer to III than to V and separated from VI by less than half a diameter of IV. Stemma V closer to IV than to VI. P<sup>1</sup> closer to Adf<sup>2</sup> than to F<sup>1</sup>. Line through O<sup>1</sup> and A<sup>1</sup> extending medially through stemma II. Line through O<sup>1</sup> and L<sup>1</sup> extending medially through stemma I.

*Thorax: Prothorax:* Spiracle dark brown, larger than those on abdominal segments. L-group pinaculum extending horizontally below spiracle, larger and darker than other pinacula. **Prothoracic Shield:** Darker lateral margins or shaded posteriorly. **Chaetotaxy:** SD<sup>2</sup> less than half as long as SD<sup>1</sup> and equal to XD<sup>1</sup>. XD<sup>1</sup> less than half as long as XD<sup>2</sup>, SD<sup>1</sup> longer than XD<sup>2</sup>. XD<sup>1</sup> and XD<sup>2</sup> in line with SD<sup>1</sup>. XD<sup>a</sup> posterodorsad to XD<sup>1</sup>. D<sup>1</sup> short, about equal in length to SD<sup>2</sup>, D<sup>2</sup> almost equal in length to SD<sup>1</sup>. D<sup>1</sup> and D<sup>2</sup> slightly posterior dorsal to SD<sup>2</sup>. L<sup>1</sup> longest, equivalent to SD<sup>1</sup> and D<sup>1</sup>, L<sup>3</sup> shortest, somewhat inconspicuous. SV<sup>1</sup> and L<sup>1</sup> equal in length SV<sup>2</sup> short, but longer than L<sup>2</sup>. V<sup>1</sup> tiny, ventral to thoracic legs; distance to coxae greater than between V<sup>1</sup>s. *Meso and metathorax:* **Chaetotaxy:** D<sup>1</sup> short, about as long as SD<sup>2</sup>, D<sup>2</sup> and SD<sup>1</sup> equal in length, more than twice as long as D<sup>1</sup>. L<sup>1</sup> and L<sup>2</sup> on same pinaculum, smaller than L<sup>3</sup> pinaculum. L<sup>1</sup> longer than L<sup>2</sup> and L<sup>3</sup>. SV<sup>1</sup> long, dorsal to thoracic legs. V<sup>1</sup>s tiny, further apart than on prothorax. Microsetae present: MD<sup>1</sup> and MD<sup>2</sup> tiny, on same pinaculum anterior to and in line with SD-group. MV<sup>2</sup> and MV<sup>3</sup> micro setae anterior to coxa and less prominent than MD<sup>1</sup> and MD<sup>2</sup>. V<sup>1</sup>s on T2 and T3 not fused with coxae. **Thoracic legs:** Coxa concolourous with body basally, gradually darkening to brown at femur, tibia and tarsus with a dark brown claw. Small V-shaped sclerotized area at anterior part of coxa. Seven seta located on coxa. One pair setae situated distally on mesal part of femur. Six setae arranged around tibia; two pairs of setae, one pair longer situated dorsally and shorter pair ventrally on tarsus.

*Abdomen:* SV-group pinacula concolourous with body. **Chaetotaxy:** A1-7: D<sup>2</sup> displaced posteroventral of D<sup>1</sup>, D<sup>2</sup> two times as long as D<sup>1</sup>. SD<sup>1</sup> and SD<sup>2</sup> on same pinaculum, but SD<sup>2</sup> puncture-like, with whitish base. SD<sup>1</sup> long, equal in length to D<sup>2</sup>. L<sup>1</sup> and L<sup>2</sup> on one pinaculum, anteroventral vertical, close to spiracle. L<sup>1</sup> twice as long as L<sup>2</sup>. L<sup>3</sup> on separate pinaculum, posteroventral to spiracle, closer to SV group than to L<sup>1</sup> and L<sup>2</sup>. SV<sup>1</sup>, SV<sup>2</sup> and SV<sup>3</sup> setae equal in length on A1-A6. On A7, SV<sup>1</sup> longest and SV<sup>3</sup> shortest. SV<sup>2</sup> anterior ventrad to SV<sup>1</sup>. SV<sup>3</sup> anterior-dorsad to SV<sup>1</sup>. V<sup>1</sup>s tiny, on A1-A2 and A7 distance of V<sup>1</sup> pinaculum apart. On A3-6, V<sup>1</sup>s medially to prolegs. A8: Same as A1-7 except D<sup>1</sup> and D<sup>2</sup> closer together, almost in horizontal line. Spiracle larger, situated on posterior <sup>2</sup>/<sub>3</sub> of segment. SD<sup>1</sup> anteroventral to spiracle. SD<sup>1</sup>, <sup>1</sup>/<sub>3</sub> the length of D<sup>2</sup>, in line with L-group. SD<sup>2</sup> puncture-like, with whitish base. L<sup>1</sup> equal in length to SD<sup>1</sup>, long. L<sup>2</sup> shortest. SV<sup>1</sup>, more than twice as long as SV<sup>2</sup>, situated on the same pinaculum close to L<sup>3</sup>, SV<sup>3</sup> absent. V<sup>1</sup>s closer together than those on A7. A9: D<sup>2</sup>s on a shared dorsal “saddle”. D<sup>2</sup> longer than D<sup>1</sup>. D<sup>1</sup> and SD<sup>1</sup> on shared pinaculum. SD<sup>1</sup> longer than D<sup>2</sup>. L-group trisetose, on same pinaculum, L<sup>1</sup> longest, equal to SD<sup>1</sup>, in

line with  $L^2$  and  $L^3$ .  $L^2$  and  $L^3$  setae equal in length.  $SV^1$  equal in length to  $L^1$ , in line with  $SD^1$  and L-group.  $V^1$ 's slightly farther apart than on A8.



**Figure 17:** *Thaumatotibia batrachopa* larvae A) lateral view of head and T1; B) stemmata; C) dorsal view of head and prothoracic shield; D) dorsal view of A9 and anal shield E) lateral view of A8 – A10; F) lateral view of final instar larvae indicating large greyish pinacula; G) anal fork. Scale: A–D, G = 1mm, E = 0.5mm, F = 2mm.

#### 2.4.6. *Epichoristodes acerbella* (Figure 18)

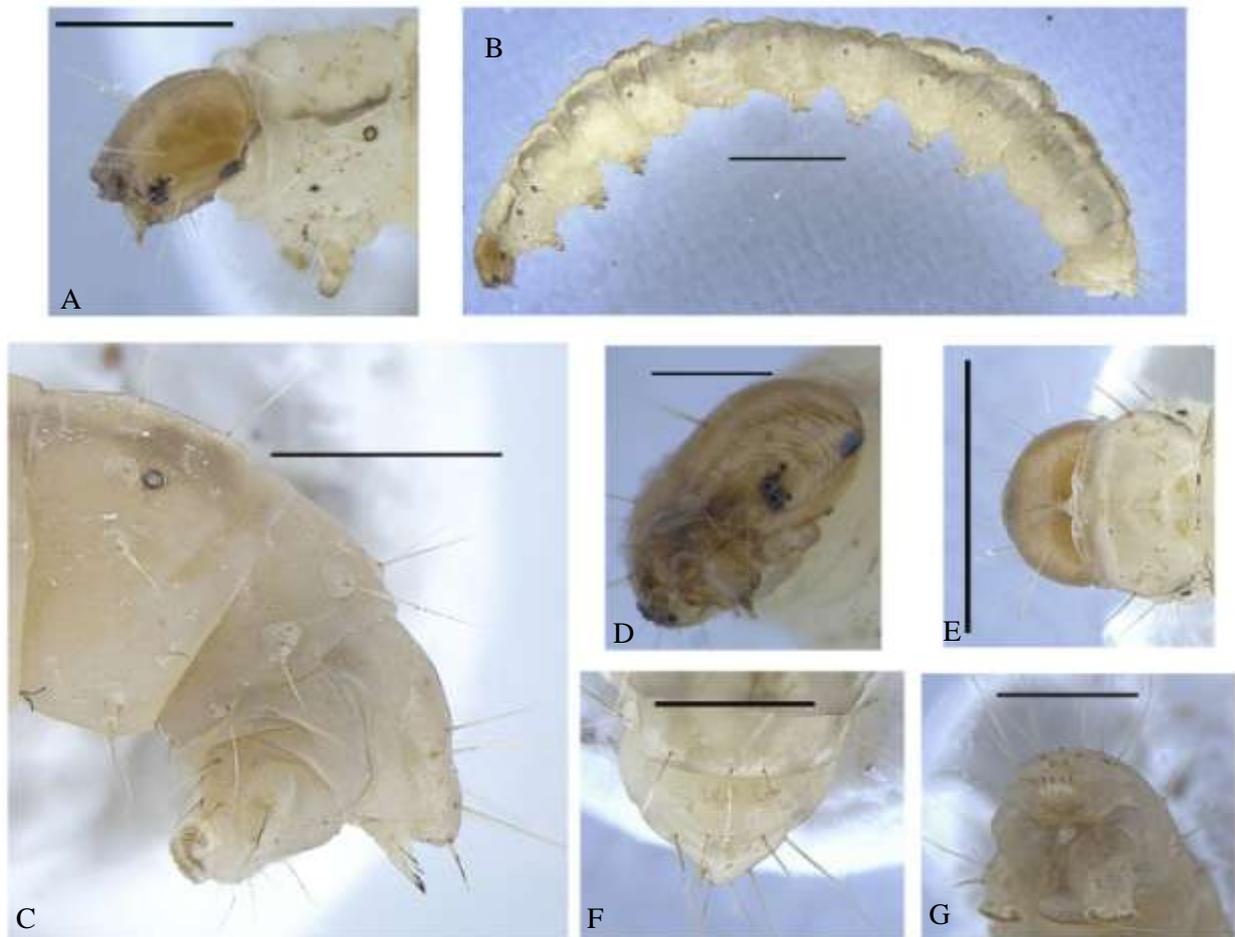
*General:* Body light green with pinacula concolourous with, or slightly lighter than, body colour. Setae moderately long.

*Head:* Hypognathous, darker pigmentation at postgenal juncture. **Chaetotaxy:** Stemmata II-IV surrounded by darker pigmentation. Stemma II separated from I by distance greater than its diameter. Stemma III closer to IV than to II. Stemma IV closer to V than to III, almost connecting. V closer to IV than to VI. Stemma V slightly closer to VI, separated by about the diameter of V. Stemma IV separated from VI by almost a diameter of IV. Stemma V separated from VI by more than a diameter.  $O^2$  posterior and in line to stemma I.  $A^2$  more or less equidistant to  $A^1$  and  $A^3$ .  $A^3$  equidistant to  $A^2$  and  $L^1$ . Line through  $O^1$  and  $A^1$  closer to II than to III. Line through  $O^1$  and  $L^1$  extending medially through stemma I. Spinneret bluntly rounded and approximately seven times longer than wide.

*Thorax:* **Prothorax:** Spiracle larger than those on A1-7, dark brown. L-group pinaculum concolourous with body with a darker dorsal pigmented line, slightly larger than other pinacula, not extending below the spiracle. **Meso- and metathorax:** **Chaetotaxy:**  $D^1$  and  $D^2$  on one pinaculum,  $D^1$  dorsal to  $D^2$ , and  $D^2$  longer than  $D^1$ . L-group ventral to spiracle,  $L^1$  and  $L^2$  on a shared pinaculum,  $L^3$  on a separate pinaculum situated posterior to  $L^1$  and  $L^2$ ,  $L^1$  longest.  $SV^1$  long, dorsal to the thoracic leg.  $V^1$ s on T2 and T3 not fused with coxae. **Thoracic legs:** Light green, concolourous with body.

*Abdomen:* **Chaetotaxy:** **A1-7:**  $D^1$  and  $D^2$  almost in horizontal line,  $D^2$  setae slightly longer than  $D^1$ s.  $SD^1$  separated from spiracle by approximately half the diameter of spiracle.  $SD^2$  highly reduced or absent.  $SD^1$  very long, dorsal to spiracle. L-group ventral to spiracle,  $L^1$  and  $L^2$  on a shared pinaculum,  $L^3$  on a separate pinaculum situated posteroventral to  $L^1$  and  $L^2$  and its setae longer than  $L^1$  and  $L^2$ . Three  $SV$  setae situated on the same pinaculum, anterodorsal to crochets,  $SV^1$  longest.  $SV^1$  ventral to  $SV^1$ .  $SV^3$  anterior-dorsad to  $SV^1$ .  $V^1$ s on A1-A6 farther apart than on those T2-T3.  $V^1$ s on A7 closer together. **A8:** Same as A1-7 except  $SD^1$  anteroventral to spiracle by half the diameter of the spiracle.  $SD^2$  sometimes inconspicuous.  $D^1$  and  $SD^1$  on separate pinaculum.  $L^1$  and  $L^2$  anteroventral to the spiracle.  $SV^3$  absent.  $V^1$  closer together than on A7. **A9:** Same as A1-7 except  $D^1$  shorter than that seta on A1-8.  $SD^2$  absent.  $D^1$  and  $SD^1$  on separate pinaculum.  $D^2$ s not sharing a pinaculum. L-group trisetose;  $L^2$  closer to  $L^3$  than to  $L^1$ ,  $L^1$  longest. Distance between  $V^1$ s equal to or less than distance of  $V^1$ s on A8. **Anal fork:** Darkening to tip.

Specimens studied differed from that illustrated by Timm *et al.* (2008; Fig. 17) in that the  $D^2$ s were not on a common pinaculum (“saddle”) on A9;  $D^1$  did not share a pinaculum with  $SD^1$ ; and the L-group was trisetose, with all setae sharing the same pinaculum. The features we observed agree with those reported by Nuzzaci (1973; Appendix 2.1, Fig. 16).



**Figure 18:** *Epichoristodes acerbella* larvae A) lateral view of head and T1; B) lateral view of final instar larvae indicating green lateral line; C) lateral view of A8 – A10; D) stemmata; E) dorsal view of head and prothoracic shield; F) dorsal view of A9 and anal shield G) anal fork. Scale: A, C, F-G = 1mm, D = 0.5mm, B, E= 2mm.

#### 2.4.7. *Lozotaenia capensana*

Despite the fact that this species is an important minor pest of apples, no specimens were obtained.

### 2.5. Summary of literature and morphological study

A complete summary of characters extracted from literature (see Appendix) (white boxes) and own morphological study (green boxes) is compiled in Table 4

**Table 4:** Important morphological characteristics to identify and distinguish between the six economically important tortricids larvae (White boxes as in literature. Dark grey and highlight boxes are morphological characteristics that were studied and added).

<b>General</b>	<i>T. leucotreta</i>	<i>C. pomonella</i>	<i>G. molesta</i>	<i>C. peltastica</i>	<i>T. batrachopa</i>	<i>E. acerbella</i>
<b>Size</b>	12-25 mm length	15-19mm length	10-15mm	20mm	13-23 mm length	17-21
<b>Shape</b>	Slender elongated	Slender elongated	Elongated	Elongated	Elongated	Elongated
<b>Colour</b>	Cream to light red, orange	Body colour to light brown	Whitish, light brown or more often reddish	Whitish brown to light pink to light red,	Cream to grey green	Light green with stripes: dark green on dorsal- yellow green on lateral midlines
<b>Integument structure</b>	Rugose					
<b>Setal pinacula</b>	Easily observed	Moderate in size	Moderately large	Easily observed, large..	Moderately large	Conspicuous
<b>Setal pinacula colour</b>	Darker than body colour	Body colour or darker greyish	Body coloured	Darker than body colour	Medium to dark greyish brown	Lighter than body colour
<b>Setal length</b>	Moderately long	Moderately long, spine-like appearance	Short, spine-like	Moderately long	Moderately long	Moderately long
<b>Spinulation of integument</b>	Easily apparent	Easily observed	Slender, darker than body colour	Slender, darker than body colour	Easily observed	Easily observed
<b>Head</b>	<i>T. leucotreta</i>	<i>C. pomonella</i>	<i>G. molesta</i>	<i>C. peltastica</i>	<i>T. batrachopa</i>	<i>E. acerbella</i>
<b>Head colour</b>	Yellowish brown to dark brown	Yellow brown	Yellow brown to black	Light to dark brown	Yellow brown	Yellow brown to olive green
<b>Head pigmentation</b>	Darker pigmentation at ocellar area and postgenal juncture	Dark brown pattern & blackish pigment on ocellar areas and at postgenal juncture.	Often overlaid with darker pattern; dark pigmentation on ocellar area & at postgenal juncture.	Darker pigmentation at ocellar area and postgenal juncture	Darker pigmentation at ocellar area	Darker pigmentation at postgenal juncture
<b>Head shape</b>	Hypognathous					
<b>Aver. width prior pupation</b>	1.31 mm	1.71 mm	0.92-1.11mm	1.7mm	1.5mm	1.04mm
<b>Head position</b>	Vertical angle acute	Vertical angle acute	Vertical angle more or less acute	Vertical angle acute	Vertical angle acute	Vertical angle acute
<b>Adfrontals</b>	Tapering anteriorly, extending to vertical angle	Extending to vertical angle	Extending to vertical angle	Extending to vertical angle, tapering anteriorly	Extending to vertical angle, tapering anterior- & posteriorly	Narrow, extending to vertical angle
<b>Ocellar shape</b>	Rounded	Rounded	Rounded	Rounded	Rounded	Rounded
<b>Stemmata size &amp; shape</b>	Equal in size, irregularly rounded	Large distinct, convex, irregularly rounded except for VI, more oval	Irregularly rounded, I larger than others	II-VI rounded equal size, I elongate, approx. 1.5x diameter of III.	Equal in size, irregularly rounded	Inconspicuous except for III, surrounded by dark pigmentation
<b>Stemma II position</b>	Closer to I than III	Closer to I than III or equidistant	Less than diameter away from stemmata I and III	Closer to I than III, by less than half a diameter of II.	Equidistant from I & III	Closer to III than I.
<b>Stemma III position</b>	Closer to IV than II	Closer to IV than II	Very close to IV	Closer to IV than II	Closer to IV than II	Closer to IV than II
<b>Stemma IV</b>	Closer to III than V	Closer to III than V	Equidistant from III and V, sometimes closer to III	IV closer to III than VI	IV closer to III than VI	Closer to V than III, almost connecting

<b>Stemma V position</b>	Close to IV than VI	Closer to IV than VI	Closer to IV than VI	Closer to IV than VI	Closer to IV than VI	Closer to IV than VI	
<b>Stemma V separated from stemma VI</b>	By nearly half diameter of V	By slightly more than half the diameter of V	By nearly diameter of V	By slightly 1.5x diameter of V	By equal diameter of V	By more than a diameter of V	
<b>Stemma IV separated from stemma VI</b>	By distance slightly less than diameter of IV	By ½ diameter of IV	By ½ diameter of IV	By distance slightly less than diameter of IV	By distance less than ½ diameter of IV	By distance slightly less than diameter of IV	
<b>O<sup>1</sup> distance from stemma II &amp; III</b>	Equidistant	Equidistant, or slightly closer to III	Closer to stemma III	Closer to stemma III	Equidistant	Equidistant	
<b>O<sup>2</sup> position</b>	Posterior ventrad to I	More ventral than caudal to O <sup>1</sup>	Ventral to I,	Posterior and in line with I	Posterior ventrad to I	Posterior and in line with I	
<b>A<sup>2</sup> position to A<sup>1</sup> and A<sup>2</sup></b>	Closer to A <sup>1</sup> than A <sup>3</sup>	Equidistant	Equidistant	Closer to A <sup>1</sup> than A <sup>3</sup>	Closer to A <sup>1</sup> than A <sup>3</sup>	Equidistant	
<b>A<sup>3</sup> position</b>	Closer to L <sup>1</sup> than A <sup>2</sup>	Closer to A <sup>2</sup> than L <sup>1</sup>	Equidistant to A <sup>2</sup> and L <sup>1</sup>	Closer to L <sup>1</sup> than A <sup>2</sup>	Closer to L <sup>1</sup> than A <sup>2</sup>	Equidistant to A <sup>2</sup> and L <sup>1</sup>	
<b>Lines joining O<sup>1</sup> &amp; A<sup>1</sup></b>	Closer to III than II	Equidistant or closer to III than II	Through anterior ventrad edge of II	Closer to III than II	Through median of III	Closer to II than III	
<b>Lines joining O<sup>1</sup> &amp; L<sup>1</sup></b>	Through median of I	Through median of I	Through median of I	Through median of I.	Through median of I	Through median of I	
<b>Lines joining O<sup>1</sup> &amp; A<sup>2</sup></b>	Closer to II than III	Through median of II	Through median or anterior edge of II	Closer to II than III.	Equidistant from II & III	Closer to II than I	
<b>P<sup>1</sup> position</b>	Closer to Adf <sup>2</sup> than F <sup>1</sup>	Closer to Adf <sup>2</sup> than F <sup>1</sup>	Closer to Adf <sup>2</sup> than F <sup>1</sup>	Closer to Adf <sup>2</sup> than F <sup>1</sup>	Closer to Adf <sup>2</sup> than F <sup>1</sup>	Closer to Adf <sup>2</sup> than F <sup>1</sup>	
<b>Mandibles</b>	Five teeth	Five teeth , darker in denticulate region	Five teeth	Five teeth	Five teeth	Five teeth	
<b>Mandibles 1 - 3 teeth</b>	Larger, acuminate, often 2 & 3 flattened	Large and pointed, often 2 & 3 flattened	Large and pointed, second largest	Larger, acuminate, often 2 and 3 flattened	Larger, acuminate, often 2 and 3 flattened	2 and 3 large and pointed	
<b>Mandibles teeth 4</b>	Smaller and flattened	Smaller, often flattened	Smaller	Smaller and flattened	Smaller and flattened	Smaller and flattened	
<b>Mandibles teeth 5</b>	Straight-edged	Bluntly rounded	Smallest and bluntly rounded	Straight-edged	Straight-edged	Straight-edged	
<b>Distal end of spinneret</b>	Rounded,	Tapered,	Rounded,	Rounded,	Rounded,	Rounded	
<b>Spinneret length</b>	8x longer than wide	6-6.5x longer than wide	7-8.5x longer than wide	7x longer than wide	7x longer than wide	7x longer than wide	
<b>Thorax</b>	<i>T. leucotreta</i>	<i>C. pomonella</i>	<i>G. molesta</i>	<i>C. peltastica</i>	<i>T. batrachopa</i>	<i>E. acerbella</i>	
<b>Prothoracic shield colour</b>	Yellowish brown to dark brown	Body coloured to slightly greyish brown	Yellowish brown	Yellow brown	Yellow brown	Yellow or body coloured	
<b>Prothoracic shield pattern</b>	Darker patches	Fully coloured or with posterior shading	Brownish pattern- speckled appearance	Sometimes with green or brown pigment present	Some medium brown pigmentation	Lightly sclerotized with small patches of darker pigmentation.	No pattern
<b>SD<sup>1</sup> position on prothoracic shield</b>	Equidistant to SD <sup>2</sup> than XD <sup>2</sup>	SD <sup>1</sup> closer to SD <sup>2</sup> than XD <sup>2</sup>	Equidistant to SD <sup>2</sup> than XD <sup>2</sup>	SD <sup>1</sup> slightly closer to SD <sup>2</sup> than XD <sup>2</sup>	SD <sup>1</sup> equidistant from XD <sup>2</sup> and SD <sup>2</sup>	Equidistant to SD <sup>2</sup> than XD <sup>2</sup>	
<b>D<sup>1</sup> position on prothoracic shield</b>	Slightly posterior to D <sup>2</sup> , slightly below level of XD <sup>1</sup>	Slightly posterior to D <sup>2</sup> , above level of XD <sup>1</sup>	Slightly posterior to D <sup>2</sup> , in line with XD <sup>1</sup>	Posterior to XD <sup>1</sup> and anterior to D <sup>2</sup>	Slightly posterior to D <sup>2</sup> , slightly below level of XD <sup>1</sup>	Slightly posterior to D <sup>2</sup> , above the level of XD <sup>1</sup>	
<b>Spiracle shape</b>	Circular, large	More oval than circular	Circular	Oval/Circular	Very prominent, circular	Circular,	
<b>Spiracle colour</b>	Medium to dark brown	Light to medium brown	Dark brown -black	Dark brown	Dark brown	Dark brown	

<b>L group pinaculum on T1</b>	Enlarged, extending below spiracle	Not extending below spiracle	Not extending below spiracle	Extending beyond spiracle	Extending beyond spiracle	Not extending below spiracle
<b>L<sup>1</sup> distance &amp; angle from L<sup>2</sup> &amp; L<sup>3</sup></b>	Equidistant, straight line	Equidistant, straight line	Equidistant or closer to L <sup>2</sup> , below a straight line joining L <sup>2</sup> and L <sup>3</sup> ,	Equidistant & in straight-line	Straight line	Equidistant, straight line
<b>L-group length</b>	L <sup>1</sup> longest, L <sup>2</sup> shortest, L <sup>3</sup> 1/3 to a 1/4 x shorter than L <sup>1</sup>	L <sup>2</sup> twice as long as L <sup>3</sup> , L <sup>1</sup> longer	L <sup>1</sup> longest,	L <sup>1</sup> longest, L <sup>3</sup> shortest	L <sup>1</sup> longest, L <sup>3</sup> shortest	L <sup>1</sup> longest, L <sup>3</sup> shortest
<b>D<sup>1</sup> position to D<sup>2</sup> on T2-3</b>	Dorsal					
<b>V<sup>1</sup>'s position on T2 &amp; T3</b>	Separated from coxae	Separated from coxae	Fused to coxae	Separated from coxae	Separated from coxae	Separated from coxae
<b>Thoracic claws</b>	Small, curved, medium brown	Short, light brown	Pale, curved, slender	Medium brown, curved	Medium brown, curved	Curved
<b>Abdomen</b>	<i>T. leucotreta</i>	<i>C. pomonella</i>	<i>G. molesta</i>	<i>C. peltastica</i>	<i>T. batrachopa</i>	<i>E. acerbella</i>
<b>Spiracle shape &amp; size</b>	Oval, small, seldom larger than setal bases	Small, elliptical, larger than setal base.	Moderate	Small, circular, seldom larger than setal base	Small, circular, seldom larger than setal base	Circular, smaller than setal base
<b>SD<sup>1</sup> distance from spiracle</b>	1.5x spiracle diameter	2-3x its diameter	1.5-3x SD <sup>1</sup> diameter except on A8	2.5x its diameter from spiracle	1.5x spiracle diameter	0.5x spiracle diameter
<b>Position of spiracle on A8</b>	Posterior third of segment	Anterior two-thirds	Posterior third of segment	Posterior third of segment	Posterior third of segment	Anterior two-thirds
<b>SD<sup>1</sup> and SD<sup>2</sup> position</b>	On same pinaculum	On same pinaculum	On same pinaculum, sometimes SD <sup>2</sup> separated	On A1 same pinaculum, On A2-A8 separate pinacula.	On same pinaculum	On same pinaculum
<b>SD<sup>2</sup> A1-A8</b>	Highly reduced, appearing absent	Highly reduced, appearing absent	Highly reduced, appearing absent	Highly reduced, appearing absent	Highly reduced, white setal base	Highly reduced, appearing absent
<b>SD<sup>1</sup> position to spiracle on A8</b>	Anteroventral, 3x spiracle diameter	Anterior or slightly anterior ventral, 1.5-2x its diameter	Approx. anterior, 1-1.5x its diameter	Anteroventrally, 1.5x spiracle diameter	Anteroventrally, 2x spiracle diameter	Anteroventrally, by half spiracle diameter.
<b>L group on A9</b>	Trisetose	Trisetose, or bisetose with L <sup>3</sup> separated on own pinacula	Trisetose	Trisetose	Trisetose	Trisetose
<b>SV group</b>	A7 Bisetose, A9 Unisetose	A1-A2 trisetose, A1-A2, A7-A8 bisetose, A9 unisetose	A9 Unisetose	A9 Bisetose	A8 Bisetose, A9 Unisetose	Bisetose on A8 and A9
<b>SV<sup>2</sup> position to SV<sup>1</sup> on A1-A2</b>	Ventrad and slightly cephalad	Anterior-ventrad	Anterior-ventrad	Ventrad and slightly cephalad from SV1	Anterior-ventrad	Ventral
<b>SV<sup>3</sup> position to SV<sup>1</sup> on A1-A2</b>	Antero-dorsad	Antero-dorsad	Antero-dorsad, or absent	Dorsal	Antero-dorsad	Antero-dorsad
<b>SV group on A1, 2, 7,8, and 9</b>	3:3:2:2:1	3:3:2:2:1 or 3:3:2,1:1:1 or 2:3:2:2:1 or other combinations	2:3,2:2:2:1; 3,2:3:2:2:1; 2:3,2:2:2:2;	3:3:3:2:2	3:3:2:2:1	3:3:3:2:2
<b>On A9 D<sup>1</sup> &amp; SD<sup>1</sup></b>	On same pinaculum					On separate pinaculum
<b>On A9, D<sup>2</sup>'s position</b>	Sharing single pinacula forming a "saddle"					Not sharing pinaculum
<b>On A9 L<sup>1</sup> distance to L<sup>2</sup> and L<sup>3</sup></b>	Equidistant	Equidistant or slightly further apart	Equidistant	Equidistant	Equidistant	Equidistant or slightly closer to L <sup>3</sup>
<b>V<sup>1</sup> on A9 compared to A8</b>	Slightly further apart	Equidistant	Equidistant or further apart	Slightly further apart	Slightly further apart	Equidistant or closer together
<b>Anal comb</b>	Present	Absent	Present	Absent	Present	Present
<b>Anal comb colour</b>	Darkly pigmented	Absent	Yellow to dark brown,	Absent	Darkly pigmented	Transparent

<b>Abdomen</b>	<i>T. leucotreta</i>	<i>C. pomonella</i>	<i>G. molesta</i>	<i>C. peltastica</i>	<i>T. batrachopa</i>	<i>E. acerbella</i>
<b>Prong shape</b>	Basal part of prong strongly tapered dorsally, width of base $\frac{1}{4}$ length of tooth, upper levels of larger prongs medially at same level	Absent	Equal in length and parallel, two mesal spines sometimes blunt	Absent	Basal part of prong strongly tapered dorsally, width of base nearly $\frac{1}{4}$ length of tooth, prongs merging into distinct medial structure	Width of base approx equal to or less than length of prongs. Basal part of each prong tapered dorsally
<b>Number of prongs</b>	2–10 bluntly dentate prongs	Absent	4-5 prongs	Absent	5-8 prongs	6-9 bluntly dentate prongs
<b>Anal shield colour</b>	Medium brown	Darker than body colour	Brown	Yellow brown	Yellow brown	Yellow or body coloured
<b>Anal shield pattern</b>	Sometimes small brown pigmentation	Speckled or patchy appearance (larger patches)	Sometimes small brown pigmentation	Sometimes small brown pigmentation	Sometimes small brown pigmentation	No pigmentation
<b>Anal shield shape</b>	Tapering posteriorly, posterior margin evenly rounded.	Posteriorly rounded	Posteriorly rounded	Posteriorly rounded	Posteriorly rounded	Rounded and strongly tapered posteriorly
<b>L<sup>1</sup>'s distance compared to D<sup>1</sup>'s</b>	Further apart	Further apart, sometimes equidistant	Further apart	Further apart	Equidistant	Closer together
<b>D<sup>2</sup>'s &amp; L<sup>1</sup>'s setal length</b>	D <sup>2</sup> 's half as long as L <sup>1</sup> 's	L <sup>1</sup> long or longer than anal segment, D <sup>2</sup> 's half of L <sup>1</sup> 's	D <sup>2</sup> 's half as long as L <sup>1</sup> 's	L1 slightly further lateral than D1s	D2 more than half as long as L1	D2s shorter than L1s
<b>D<sup>1</sup>'s distance</b>	Closer to SD <sup>1</sup> than each other.	Closer to SD <sup>1</sup> than each other	Equidistant from SD <sup>1</sup> and each other	Closer to SD <sup>1</sup> than each other almost in straight line.	Closer to SD <sup>1</sup> than each other.	Closer to SD <sup>1</sup> than each other.
<b>D<sup>1</sup>'s &amp; SD<sup>1</sup>'s setal length</b>	D <sup>1</sup> 's slightly shorter than SD <sup>1</sup>	D <sup>1</sup> 's shorter than SD <sup>1</sup>	D <sup>1</sup> 's slightly shorter than SD <sup>1</sup>	D <sup>1</sup> 's shorter than SD <sup>1</sup>	Equally long or D <sup>1</sup> slightly longer	Equally long
<b>Proleg crochets arrangement</b>	Irregularly triordinal	Unevenly uniordinal	Uniordinal	Biordinal	Triordinal	Unevenly uniordinal, almost biordinal
<b>Crochets number</b>	36-42	28-35	30-40	50-58	34-44	32-54
<b>Anal proleg crochets arrangement</b>	Irregularly triordinal, absent in medial half	Unevenly uniordinal, "in situ" more or less ovoid	Uniordinal, "in situ" sometimes oval or almost circular	Biordinal, absent in medial half.	Triordinal, absent in medial half	Unevenly uniordinal, almost biordinal
<b>Anal crochet numbers</b>	24-32	15-25	19-25	46-54	26-32	28-36

## 2.6. Discussion and conclusion

A few larval morphological characteristics are distinct and diagnostic for specific species, and are summarized below.

General: Setal pinacula are usually concolourous with or darker than the body, however, in *E. acerbella* the pinacula are lighter than the body colour. In *T. batrachopa* the pinacula are very distinct and visible with the naked eye, giving the larvae a spotted appearance. The prothoracic and anal shields of *C. pomonella* have characteristic patterns of spots, and those of *E. acerbella* lack markings. Crochets are triordinal in *T. leucotreta* and *T. batrachopa*, biordinal in *C. peltastica*, and uniordinal in *C. pomonella*, *G. molesta* and *E. acerbella* (in the latter, weakly biordinal).

Head: The head in the studied specimens are yellow brown to dark brown, except for that of *E. acerbella*, which is yellow to olive green. *C. pomonella* has a distinctive pattern on the head, giving it a more mottled appearance than in the other species. *T. batrachopa* has no darker pigmentation at the stemmatal region. *E. acerbella* has pigmentation around stemmata II-IV, and the other stemmata are inconspicuous. Stemmata are equal in size except in *G. molesta* and *C. peltastica*, where stemma I is larger. Stemma II is closer to I than to III, except for *C. pomonella* where the three are sometimes equidistant. In *T. batrachopa* they are equidistant, and in *E. acerbella* stemma II is closer to III than to I. Stemma VI is closer to III than to V except in *G. molesta* where it is also sometimes equidistant, and in *E. acerbella* where it is closer to V than III, almost immediately adjacent.  $O^1$  is equidistant to II and III, except in *C. pomonella*, where it is sometimes closer to III. In *G. molesta* and *C. peltastica*  $O^1$  is always closer to III than to II.  $A^2$  is closer to  $A^1$  and  $A^3$  in *T. leucotreta*, *C. peltastica*, and *T. batrachopa*.  $A^2$  is equidistant to  $A^1$  and  $A^3$  in *C. pomonella*, *G. molesta*, and *E. acerbella*. The spinneret is usually rounded distally except in *C. pomonella* where it is tapered. The spinneret at least 8× as long as wide in *T. leucotreta* and *G. molesta*, but less than 7× as long as wide in *C. pomonella*. It is usually about 7× as long as wide in *C. peltastica*, *T. batrachopa*, *E. acerbella*.

Thorax: The pre-spiracular group (L-group) pinaculum is unmodified in *C. pomonella*, *G. molesta* and *E. acerbella*, but in *Thaumatotibia* and *Cryptophlebia* it extends below the spiracle. Distinct micro setae are easily observed on T2-T3 only in *T. batrachopa*.  $V^1$ s are fused to T2-T3 coxae only in *G. molesta*.

Abdomen: The spiracle on A8 is situated on the posterior two-thirds of the segment except on *C. pomonella* and *E. acerbella* where it is situated on the anterior third.  $SD^2$  usually shares a pinacula with  $SD^1$ , but it is sometimes on a separate pinacula in *G. molesta*. In *T. batrachopa*  $SD^2$  shares a pinacula with  $SD^1$  only on A1, and they are on separate pinacula on A2-A8.  $D^1$  and  $SD^1$  share a common pinaculum on A9 except in *E. acerbella* where they are on separate pinacula. The  $D^2$  setae share a pinaculum, forming a dorsal "saddle" on A9 in all but *E. acerbella* where they are on separate pinacula. L-group on A9 is trisetose and on same pinaculum in all but *C. pomonella* where  $L^1$  and  $L^2$  share a pinaculum and  $L^3$  is on a separated pinaculum. Distance between  $V^1$ s A9 compared to A8 is usually farther apart, except in *G. molesta* where they sometimes are equidistant, always equidistant in *C. pomonella*, and closer together in *E. acerbella*. The anal comb is present in all but *C. pomonella* and *C. peltastica*.

From the above it is clear that distinct and unique suites of characters exist that can be applied in the development of a diagnostic key (Appendix 2.1).

## 2.7. References

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## 2.8. Appendix 2.1

Published descriptions of the larvae of the tortricids presently studied.

### 2.8.1 *Thaumatotibia leucotreta*

Williams (1953), Dugdale *et al.* (2005), Timm *et al.* (2005) and Gilligan *et al.* (2011) all provided descriptions of *T. leucotreta* larvae.

Stofberg (1948) described the larva of *T. leucotreta*, but not used in this study for reasons discussed by Timm (2005).

Williams (1953) described *T. leucotreta* as:

When mature, length about 15 mm, breadth about 2.5 mm. Colour: head rather light brown; body pale with reddish hue, tubercles without, or with faint, pigmentation. Head wider than long. Ocelli 3 and 4 very close together. Spiracles round. Body with spines as in figure 2. Anal comb present. Chaetotaxy: head with puncture  $V^a$  between and equidistant from  $V^2$  and  $V^3$ . Puncture  $P^b$  nearer  $P^2$  than  $P^1$ . Seta  $P^2$  nearer  $A^1$  than  $A^3$ . Puncture  $Af^a$  much nearer  $AF^2$  than  $AF^1$ . Body with puncture  $XD^a$  postero-ventrad from  $XD^1$ . Seta  $D^1$  on slightly posterior to  $D^2$  and slightly below the level of  $XD^1$ . Setae  $SD^1$  and  $SD^2$  with common tubercle on abdominal segments,  $SD^1$  on 8 antero-ventrad from spiracle. Setae  $L^1$  and  $L^3$  subequal on abdomen, on 8  $L^1$  postero-ventrad from  $L^2$  as on 1-7. Subventral group bisetose on 7, unisetose on 9. On 1 and 2  $SV^2$  ventrad and slightly cephalad from  $SV^1$ ,  $SV^3$  antero-dorsad  $SV^1$ . Tubercle of ventral seta not in contact with coxa on II & III.

Komai (1999) described *T. leucotreta* as:

Body length of mature larvae 15 mm. Head yellow brown. Body orange or pink in final instar. pinacula large, darker than body colour. Spiracle on A8 near the posterior margin. Prolegs with 31-40 crochets arranged in a biordinal circle. Anal fork present. Chaetotaxy:  $SD^1$  and  $SD^2$  on same pinaculum on A1-A7;  $D^1$  and  $SD^1$  on same pinaculum on A9; SV group on A1-A6 trisetose, on A7 and A8 bisetose, A9 unisetose; L group trisetose on A9.

Dugdale *et al.* (2005) established a key for tortricids encountered in the field in New Zealand and the following characteristics were described in the key:

Setal group SV on abdominal segments A7-9 not with 3,2 and 2 setae respectively, but usually 3,2,1 or 2,2,2, or 2,2,1; Head capsule in most species with axes of setal series P and MD forming an obtuse angle between  $100^\circ$  and  $140^\circ$ . Setal group SV on A7 with 2 setae. A9 setae  $D1$ ,  $D2$ ,  $SD1$  either arranged on 3 separate pinacula ( $D1+SD1$ ;  $D2+D2$ ;  $D1 + SD1$ ) or these can be narrowly joined; setal group SV on A1, A2 bisetose or trisetose; A7-9 setae  $V1$  usually equally far apart. T1 prespiracular setal group A1, A2 setal group SV, and A9 setal group L all trisetose. Head capsule seta  $P1$  close to adfrontal suture (separated by  $\pm 3 \times P1$  socket diameter); A9 setal group SV unisetose. A9 setae  $D1$  on a line anterior to setae  $D2$ ,  $Sd1$  in dorsal view. Anal shield longer than wide; anal comb with 5-6 teeth, narrower than the distance between the  $D2$ ; A9 setal pinacula  $D2 + D2$ ,  $SD1+ D1$  separate or narrowly joined.

Timm *et al.* (2007) described *T. leucotreta* as (Fig. 19):

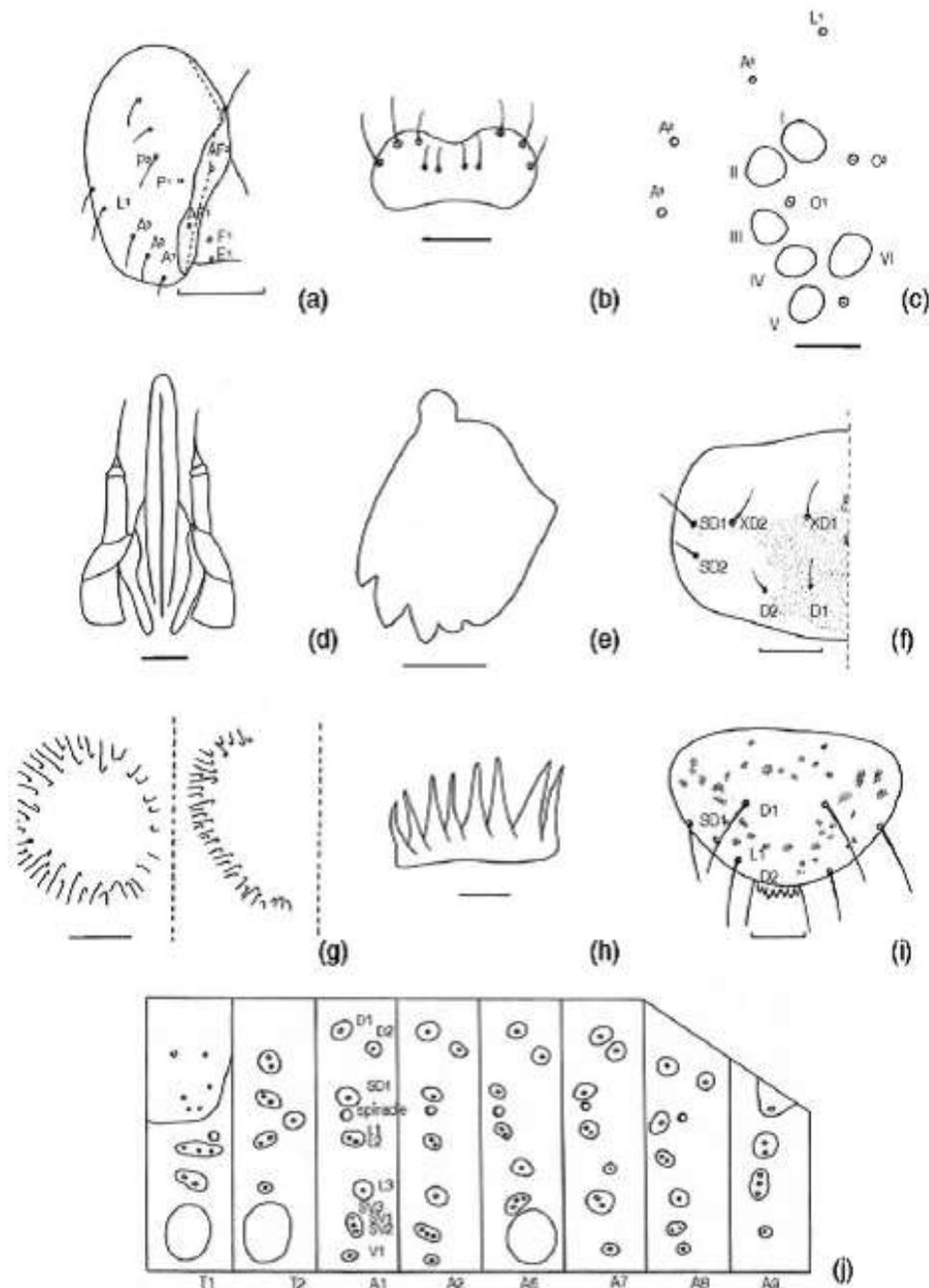
*General.* Larva slender, elongate, cream to light red. Integument rugose. Setal pinacula easily observed, darker than body colour; spinulation of integument easily apparent, setae moderately long. Head yellowish brown with dark pigmentation at ocellar area and postgenal juncture. Prothoracic and anal shields distinct, medium brown with darker patches due to moderate and extensive sclerotization. Thoracic legs medium brown.

*Head* (Figs 19a-e). Hypognathous, dorsal surface flattish and broad. Average width prior to pupation 1.31 mm ( $n = 29$ ). Vertical angle acute. Adfrontals tapering anteriorly and extending to vertical angle.  $P^1$  closer to  $Adf^2$  than  $F^1$ . Ocellar areas rounded. Stemmata approximately equal in size, irregularly rounded. Stemma II closer to stemma I than III. Stemmata III and IV situated close together. Stemma V closer to stemma IV than VI. Stemma V separated from VI by distance nearly equal to half diameter of stemma V.  $O^1$  equidistant from

stemma II and III.  $A^2$  closer to  $A^1$  than  $A^3$ .  $A^3$  closer to  $L^1$  than  $A^2$ . Line joining  $O^1$  and  $A^1$  closer to stemma III than stemma II. Line joining  $O^1$  and  $L^1$  through median of stemma I. Mandible with five teeth, the outer three large, usually acuminate although second or third often flattened, fourth smaller and flattened and fifth straight-edged. Antenna elongate, shorter, less robust than labial palps. with long terminal seta. Distal end of spinneret rounded, about eight times longer than wide.

*Thorax* (Figs 19f, j). Prothoracic shield with anterior lateral margin obtuse, slightly concave, curved at about one-third of its length and curved convexly towards the mid-line, lateral margin fairly straight and posterior margin evenly rounded towards mid-line. On prothorax, spiracle circular;  $L^1$  equidistant from  $L^2$  and  $L^3$ ,  $L^1$  more or less in a straight line with  $L^2$  and  $L^3$ ,  $SD^1$  equidistant from  $XD^2$  and  $SD^2$ . On meso- and metathorax  $D^1$  dorsal to  $D^2$ . Thoracic claws small, curved.

*Abdomen* (Figs 19g-j). Spiracles oval, small, seldom larger than setal bases.  $SD^1$  separated from spiracle by approximately 1.5 times diameter of spiracle. On segment 8 (A8) spiracle slightly anterior to midvertical line through segment;  $SD^1$  anteroventral to spiracle at about three times spiracle diameter. SV group on A1, 2, 7, 8 and 9 usually 3:3:2:2:1. On A9,  $D^1$  and  $SD^1$  on same pinaculum;  $L^1$  equidistant to  $L^2$  and  $L^3$ . Anal fork well developed, darkly pigmented, with 2–10 bluntly dentate prongs. Basal part of each prong strongly tapered dorsally, with width of the base nearly one-quarter length of tooth, upper levels of larger prongs medially at about same level. Anal shield tapering posteriorly, evenly rounded along posterior margin, lateral margin acute, angled anteriorly, anterior margin broadly curved.  $L^1$ s further apart than  $D^1$ s.  $D^2$ s half as long as  $L^1$ s.  $D^1$ s slightly closer to  $SD^1$ s than to each other,  $D^1$ s slightly shorter than  $SD^1$ s. Crochets of abdominal prolegs irregularly triordinal, 36–42 and 24–32 on anal prolegs. Anal prolegs with crochets absent in medial half.



**Figure 19 :** *Thaumatotibia leucotreta* final instar larva. a, Head (frontal aspect); b, labrum; c, stemmata; d, spinneret; e, mandible; f, prothoracic shield; g, crochets on ventral and anal prolegs; h, anal comb; i, anal shield; j, setal map. Scale bars: a, f, i = 1 mm, b–e, g, h = 0.1 mm. (Taken from Timm *et al.*, 2007; Fig. 2)

Gilligan *et al.* (2011) described *T. leucotreta* as follows:

First instar larvae are ca. 1mm in length and are pale with dark pinacula. Mature larvae are ca. 12-18mm long with yellowish brown to dark brown head and prothoracic shield. The abdomen is orange to pink with large pinacula that are darker than the body colour. *Thaumatotibia leucotreta* larvae can be distinguished from many tortricids in California by the following combinations of characters: L pinaculum on T1 enlarged, extending beneath and beyond (posterad of) spiracle; D<sup>1</sup> and SD<sup>1</sup> on A9 on same pinaculum, separate from D<sup>2</sup>; L group on A9 trisetose; anal comb present with 2-10 teeth. Other larval characters of *T. leucotreta* include: SD 2 on A1-8 highly reduced or appearing absent; SV groups on A1,2,7,8,9 with 3:3:2:2:1 setae; spiracle on A8 displaced posterad of SD pinaculum; V setae on A9 slightly farther apart than those on A8. Enlarged L-pinaculum on A9.

## 2.8.2 *Cydia pomonella*

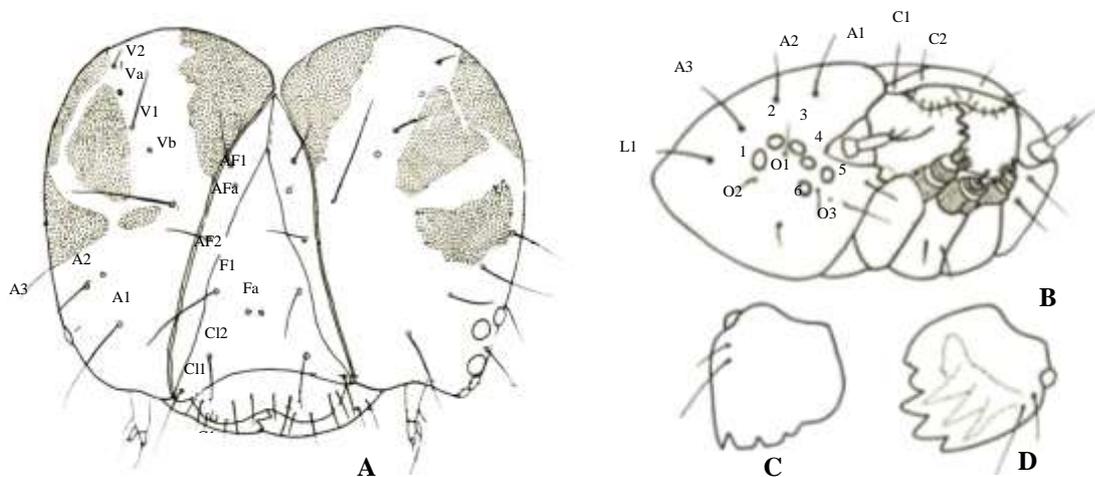
Swatschek (1958), MacKay (1959), Brown, (1987) and Dugdale *et al.* (2005) all provided descriptions of *C. pomonella* larvae.

Lopez (1929) did an extensive study on the head and mouth parts of *C. pomonella* larvae. However, for this study only the labrum and mandible sections were used.

**Mandibles.** The mandibles articulate ventrally with the cranial margin of the head by means of the hypocondyles, and dorsally with the cranial margin through the epicondyles. The mandibles are about 0.4mm long, about 0.4mm. wide and are five-toothed. They are much darker in the denticulate region. From the dorsal aspect concave. Two setae, one long and one short, arise from the dorsal surface of the mandibles.

Swatschek (1958) described *C. pomonella* in German, part of his elaborate description has been abridged and text freely translated: bracketed nomenclature is that of Hinton (1946) (Figs. 20 and 21).

Larvae whitish with reddish hue. Head and prothoracic shield light to dark brown. Prothoracic and anal shield with darker spots. Body either faintly or not at all granulated. Ocellus 2 closer to 1 than 3. On the prothoracic shield, IIIa (SD<sup>1</sup>) is closer to III (SD<sup>2</sup>) than IX (XD<sup>2</sup>). IV (L<sup>1</sup>) ventral from V (L<sup>2</sup>) and VI (L<sup>3</sup>) equidistant to both. V (L<sup>2</sup>) twice as long as VI (L<sup>3</sup>), IV (L<sup>1</sup>) even longer. On A1 and A2, group VII (SV) has 3 setae, on A7 and A8, 2 setae and on A9, one setae. On all abdominal segments, IIIa (SD<sup>2</sup>) is on the same pinaculum as III (SD<sup>1</sup>). IV (L<sup>2</sup>) and V (L<sup>1</sup>) positioned vertically on A1 and horizontally on the other abdominal segments. On A2, spiracles elliptical, and larger than the setal base of III (SD<sup>1</sup>). On A8, II (D<sup>2</sup>) and I (D<sup>1</sup>) equidistant. On A9, I (D<sup>1</sup>), II (D<sup>2</sup>) and III (SD<sup>1</sup>) situated on same pinaculum. VI (L<sup>3</sup>) is separate from IV (L<sup>2</sup>) and V (L<sup>1</sup>). A microsetae is positioned anteriorly to the pinacula of I (D<sup>1</sup>) and III (SD<sup>1</sup>). VIII (V<sup>1</sup>) on A9 equally apart as on A8. Abdominal prolegs crochets 28-35 and anal proleg crochets, 23.



**Figure 20:** A) Dorsal head chaetotaxy of *Cydia pomonella*, B) Lateral head chaetotaxy; C) Mandible right; D) Mandibles left (Collated and modified from Swatschek, 1958; Figs 1, 3, 5, 6)



**Figure 21:** A) Prothoracic shield; B) Anal shield of *Cydia pomonella* (Collated and modified from Swatschek, 1958; Figs, 89, 90).

MacKay (1959) described *C. pomonella* as follows (Fig. 22):

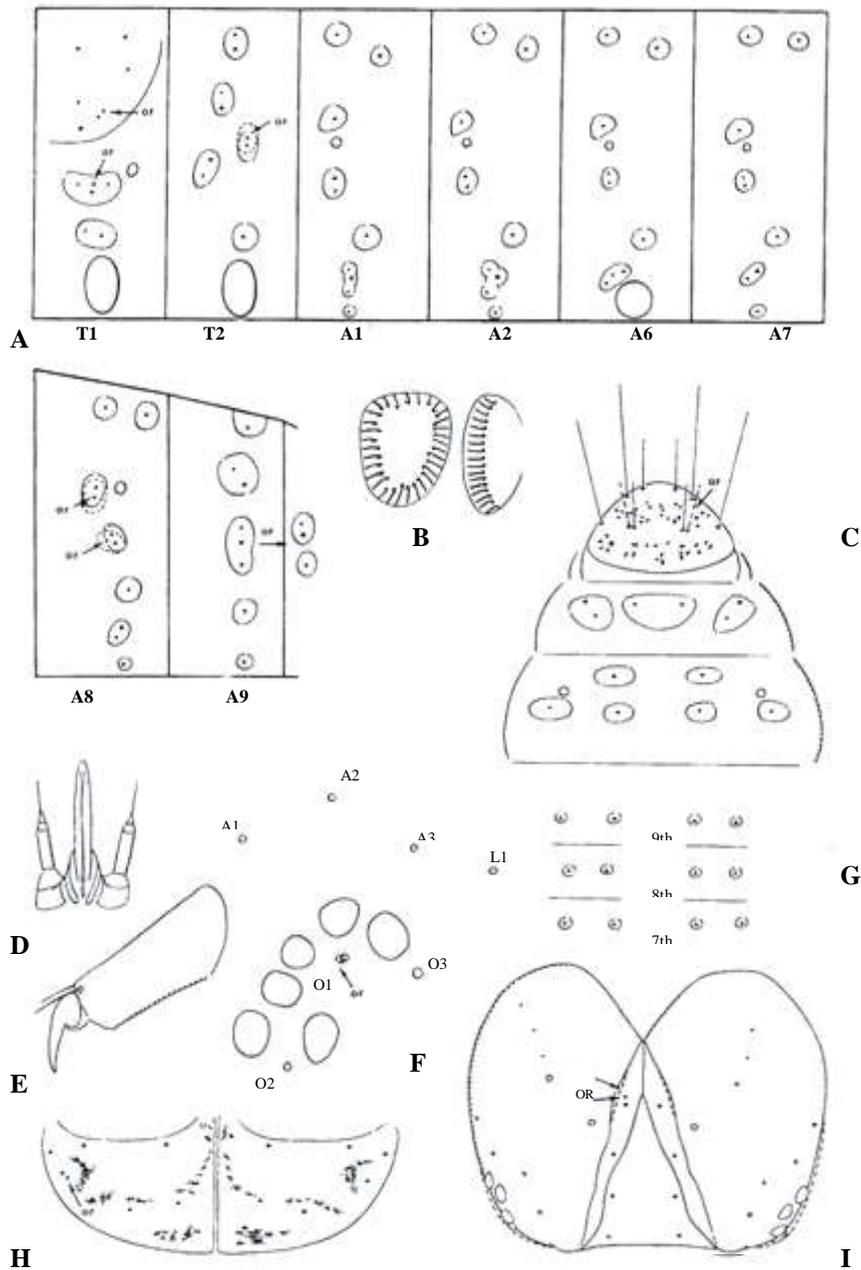
*General:* Mature length between 15-19 mm; larvae moderately stout with light brown body colour, setal pinacula moderate in size, of body colour or darker. Spinulation of integument easily observed the spinules slender with bases of the body colour. Setae moderately long, often spine-like in appearance. Head yellow brown, often overlaid with a darker brown pattern and blackish pigment on ocellar areas. Prothoracic and anal shields usually somewhat darker than body colour with a brownish pattern on the former and a speckled appearance on the latter. Thoracic legs light brown and short. Anal fork absent.

*Head:* "Hypognathous, head capsule as an average length of 1.42 mm and 1.71 mm wide. Vertical angle acute. Adfrontals extending to vertical angle. The distance between  $E^2$  and  $F^1$  about two thirds of that between  $E^2$ 's and  $F^1$ 's.  $P^1$  much closer to  $Adf^2$  than  $F^1$ . Ocellar areas rounded. Stemma II usually much less than its diameter from stemma I and III. Stemma IV usually slightly closer to stemma III than to V.  $O^1$  equidistant from stemma I and III or slightly closer to III.  $O^2$  more ventral than caudal to stemma I.  $A^2$  more or less equidistant from  $A^1$  and  $A^3$ . Spinneret about six to six and half times as long as wide and tapered to distal end.

*Thorax:* On prothorax, spiracle more oval than circular;  $L^1$  more or less equidistant from  $L^2$  and  $L^3$ , and distinctly below a straight line joining  $L^2$  and  $L^3$  but sometimes in line with both.  $SD^1$  usually closer to  $SD^2$  than to  $XD^2$  but occasionally equidistant from both. On mesothorax and metathorax  $D^1$  more or less dorsal to  $D^2$ . Coxae of metathoracic legs their own diameter or more apart. Claws moderately slender, dorsal setae shorter than claws.

*Abdomen:* Spiracle small.  $SD^1$  on A1-7 usually two or three times its diameter from spiracle. Spiracle on A8 tending to be on posterior half of segment and  $SD^1$  anterior or slightly anterior ventral to it and one and a half or two times its diameter from it.  $L^1$  and  $L^2$  more or less ventral to spiracle. On A9,  $D^1$  &  $SD^1$  on the same pinaculum;  $L^1$ ,  $L^2$  and  $L^3$  on same pinaculum, or apparently  $L^3$  more often distant from  $L^1$  and  $L^2$  and on own pinaculum. SV group on A1, 2,7,8,9 usually 3:3:2:2:1 or 3:3:2, 1:1:1 or 2:3:2:2:1 or other combinations;  $V^1$ 's setae on A9 the same distance or slightly farther apart than these on A8.

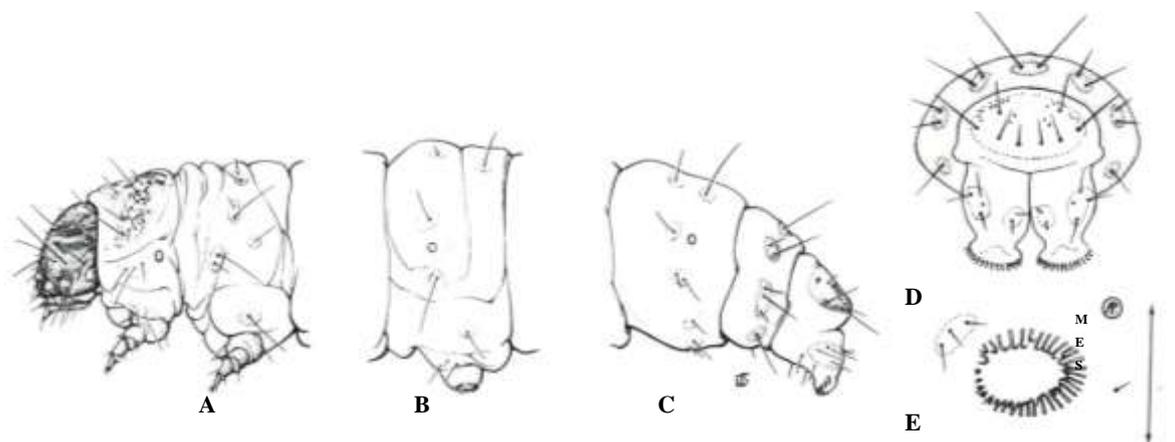
Anal fork absent. Anal shield rounded posteriorly;  $L^1$  usually farther apart than  $D^1$ 's but occasionally about same distance, and as long or longer than the anal segment.  $D^2$ 's less than half as long as  $L^1$ 's;  $D^1$ 's usually somewhat closer to corresponding  $SD^1$  than to each other, sometimes distinctly so, and shorter than  $SD^1$ 's. Crotchets unevenly uniordinal, 30-35 on ventral prolegs and 15-25 on anal prolegs. Crotchets "in situ" more or less ovoid.



**Figure 22:** *Cydia pomonella* larvae , A) Setal map; B) Ventral and anal prolegs; C) Dorsal view of A8-A10; D) Spinneret; E) Thoracic legs; F) Ocellar area; G) V<sup>1</sup>'s position on A7-A9; H) Prothoracic shield; I) Dorsal head. (Taken and modified from MacKay, 1959; Fig. 50).

Brown (1987) established a key for some common tortricid larvae on apple, peaches and generically related fruit and gave a short description and illustration (Fig. 23):

14-18 mm. Head yellow-brown, often overlaid with darker pattern, prothoracic and anal shields with dark speckling, spinules of integument distinct. Anal comb absent.



**Figure 23:** *Cydia pomonella*, A) Head, T1, T2; B) A3; C) A8-A10 D) A9-A10 caudal view E) A6 crochets (Taken from Brown, 1987; Fig 26.126).

Dugdale *et al.* (2005) established a key for tortricids encountered in the field in New Zealand and the following characteristics were described in the key:

Setal group SV on abdominal segments A7-9 not with 3,2 and 2 setae respectively, but usually 3,2,1 or 2,2,2, or 2,2,1. Head capsule in most species with axes of setal series P and MD forming an obtuse angle between 100° and 140° (However, *Cydia pomonella* has these setae series in line). Setal group SV on A7 with 2 setae. A9 setae D<sup>1</sup>, D<sup>2</sup>, SD<sup>1</sup> either arranged on 3 separate pinacula (D<sup>1</sup>+SD<sup>1</sup>; D<sup>2</sup>+D<sup>2</sup>; D1 + SD<sup>1</sup>) or these can be narrowly joined; setal group SV on A1, A2 bisetose or trisetose; A7-9 setae V1 usually equally far apart. T1 prespiracular setal group A1, A2 setal group SV, and A9 setal group L all trisetose. Head capsule seta P<sup>1</sup> close to adfrontal suture (separated by ± 3× P<sup>1</sup> socket diameter); A9 setal group SV unisetose. A9 setae D<sup>1</sup> on a line anterior to setae D<sup>2</sup>, SD<sup>1</sup> in dorsal view. Anal shield wider than long; anal comb absent, A9 setal pinacula D<sup>2</sup> + D<sup>2</sup> and D<sup>1</sup>+SD<sup>1</sup> separate. T2, T3 seta V<sup>1</sup> pinacula separate from coxal sclerite; prolegs with outer crochets more widely spaced than the rest of the series; Anal shield speckled in most instars; A1-6 setal pinaculum SD with an anteroventral lobe bearing seta SD<sup>2</sup> in early instars; head capsule setal series P and MD axes forming an angle closer to 180°.

### 2.8.3 *Grapholita molesta*

Garman (1917), Wood & Selkregg (1918), MacKay (1959) Brown, (1987) and Dugdale *et al.* (2005) all described *G. molesta* as follows:

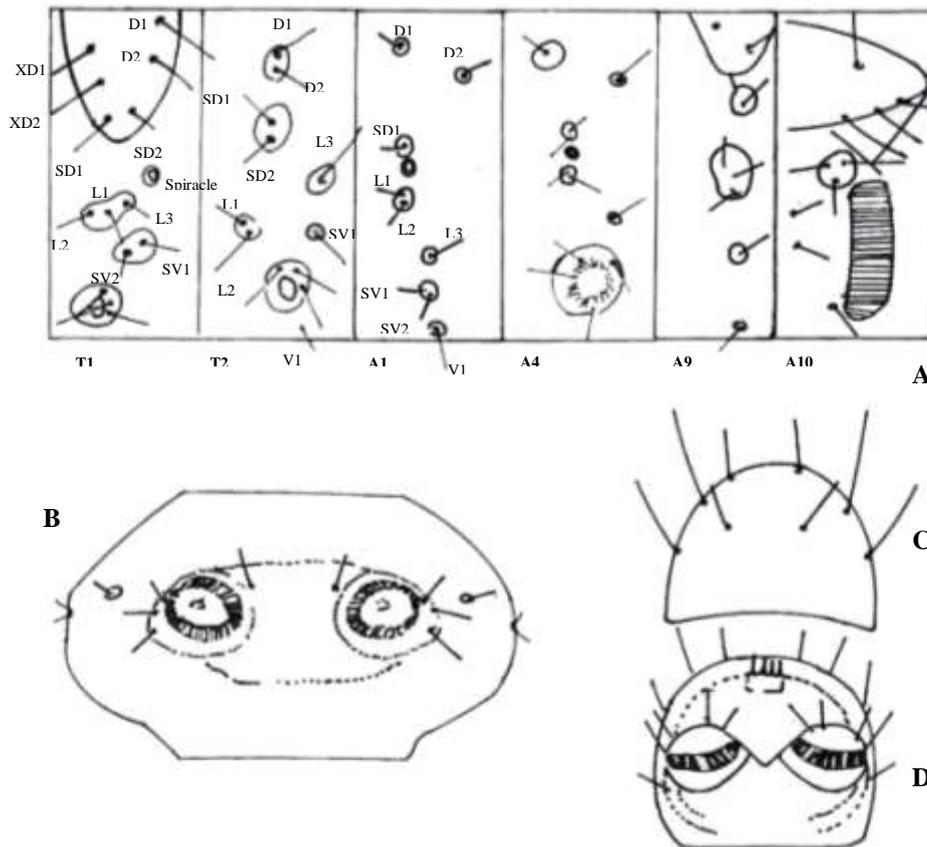
Garman (1917) (Fig. 24):

\*For uniformity, Hinton's (1946) setal nomenclature is also given.

*General:* Head capsule black and shining, sometimes provided with pale markings; body white to pinkish, the prothoracic and anal shields usually brown; length of full-grown larva 12-15mm. Length of labium one and one-half times its width, cardo as long as the stripes; mentum expanded at the caudal extremity and with two heavy setae near the middle; maxillary palpi three-segmented, the basal segment with a long seta on the inner surface; galea-lacinia with four distinct teeth, two of which are chitinized, the tips of the chitinized, projections with blunt tubercles; labial palpi slender, composed of two segments, a very short, globular, distal segment tipped with a long seta and a long proximal segment with a short seta at the apex; tip of the labium heavily chitinized; antennae four-segmented, the third segment with a long seta near the distal end, the distal segment about one-half the diameter of the preceding segment and provided with a blunt projection and a long seta; third segments with two short setae, one long setae and a blunt projection similar to that of the distal segment; the anterior setae being nearly equidistant and in almost a straight line; anterior puncture directly mesad of the second anterior seta; first posterior seta near the adfrontal suture and about midway between the vertical

triangle and the articulation of the mandible; arms of the epicranial suture concave in the dorsal third; ultraposterior tubercles four in number, at least three of which are provided with short setae.

*Thorax and abdomen:* Segment nine of the abdomen with alpha sometimes represented by a tubercle or short seta near the dorso-meson delta (II) (D2) located on the same pinaculum with rho (III) (SD1); kappa (IV) (L1) and mu (V) (L2) on the same pinaculum and about equidistant; kappa (L) (pre-spiracular) group of the prothorax with the middle seta longest and equidistant from the remaining two; kappa (L) group (V, VI) bisetose on segments one to eight; pi (VII) (SV) group unisetose on segment seven, eight and nine. Crochets uniordinal, densely placed, the lateral hooks sometimes short; number of crochets on prolegs 3 to 6 varying from about 25 to 35; hooks of irregular length infrequent, at least nothing present which approaches the biordinal type; crochets of the anal prolegs in full grown specimens 19 to 20, the cuticle immediately cephalad without thickest pad of spines; anal fork with four to five spines usually of equal length and parallel, the two mesal spines sometimes blunt.



**Figure 24:** *Grapholitoa molesta* **A)** Setal maps of the larva; **B)** Ventral view of fourth abdominal segment; **C)** Dorsal view of anal shield; **D)** Ventral view tenth abdominal segment of the larvae (Redrawn from Garmen, 1917; Fig. 3, 4, 5).

Wood & Selkregg (1918) (Fig. 25):

\* For uniformity, Hinton's (1946) setal nomenclature is also provided.

The larva is cylindrical; without secondary hair; colour varying from white deep pink, usually more strongly suffused with pink on dorsal side. Legs and prolegs normal. Crochets (31 o 46) uniordinal, in a complete circle. Anal fork developed, yellow to black in colour, three to six pointed, prominent. Setal areas broadly chitinized, grayish brown. Thoracic shield light yellow edged with yellowish brown, narrowly divided, moderately broad. Spiracles dark brown or black, small circular, slightly produced; spiracle on prothorax and that on abdominal segments 1 to 7. Entire body, except chitinized areas, evenly and finely scobinate; what appears to be a coarse pubescence under low magnification proves, under high magnification, to be a mass of short aculei.

Body setae yellow shading to deep brown, moderately long. Prothorax with Ia (XD<sup>1</sup>) and Ib (XD<sup>2</sup>) on, and Ic (SD<sup>1</sup>) behind the anterior margin of the shield; IIa (D<sup>1</sup>) and puncture y (XD<sup>b</sup>) caudad of Ia (XD<sup>1</sup>), IIb (D<sup>2</sup>)

directly laterad of IIa ( $D^1$ ); puncture x ( $XD^c$ ) dorsad of and approximate to Ib ( $XD^2$ ), lower than the level of IIb ( $D^2$ ); Ib ( $XD^2$ ), Ic ( $SD^1$ ) and IIc ( $SD^2$ ) equidistant; prespiracular shield oval, situated ventro-cephalad of the spiracle; IV ( $L^1$ ) and V ( $L^2$ ) on the same chitinization, under the spiracle approximate. Abdominal segment 8 with II ( $D^2$ ) only slightly below the level of I ( $D^1$ ); III ( $SD^1$ ) and IIIa ( $SD^2$ ) cephalad of the spiracle. Abdominal segment 9 with all setae in a line I ( $D^1$ ) and III ( $SD^1$ ) closely approximate; V ( $L^1$ ), IV ( $L^2$ ), and VI ( $L^3$ ) on the same chitinization, approximate; VII (SV group) unisetose.

Head light brown, with darker brown mottling; hind margin, ocellar area, and tips of trophy black.

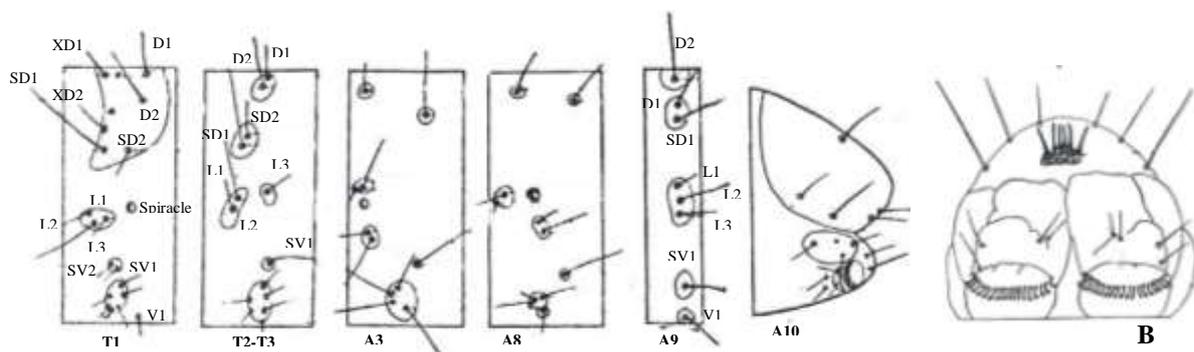
Head capsule nearly spherical, slightly flattened, broadly oval in outline viewed from above, a little wider than long; greatest width well behind the middle; incision of dorsal hind margin about one-fourth the width of the head; distance between dorsal extremities of hind margin less than one-half the width of the head. Frons (Fr) only slightly longer than wide, reaching to middle of head; adfrontal ridges (AdfR) sinuate; longitudinal ridge half the length of the frons; adfrontal suture (AdfS) reaching to dorsal incision of hind margin. Projection of dorsal margin over ventral slightly less than one-third the diameter of the head.

Ocelli six, in normal tortricid arrangement; III, IV and V in a straight line; I larger than the others.

Epistoma with the normal setae ( $E_1$ ,  $E_2$ ).

Frontal punctures ( $F^a$ ) lying rather closely together, anterior to the setae ( $F_1$ ); distance between punctures less than from puncture ( $F^a$ ) to seta ( $F_1$ ); adfrontal seta ( $Adf_1$ ) nearer to  $F_1$  than to Adf; adfrontal puncture ( $Adf^a$ ) approximate to  $Adf_2$ .

Epicranium with the normal number of primary setae and six punctures, and with three small ultra posterior puncture. Anterior and lateral setae ( $A_1$ ,  $A_2$ ,  $A_3$ , and  $L_1$ ) in line, with distance between  $A_1$  and  $A_2$ ,  $A_2$  and  $A_3$  and  $L_1$  about equal; puncture ( $A^a$ ) postero-dorsad of  $A_2$ ;  $A_1$ ,  $A_2$  and  $A_3$  on a level respectively with  $F^a$ ,  $F_1$  and  $Adf_1$ . Posterior setae ( $P_1$  and  $P_2$ ) and punctures ( $P^a$  and  $P^b$ ) at middle of head;  $P_1$  on a level with adfrontal puncture ( $Adf^a$ )  $P_2$  and puncture ( $P^b$ ) on a level with beginning of longitudinal ridge (LR);  $P_2$ ,  $P_1$ , and adfrontal seta ( $Adf_1$ ) in a line; puncture ( $P^a$ ) approximate to and equidistant from  $A_3$  and  $L_1$ . Lateral seta ( $L_1$ ) on a line with  $P_1$  and adfrontal puncture ( $Adf^a$ ); lateral puncture ( $L^a$ ) directly posterior to the seta. Ocellar setae ( $O_1$ ,  $O_2$ ,  $O_3$ ) well separated.  $O_1$  closely approximate to and equidistant from ocelli II and III, within the area bounded by the ocelli;  $O_2$  closely approximate to and postero-ventrad of ocellus I;  $O_3$  postero-ventrad of and remote from  $O_2$ , slightly below the level of ocellus I;  $O_3$  postero-ventrad of and remote from  $O_2$ , slightly below the level of ocellus VI; puncture  $O^a$  absent. Subocellar setae ( $So_1$ ,  $So_2$ ,  $So_3$ ) triangularly placed.  $So_2$  and  $So_3$  closer together than  $So_2$  and  $So_1$ ; puncture ( $So^a$ ) lying midway between  $So_2$  and  $So_3$ . Genal seta ( $G_1$ ) and puncture ( $G^a$ ) both present; puncture anterior to the seta. Length of full-grown larva 11 to 13mm."



**Figure 25:** *Grapholita molesta* A) Setal map, B) Ventral view of anal prolegs and caudal end of abdomen. (Taken and modified from Wood & Selkregg, 1918; Fig. 8)

MacKay (1959) (Fig. 26):

*General:* Length 10 or 12 mm. Length and width, respectively, of head on six specimens averaging 0.92mm and 1.11mm. Position of  $P^1$  in relation to anterior and posterior margins of head ranging from 33:42 to 31:46. Head yellow-brown, often overlaid with a darker pattern; dark pigmentation on ocellar area and at postgenal juncture. Thoracic shield yellowish, occasionally with some green or brown pigment present. Thoracic legs

pale. Anal shield usually with some brown pigmentation. Setal pinacula moderately large, easily observed usually pale except possibly on eight and nine segments; setae short, sometimes spinelike in appearance. Spinulation of integument easily observed, the spinules slender and darker than body colour. The integument in preserved specimens variable in colour, whitish, light brown or more often reddish. Anal fork present. Larvae moderately slender, hypognathous.

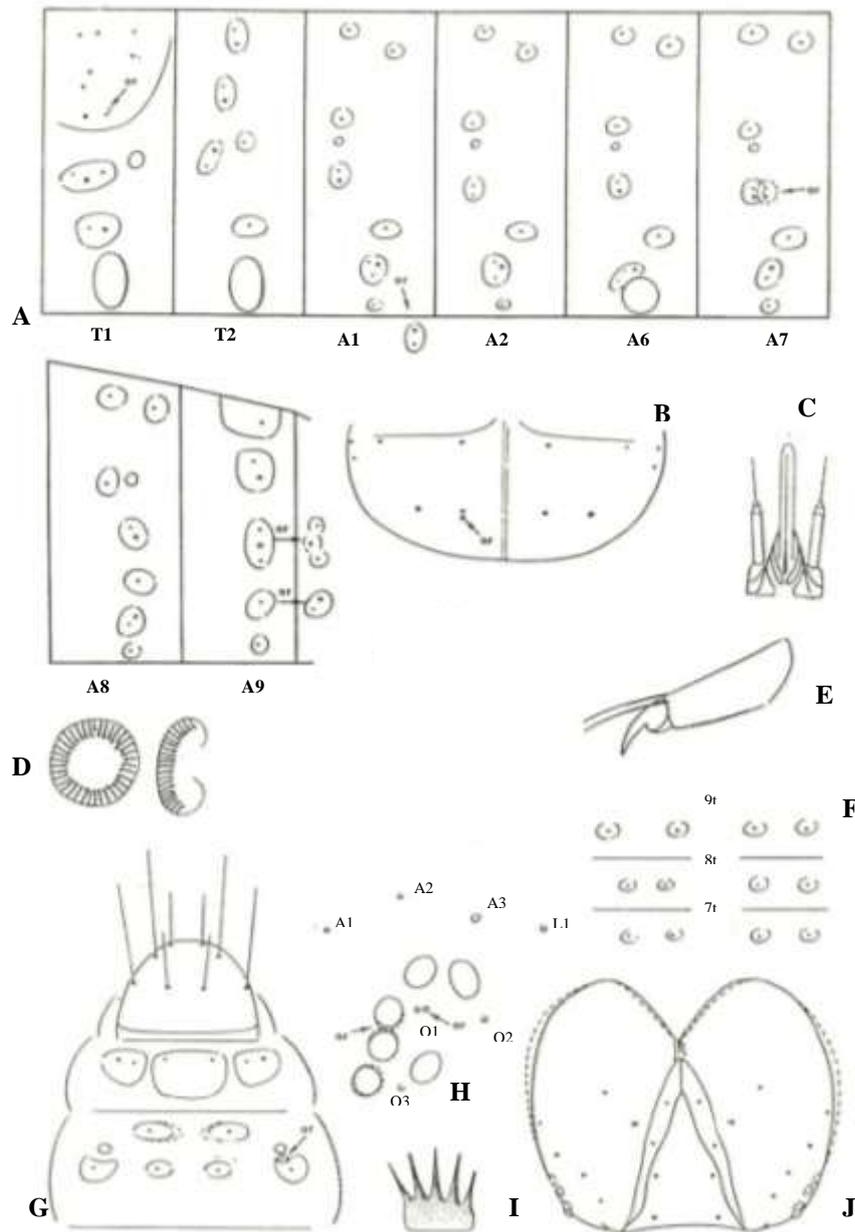
*Head:* In dorsal view variable in outline, but ocellar area rounded and vertical angle more or less acute. Adfrontals extending to vertical angle. The distance between  $E^2$  and  $F^1$  about two thirds of that between  $E^2$ 's or  $F^1$ 's.  $P^1$  closer to  $Adf^2$  than to  $F^1$ .  $A^2$  more or less equidistant from  $A^1$  and  $A^3$ .  $O^2$  ventral to ocellus I.  $O^1$  closer to ocellus III than to I. Ocellus II less than its diameter from I and usually slightly less than its diameter from III. Ocellus IV sometimes equidistant from III and V, but usually closer to III than to V. All ocelli more or less equal in size. Spinneret about seven to eight and a half times as long as wide.

*Thorax:* On prothorax, spiracle circular;  $SD^1$  much closer to  $SD^2$  than to  $XD^2$ ,  $SD^2$  very short and delicate.  $D^1$ 's closer to corresponding  $D^2$ 's than to each other and in a straight line with  $D^2$ 's or slightly posterior to that line.  $L^1$  usually slightly closer to  $L^2$  than to  $L^3$  and below a straight line joining  $L^2$  and  $L^3$ . On mesothorax and metathorax  $D^1$  more or less dorsad of  $D^2$ .

*Abdomen:* Spiracle moderate in size, and  $SD^1$  about one and a half to three times its diameter from it, except on segment 8. Spiracle on segment 8 tending to be on posterior half of segment, and  $SD^1$  more or less anterior to it and one or one and a half times its diameter from it.  $L^1$  and  $L^2$  usually directly below spiracle even on segment 8, but tending to be slightly posterior to a vertical line through spiracle on some specimens, and  $L^2$  usually dorsal to  $L^1$ . SV group on segments 1,2,7,8 and 9 usually 3:3:2:2:1 but unstable and occasionally 2:3,2:2:2:1 or 3, 2:3:2:2:1 and even 2:3,2:2:2:2 on one specimen. On segment 9,  $D^1$  and  $SD^1$  on the same pinaculum;  $L^1$  usually equidistant from  $L^2$  and  $L^3$ .  $V1$ s the same distance apart or more often farther apart on A9 than those on segment 8.

*Anal shield:* Rounded posteriorly.  $L^1$ 's farther apart than  $D^1$ 's and about length of anal segment.  $D^2$ 's about half as long as  $L^1$ 's.  $D^1$ 's about equidistant from corresponding  $SD^1$ 's and each other and usually equidistant from corresponding  $SD^1$ 's and each other and usually shorter than  $SD^1$ 's

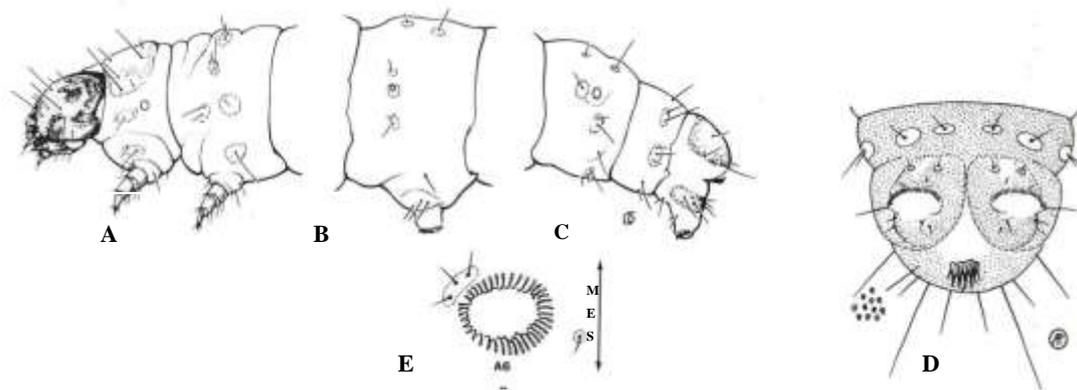
*Legs:* Coxae of metathoracic legs their diameter or less apart; pinacula of  $V^1$ 's fused with coxae. Claws curved but slender; dorsal setae as long as or much longer than claws. Crotchets uniordinal and comparatively long, 30 or 40 on ventral prolegs and about 25 on anal prolegs; crotchets 'in situ' sometimes oval, sometimes almost circular. Anal fork moderately developed, dark brown, easily seen.



**Figure 26:** *Grapholita molesta* A) Setal map; B) Prothoracic shield; C) Spinneret; D) Ventral and anal prolegs; E) Thoracic legs; F) V<sup>1</sup>'s position on A7-A9; G) Dorsal view of A8-A10; H) Ocellar area; I) Anal Comb; J) Dorsal head. (Taken and modified from MacKay, 1959: Fig 54).

Brown (1987) established a key on some common tortricid larvae on apple, peaches and generically related fruit and gave a short description and illustration (Fig. 27):

9-13 mm. Pinkish to near white with light brown head; length and width of head more than 9 and 9.5mm respectively thoracic and anal shields lightly sclerotized, pinacula large and pale; spinules of integument distinct, slender and darker than body color; anal comb present.



**Figure 27:** *Grapholita molesta* A) Head, T1, T2; B) A3; C) A8-A10 D) A9-A10 caudal view E) A6 crochets (Taken from Brown, 1987; Fig 26.124).

Dugdale *et al.* (2005) established a key on tortricids encountered in the field in New Zealand and the following characteristics were described in the Key:

Setal group SV on abdominal segments A7-9 not with 3,2 and 2 setae respectively, but usually 3,2,1 or 2,2,2, or 2,2,1; Head capsule in most species with axes of setal series P and MD forming an obtuse angle between 100° and 140° (However, *Cydia pomonella* has these setae series in line). Setal group SV on A7 with 2 setae. A9 setae D1, D2, SD1 either arranged on 3 separate pinacula (D1+SD1; D2+D2; D1 + SD1) or these can be narrowly joined; setal group SV on A1, A2 bisetose or trisetose; A7-9 setae V1 usually equally far apart. T1 prespiracular setal group A1, A2 setal group SV, and A9 setal group L all trisetose. Head capsule seta P1 close to adfrontal suture (separated by  $\pm 3 \times$  P1 socket diameter); A9 setal group SV unisetose. A9 setae D1 on a line anterior to setae D2, SD1 in dorsal view. Anal shield wider than long; anal comb with 4 teeth, A9 setal pinacula D2 + D2 and D1+SD1 separate. T2, T3 setae V1 fused to coxal sclerite; prolegs with crotchets evenly arranged around the planta ("sole" of the proleg); Anal shield  $\pm$  immaculate except in the last instar; A1-6 setal pinaculum SD  $\pm$  circular in early instars; head capsule setal series P and MD axes forming an angle closer to 90°.

#### 2.8.4 *Cryptophlebia peltastica*

Williams (1953) and Timm *et al.* (2005) both described *C. peltastica*.

Williams (1953)

Larva when mature, length about 20 mm, breadth about 3 mm. Colour: head dark brown; body with reddish hue which is often pronounced, body with tubercles slightly smaller, and lightly pigmented so spotting is not pronounced. Head wider than long. Ocelli 3 and 4 widely separated, but closer together than the others. Spiracles broadly oval. Chaetotaxy: head with puncture V<sup>a</sup> between V2 and V3 usually slightly nearer the former. Pb near P2, P1 closer to Adf2 than F1. AF<sup>a</sup> much nearer to AF2 than AF1. Body with puncture XD<sup>a</sup> postero-dorsad from XD<sup>1</sup>. Seta D1 on I directly above D2, and slightly above the level of XD1. Setae SD<sup>1</sup> and SD<sup>2</sup> with common tubercle on 1, on 2-8 SD<sup>2</sup> with its own small tubercle which is occasionally confluent (especially on 8) with the SD1 tubercle. Seta L1 on 8 postero-ventrad from L2 as on 1-7 Subventral group bisetose on 9. On 1 and 2 SV2 ventrad and slightly cephalad from SV1, SV3 antero-dorsad from SV1. Tubercle of ventral seta quite separate from coxa on II and III.

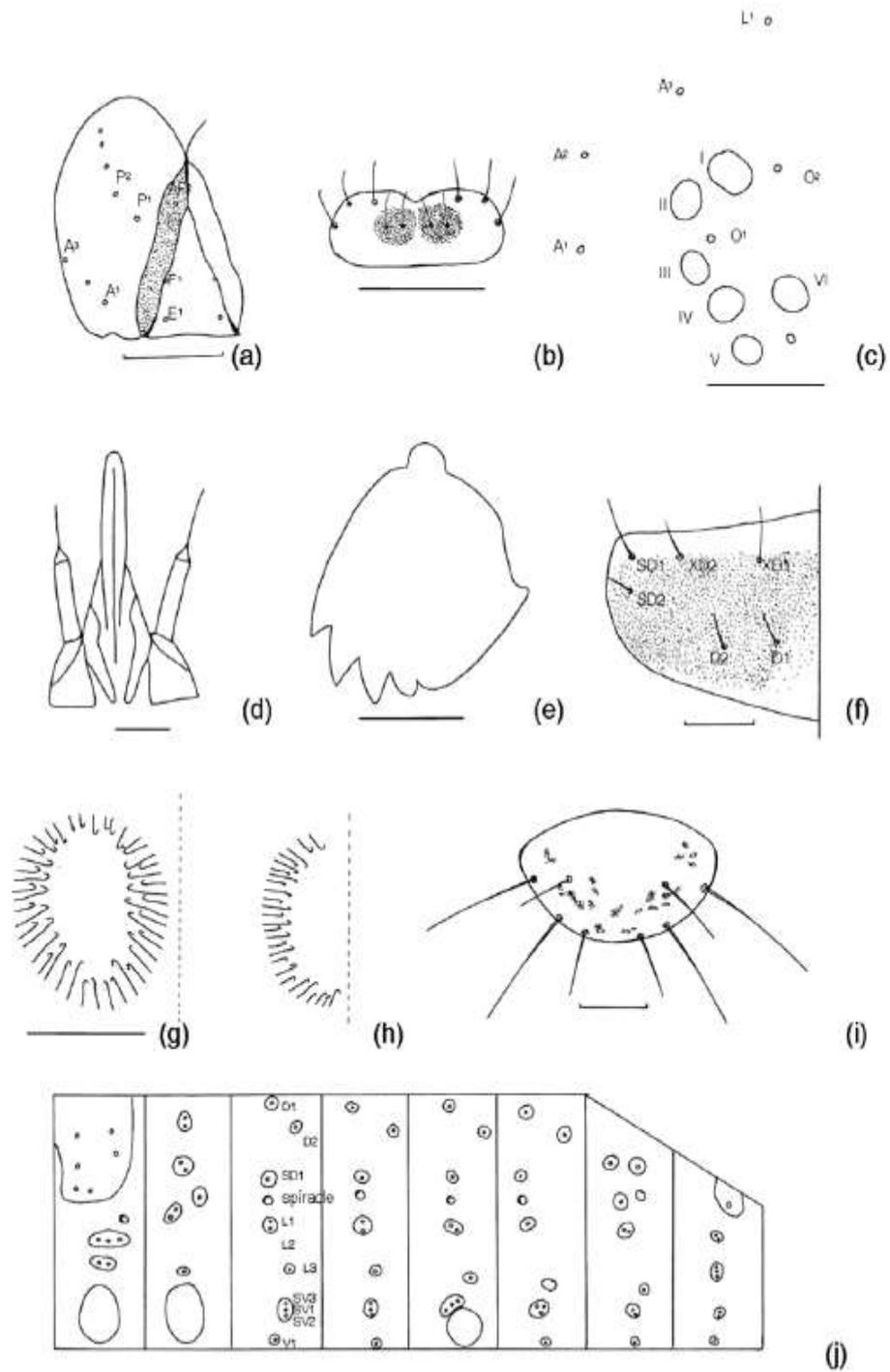
Timm *et al.* (2007) (Fig. 28):

*General.* Larva elongate, light pink to light red. Integument rugose. Setal pinacula easily observed, with brown pigmentation. Spinules slender, darker than body colour. Head brown with darker pigmentation at ocellar areas. Prothoracic shield dark brown. Anal shield yellow brown with some medium brown pigmentation. Thoracic legs medium brown.

*Head* (Figs 28 a-e). Hypognathous, dorsoventrally flattened. Average width prior to pupation 1.7 mm (n = 11). Adfrontals extending to vertical angle, tapering anteriorly. Vertical angle acute. P<sup>1</sup> closer to Adf<sup>2</sup> than F<sup>1</sup>. Stemmata II – VI rounded, approximately equal in size. Stemma I elongate, length nearly 1.5 times diameter of III. Stemma IV closer to III than VI. Stemmata IV and VI separated by distance slightly less than diameter of stemma IV. Stemma V and VI separated by distance roughly 1.5 times diameter of stemma V. O<sup>1</sup> closer to stemma III than stemma II. Line through O<sup>1</sup> and A<sup>1</sup> closer to stemma III than II, through O<sup>1</sup> and A<sup>2</sup> closer to stemma II than III and through O<sup>1</sup> and L<sup>1</sup> through the median of stemma I. A<sup>1</sup>, A<sup>3</sup> and L<sup>1</sup> on regular-shaped arc with A<sup>2</sup> dorsal. Mandibles with five teeth, outer three large, usually acuminate, second or third sometimes flattened, fourth smaller and flattened and fifth straight-edged. Distal end of spinneret rounded, about seven times longer than wide. Antenna elongate with long terminal seta, shorter, less robust than labial palpus.

*Thorax* (Figs 28f, j). Prothoracic shield with anterior lateral margin obtuse, lateral margin fairly straight and posterior margin evenly rounded towards mid-line. On prothorax, spiracle circular, L<sup>1</sup> equidistant from and in straight line with L<sup>2</sup> and L<sup>3</sup>, SD<sup>1</sup> slightly closer to SD<sup>2</sup> than XD<sup>2</sup>. On meso- and metathorax D<sup>1</sup> dorsal to D<sup>2</sup>. Thoracic claws curved.

*Abdomen* (Figs 28g-j). Spiracles small, circular, seldom larger than setal bases, SD<sup>1</sup> approximately 2.5 times its diameter from spiracle except on A8. On A8 spiracle slightly posterior to mid-vertical line through segment; SD<sup>1</sup> situated anteroventrally to spiracle and about 1.5 times of spiracle diameter. L<sup>1</sup> and L<sup>2</sup> usually ventral to spiracle and on A8 L<sup>2</sup> slightly anterodorsal to L<sup>2</sup>. SV group on A1, 2, 7, 8, 9 usually 3:3:3:2:2. On A9, D<sup>1</sup> and SD<sup>1</sup> on same pinaculum, L<sup>1</sup> usually equidistant to L<sup>2</sup> and L<sup>3</sup>. Anal fork absent. Anal shield rounded posteriorly. L<sup>1</sup>s slightly further lateral than D<sup>1</sup>s. D<sup>1</sup>s closer to corresponding SD<sup>1</sup>s than to each other and almost in a straight line. Prolegs with 50–58, and anal prolegs with 46–54 mostly biordinal crochets. Anal prolegs with crochets absent in medial half.



**Figure 28:** *Cryptophlebia peltastica* final instar larva. a, Head (frontal aspect); b, labrum; c, stemmata; d, spinneret; e, mandible; f, prothoracic shield; g, crochets on ventral prolegs; h, crochets on ventral prolegs; i, anal shield; j, setal map. Scale bars: a, f, i = 1 mm, b–e, g, h = 0.1 mm. (Taken from Timm *et al.*, 2007; Fig 6)

### 2.8.5 *Thaumatotibia batrachopa*

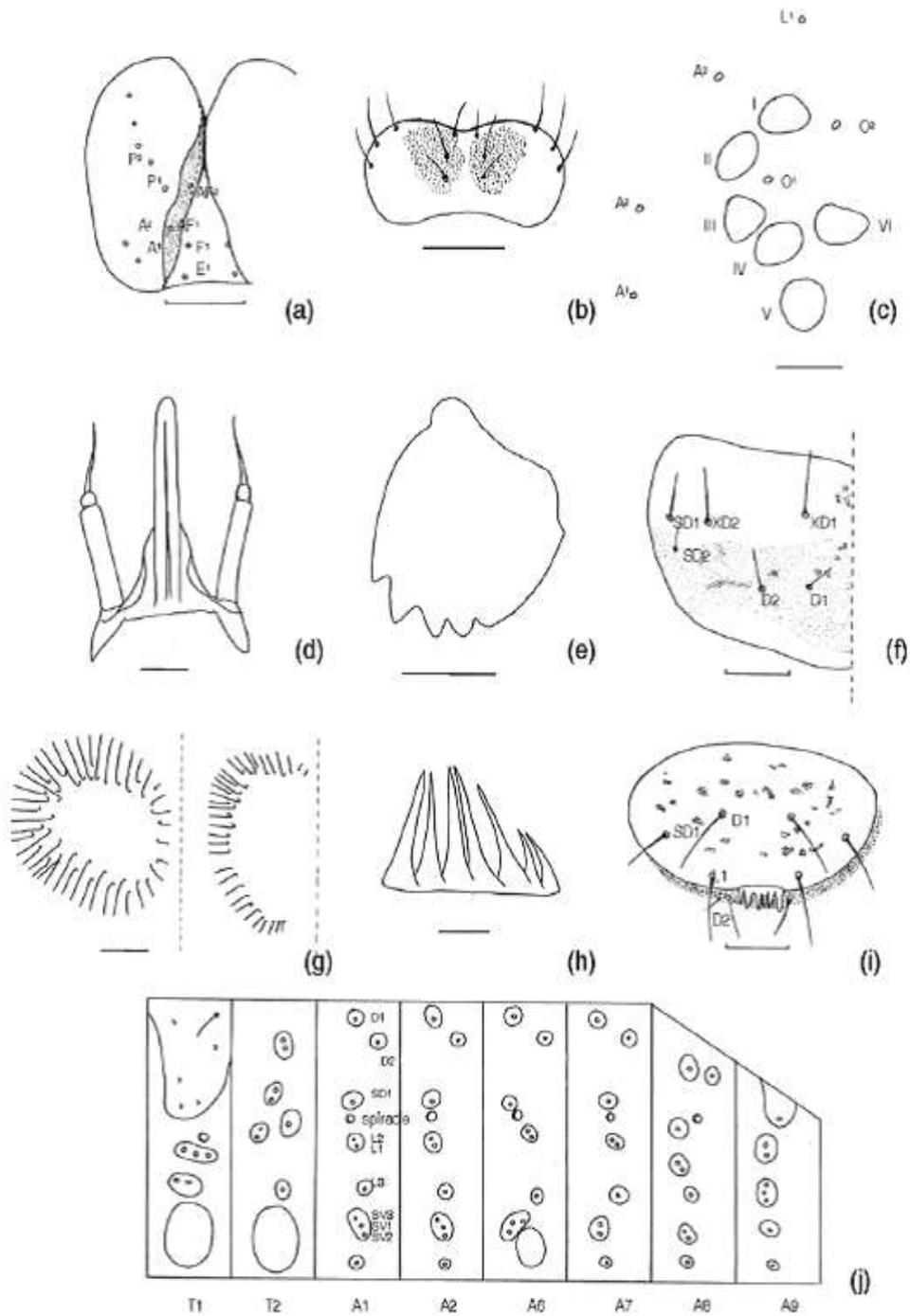
Timm *et al.* (2007) described *T. batrachopa* as follows (Fig. 29):

*General:* Larva elongate, cream to grey green. Setal pinacula moderately large, easily observed. Integument rugose and spinulation of integument conspicuous, spinules slender and darker than body colour. Head yellow brown with darker pigmentation at ocellar area. Prothoracic and anal shields yellow brown, lightly sclerotized with small patches of darker pigmentation. Thoracic legs medium brown.

*Head* (Figs 29 a-e). Hypognathous, dorsoventrally flattened. Average width prior to pupation 1.5 mm ( $n = 10$ ). Vertical angle acute. Adfrontals extending to vertical angle, tapering anteriorly and posteriorly.  $P^1$  closer to  $Adf^2$  than  $F^1$ . Ocellar areas rounded. Stemmata approximately equal in size, irregularly rounded. Stemma II equidistant from I and III. Stemmata III and IV close together, IV closer to III than VI. Stemmata V and VI separated by distance nearly equal to diameter of V.  $O^1$  equidistant from II and III.  $A^2$  closer to  $A^1$  than  $A^3$ .  $A^3$  closer to  $L^1$  than  $A^2$ . Line through  $O^1$  and  $A^2$  equidistant from stemma II and III. Lines joining  $O^1$  and  $A^1$  and  $O^1$  and  $A^3$  nearly right-angled.  $A^1$ ,  $A^2$ ,  $A^3$  and  $L^1$  on regular rounded arc. Mandible with five teeth, outer three pointed, second largest, fourth smaller and fifth smallest and straight-edged. Antenna elongate with long terminal seta, shorter, less robust than labial palpus. Distal end of spinneret rounded, about seven times longer than wide.

*Thorax* (Figs 29 f, j). Prothoracic shield with anterior lateral margin obtuse, slightly concave and curved about one-third its length, curved convexly towards mid-line, lateral margin fairly straight, posterior margin evenly rounded towards mid-line. On prothorax, spiracle very prominent, circular  $L^1$ ,  $L^2$  and  $L^3$  in straight line.  $SD^1$  equidistant from  $XD^2$  and  $SD^2$ . On meso- and metathorax  $D^1$  dorsal to  $D^2$ . Thoracic claws curved.

*Abdomen* (Figs 29 g-j). Spiracles circular, small, seldom larger than setal bases,  $SD^1$  usually separated by distance 1.5 times diameter of spiracle except on A8. On A8 spiracle on mid-vertical line through segment;  $SD^1$  situated anteroventrally of spiracle at about twice its diameter.  $L^2$  anterodorsal to  $L^1$  on same pinaculum and  $L^1$  and  $L^2$  anterodorsal to spiracle. On A9,  $D^1$  and  $SD^1$  on same pinaculum;  $L^1$  equidistant from  $L^2$  and  $L^3$ . SV group on A 1, 2, 7, 8, and 9 usually 3:3:2:2:1. Anal fork well developed, darkly pigmented, with 5–8 prongs. Basal part of each prong strongly tapered dorsally, width of the base nearly one-quarter length of tooth, prongs merging into distinct medial structure. Anal shield posteriorly rounded.  $L^1$ s approximately same distance apart from each other as  $D^1$ s.  $D^2$ s slightly more than half as long as  $L^1$ s.  $D^1$ s somewhat closer to corresponding  $SD^1$ s than to each other. Prolegs with 34–44, and anal prolegs with 26–32 unevenly arranged triordinal crochets with crochets absent in medial half.



**Figure 29:** *Thaumatotibia batrachopa* final instar larva. a, Head (frontal aspect); b, labrum; c, stemmata; d, spinneret; e, mandible; f, prothoracic shield; g, crochets on ventral and anal prolegs; h, anal comb; i, anal shield; j, setal map. Scale bars: a, f, i = 1 mm, b–e, g, h = 0.1 mm. (Taken from Timm *et al.*, 2007; Fig 4)

### 2.8.6 *Epichoristodes acerbella*

Nuzzaci (1973) described *E. acerbella* in Italian; part of his elaborate descriptions has been abridged and text freely translated:

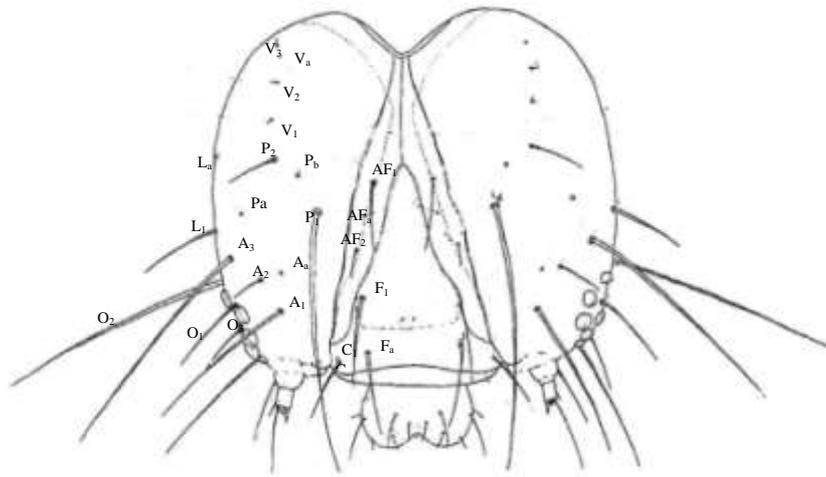
*General appearance and colouration:* The mature larvae reaches a length between 17-21 mm and 1.2 mm in diameter, from the head backwards, the body reaches a maximum of 2 mm across the major segments to eventually reduces to 1.4 mm at the caudal region. The colour of the head is brownish to olive-green with distinct colour of the pronotum; the remainder of the body is yellowish –green. The abdomen of the larva has a medially dorsal line with two lateral bands.

*Morphology and taxonomy:*

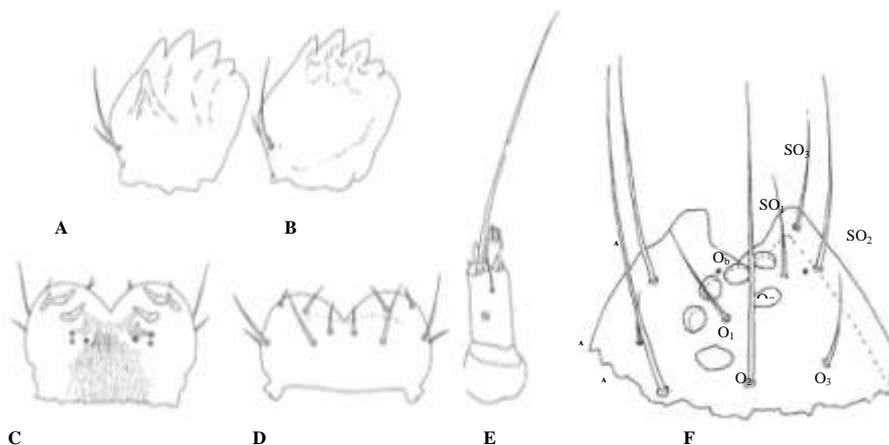
*Head* (Figs 30-31). The cranium is prognathous, longer than broad, with the epicranial suture about a fifth of the head's length. The frontal sutures are slightly sinus between the anterior angle of the clypeus and the posterior cranium. The epistomal sutures strongly developed, bracing the dorsa; part of the tentorium. The head has following chaetotaxy: Four clypeal setae ( $C^n$ ), two on each side, with  $C^2$  longer than  $C^1$ , two frontal setae ( $F^1$ ), one on each side, in line with  $C^2$ , of similar length; four frontal sensilla ( $F^a$ ), one on each side, the longitudinal axis of the cranium; four adfrontal setae ( $Afn$ ), two on each side, the anterior  $AF^1$  a third the length of  $AF^2$  in line with the longitudinal axis of the head; two adfrontal sensilla ( $AF^a$ ), one on each side, situated in a line equidistant from those and between  $Af^1$  and  $Af^2$ , six anterior setae ( $An$ ), three on each side, diagonally to the cranial longitudinal axis and in line with  $A^2$  the shortest,  $A^1$  longer than  $A^2$ , and  $A^3$  longer than  $A^2$ ; two anterior sensilla ( $A^a$ ), one on each side, closer to  $A^2$ . Slightly before connecting lone seta  $A^2$  and  $P^1$ . Six Ocellar setae ( $O^n$ ), three on each side ventral to the ocelli with  $O^1$  a little longer than  $O^2$  and  $O^2$  as long as  $A^3$ , four Ocellar sensilla, two on each side, one ( $O^a$ ) situated ventral to  $SO^2$  and  $SO^3$ , the other ( $O^b$ ) between the third and fourth ocelli; six subocellar setae ( $SO^n$ ), three on each side, situated anterior ventral to the Ocellar region with  $SO^1$ , anterior and longer than  $SO^2$  dorsal to  $SO^3$  which is larger than the preceding setae; four subocellar setae, two on each side, anterior ventral margin of the mouth opening (peristoma) and small; two lateral setae ( $L^1$ ), one on each side situated on a position ventral to  $A^3$ , its length similar to  $O^1$ ; two lateral sensilla ( $L^a$ ), one on each side situated close to  $L^1$ ; four posterior setae ( $P^n$ ), two on each side, placed dorsally with  $P^1$  (the longest cranial seta) slightly before  $Af^2$ ,  $P^2$  posterior to a line for  $A^2$  to the cranial longitudinal axis; four posterior sensilla; two on each side, situated ( $P^a$ ) on a line between  $P^1$  and  $L^1$  and the other ( $P^b$ ) on a line between  $P^1$  and  $P^2$ ; six vertical setae ( $Vn$ ) three on each side, angled on the anterior-posterior line to the cranial longitudinal axis; two vertical sensilla ( $Va$ ), one on each side situated between  $V^2$  and  $V^3$ ; two genal setae ( $G^1$ ), one on each side, close to the foramen occipital; two genal sensilla ( $G^a$ ), one on each side, situated anterior to  $G^1$  in a line between that seta ( $G^1$ ) and  $O^3$ . Six ocelli, five arranged in an arc and 1 placed ventrally to the height of II.

*Antenna* (figure 15). The antenna made up in 4 parts. First segments broader than wide, connected to the skull by a membranous base which can be invaginated. Antennal base can be hollowed out. Second segment much longer than the first, ventral side a placoid sensilla (1) towards distal part. Robust short seta (2) on pinaculum (shorter than the maximum width of this segment). On the tip (apical) part of second segment on the ventral margin there is a prominent seta (3), larger than the entire length of the antenna as well as a subconical sensillum (4) which is a shorter version of the one on the dorsal margin (placoid sensilla). On the same apical part where (long bristle seta is) there is another sensilla half of the smallest sensilla on the subconical (rounded). Third antennal segmented a third of the width of the second segment and has on the distally part towards the margin a subconical sensillum (6). Slightly longer (2) and on the edge. In addition another subconical sensillum (7) slightly shorter than (4). Fourth antennal segment adjoining third segment has two subconical (cone-like) structures of almost equal and slightly longer than third antennal segment. Another conical sensilla adjoining seta (6). *Clypeus* (Frons) borders anteriorly to the post labial membrane and posteriorly to the epistomal suture to form a sub triangular shape. *Anteclypeus*: sub rectangular margin and on its anterior margins concave median incision with the margins rounded and its extremities two sclerifications. Dorsally provided with twelve seta, six on each side of which two are on the anterior margin (front edge), and two in the proximity of the lateral margin (shorter). Inner pair more robust and larger than the clypeus. Another pair almost as long as sub marginal ones behind the anterior median marginal bristles. Ventral face membranous and provided anterior laterally with six sub conical sensilla, rounded tips and compressed. Rear (posterior) formations of placoid sensilla placed behind the sensory medial region. Third pair medial. Placoid

sensilla (small/tiny) starts from the front and extends backwards a terminating in an irregular shaped post labral margin. **Mandibles** (Figure 31): The robust mandibles are sub-pyramidal in shape and provided with five teeth, rising from the inner margin with the third and fourth teeth more developed and pointed. Laterally there are two sensilla on each mandible; ventrally four grooves, diverging medially from the teeth. **Maxilla:** Laminar cardines hinge in part to the indented posterior of the head capsule and is part to the submental sclerites. The stipites are in part membranous in part sclerotized; in the antero-lateral region two sensilla, the longer one median posteriorly, situated on a longer placoid sensillum. The palpifer with sensillum about four-fifth of the shorter sensillum of the stipite. The maxillary palpus articulates ventrally and dorsally on the palpifer with a sensillum on a placoid sensillum, maxillary palpus has on the first segment on the distal ventral margin, one sensillum with second sensilla probably on a placoid sensillum. On the second segment a distally placed placoid sensillum on the second segment there is a placoid sensillum. The distal part of the third segment subconical sensilla of different lengths on a cylindrical base and distally articulating subconical of various lengths and shapes. A lobe on the ventral side situated on a placoid sensillum with the dorso-lateral side one sensillum. Part of the distal area has two biarticulate sensilla on the cylindrical base, with apical subconical structure on top. **Prementum** of the labium (Figure 15) sclerotized anteriorly and at its base two minute sensilla, an the elongated postmentum bi-articulate a basal segment longer than wide and the second segment much smaller than distal base each with a single sensillum on the first distal and apical base of second sensillum, the former about half the length of that of the second segment.



**Figure 30:** *Epichoristodes acerbella*, dorsal head chaetotaxy (Taken and adjusted from Nuzzaci, 1973; Fig.12).



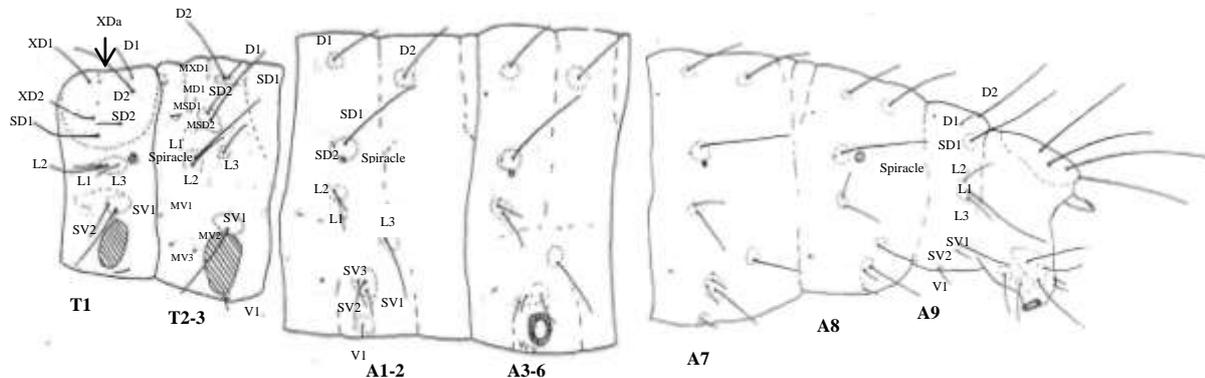
**Figure 31:** *Epichoristodes acerbella*, A-B) Ventral and dorsal aspect of left mandible. C-D) Dorsal and ventral labrum; E) Antenna (Taken and adjusted from Nuzzaci, 1973; Fig.13, Fig14).

\*Bracketed nomenclature is that of Hinton (1946)

**Thorax** (Fig. 32): **Prothorax** dorsally presents a plaque clarification. **Chaetotaxy:** Two MXD<sup>1</sup>: Far apart on the posterior margin of the dorsal plate. Two MVN on each side anterodorsal to the legs MV<sup>2</sup> more dorsally. Two

XD on each side: towards the antero-lateral aspect of the dorsal plate with XD<sup>2</sup> (SD<sup>1</sup>) longer than XD<sup>1</sup> (XD<sup>2</sup>). Three punctures (XD<sub>a-c</sub>). Two D-setae on each side D<sup>1</sup> (XD<sup>1</sup>) anterior and longest D<sup>2</sup> (D<sup>1</sup>). Two SD setae, SD<sup>2</sup> (D<sup>2</sup>) longer and posterior to SD<sup>1</sup> (SD<sup>2</sup>). Three L-group setae on one pinaculum anteroventral to pinaculum not reaching below. L<sup>1</sup> (middle setae) longest of all three, Two SV setae SV<sup>1</sup> longer than SV<sup>2</sup>. V<sup>1</sup> very small located behind/below legs. **Meso and metathorax:** Chaetotaxy: One MXD<sup>1</sup> micro bristle ridges. Two MSD<sup>n</sup> with MSD<sup>1</sup> anterior to MSD<sup>2</sup>, in one line. Two D setae, D<sup>1</sup> and D<sup>2</sup> on one pinaculum with D<sup>2</sup> (D<sup>1</sup>) anterior to and longer than D<sup>1</sup> (D<sup>2</sup>). Two SD setae single pinaculum. SD<sup>1</sup> ventral to SD<sup>2</sup> and very long compared to SD<sup>2</sup>. L-setae L<sup>1</sup> and L<sup>2</sup> on 1 pinaculum, L<sup>3</sup> on a separate pinaculum and posterior dorso to L<sup>1</sup> and L<sup>2</sup>. L<sup>1</sup> longest of all three. V<sup>1</sup> setae same size and position as on V<sup>1</sup> on prothorax. Three MV microbristle anterior to leg. MV<sup>1</sup> and MV<sup>3</sup> anterior to MV<sup>2</sup>. **Thoracic legs:** Coxa provided with eight bristles, varying length and positions, and three bristles very small.

**Abdomen** (Fig. 32): Ten segments, eight with spiracles and five with a pair of crotchets. **Chaetotaxy 1-7:** One MXD<sup>1</sup> (microbristle ridges) on each side near anterior margin of segment. One MV<sup>3</sup> on each side before SV group. Two D setae, D<sup>1</sup> and D<sup>2</sup> in line but D<sup>2</sup> setae slightly longer than D<sup>1</sup>. Two SD setae, one pinaculum dorsally to spiracle. SD<sup>2</sup> tiny, anterior to SD<sup>1</sup>. Three L-setae, L<sup>1</sup> and L<sup>2</sup> on one pinaculum below spiracle, L<sup>3</sup> more longer and posterior ventral to L<sup>1</sup> and L<sup>2</sup>. Three SV setae on one pinaculum, SV<sup>1</sup> longest of the three. V<sup>1</sup> as on the thoracic segments. **A8 chaetotaxy:** Same as above only difference is that it has no SV<sup>3</sup>. **A9 chaetotaxy:** Same as above with the following differences: D<sup>1</sup> shorter than D<sup>1</sup>'s on other segments. D<sup>2</sup> longer than D<sup>2</sup>'s on other segments. SD<sup>2</sup> disappears. L-group united on a single plate. L<sup>1</sup> longest of all three.



**Figure 32:** *Epichoristodes acerbella* setal map (Taken and adjusted from Nuzzaci, 1973; Fig.15).

Timm *et al.* (2008) described *E. acerbella* as follows (Fig.33):

**General** Larva elongate, light green with darker green stripe on dorsal midline and often yellow green stripes at lateral midlines. Setal pinacula conspicuous, lighter than body colour Integument rugose. Spinules long, slender, lighter than body colour, easily observed. Head yellow brown. Prothoracic and anal shields yellow or body coloured, easily observed.

**Head** (Figs 33 a-e). Average width prior to pupation 1.04 mm (n = 16). Vertical angle acute. Adfrontals narrow, extending to vertical angle. P<sup>1</sup> closer to Adf<sup>2</sup> than F<sup>1</sup>. Ocellar areas rounded. Stemmata inconspicuous with exception of stemma III, surrounded by dark pigmentation. Stemma II closer to stemma III than stemma I. Stemma II separated from stemma I by distance greater than its diameter. Stemmata III, IV and V in straight line, stemma VI at right angles to this line. O<sup>1</sup> equidistant from stemmata II and III. Line drawn through O<sup>1</sup> and A<sup>2</sup> closer to stemma II than I. Mandible with five teeth, second and third large and pointed, fourth smaller and slightly flattened, fifth straight-edged.

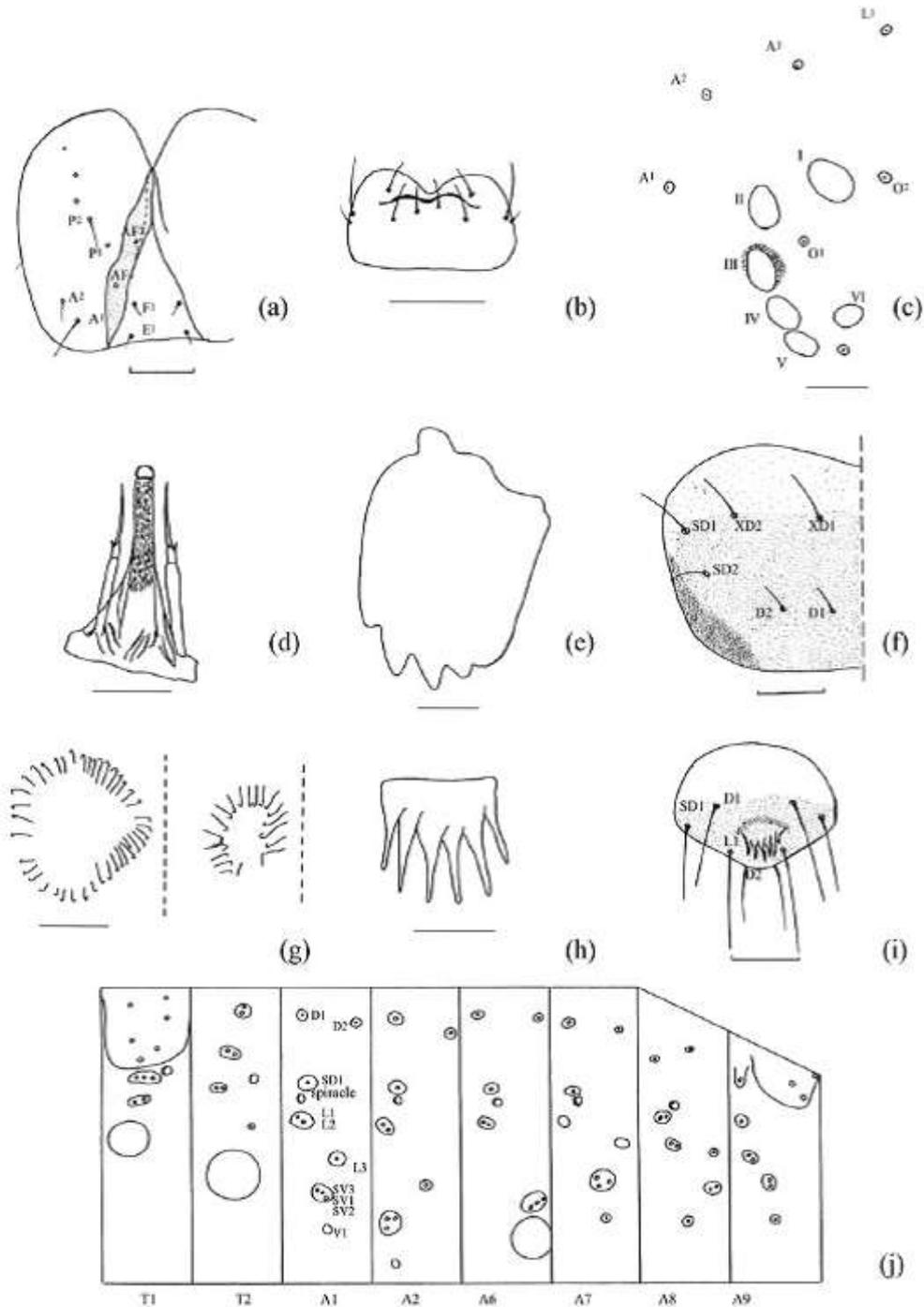
**Thorax** (Figs 33 f, j). On prothorax, spiracle small, circular, L<sup>1</sup> equidistant from and in straight line with L<sup>2</sup> and L<sup>3</sup>, SD<sup>1</sup> equidistant from XD<sup>2</sup> and SD<sup>2</sup>. On meso- and metathorax D<sup>1</sup> dorsal to D<sup>2</sup>. Thoracic claws curved.

**Abdomen** (Figs 33 i-j). Spiracles circular, smaller than setal bases. SD<sup>1</sup> separated from spiracle by approximately half the diameter of spiracle. Spiracle on A8 on midventral line drawn through segment. L<sup>2</sup> usually posteroventral to L<sup>1</sup>. SV group on A1, 2, 7, 8 and 9 usually 3:3:3:2:2. Anal shield: rounded and strongly

tapered posteriorly. D<sup>1</sup>s further apart than L<sup>1</sup>s. D<sup>2</sup>s slightly shorter than L<sup>1</sup>s. D<sup>1</sup>s closer to corresponding SD<sup>1</sup>s than to each other. D<sup>1</sup>s anterior to SD<sup>1</sup>s.

*Anal fork* (Fig 33h). well developed, transparent, with 6–9 bluntly dentate prongs of approximately similar length. Width of base approximately equal to or less than length of prongs. Basal part of each prong tapered dorsally.

*Proleg* (Fig 33j). prolegs with 32–54 and anal prolegs with 28–36 unevenly uniordinal, almost biordinal, crochets.



**Figure 33:** *Epichoristodes acerbella* final instar larva. a, Head (frontal aspect); b, labrum; c, stemmata; d, spinneret; e, mandible; f, prothoracic shield; g, crochets on ventral and anal prolegs; h, anal comb; i, anal shield; j, setal map. Scale bars: a, f, i = 1 mm, b–e, g, h = 0.1 mm. (Taken figure from Timm *et al.*, 2008; Fig. 2).

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## CHAPTER 3

### Morphological study for the pupal stages of economic importance tortricids in South Africa

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#### 3.1 Abstract

Seven economic important tortricids causing extensive damage and losses to the fruit industry are present in South Africa, The correct identification of these species in the immature stages is important as misidentifications could lead to ineffective pest management. In South Africa no proper identification guide exists to distinguish between the pupae of these species. Thus the aim was to use the literature available and carry out a morphological study of the pupae to provide descriptions of the pupal stages of each species and to develop an identification guide for this stage.

#### 3.2 Introduction

Seven tortricid species have a major impact on the fruit industry in South Africa, their larvae causing extensive damage and crop losses yearly (Powell, 1964; Timm, 2005). Five of the species belong to Olethreutinae and two to Tortricinae (See Chapter 1, Table 1) (Pinhey, 1975; Karisch, 2001; Brown, 2005): *Cydia pomonella* (Linnaeus, 1758) (Codling moth), *Thaumatotibia leucotreta* (Meyrick, 1913) (False codling moth), *Grapholita molesta* (Busck, 1916) (Oriental fruit moth), *Cryptophlebia peltastica* (Meyrick, 1921) (Litchi moth), *Thaumatotibia batrachopa* (Meyrick, 1908) (Macadamia nut borer), *Epichoristodes acerbella* (Walker, 1864) (Pear leafroller/Carnation worm), and *Lozotaenia capensana* (Walker, 1863) (Apple leafroller) (Brown, 2005). Misidentifications of these economically important species, especially the immature stages, may lead to ineffective pest management (Timm, 2005) or result in export restrictions. The main objective of this study was to provide a complete, or nearly complete, description of each species that could subsequently be used to distinguish between them, leading to the development of an identification guide. The over-arching goal was to provide a reliable identification tool for workers in the South African fruit industry.

#### 3.3 Material and methods

Literature of various authors was studied, summarized (see Appendices 3.1), and compared for descriptions of the pupal stages of *T. leucotreta*, *C. pomonella*, *G. molesta*, *C. peltastica*, *T. batrachopa*, *E. acerbella*, and *L. capensana*. The descriptions were then compared with specimens at hand, and gaps in the descriptions were filled by additional morphological studies.

For *L. capensana* no published morphological description of the pupa could be found. The morphological characteristics described in this chapter are not always comprehensive for every taxon, but they fulfil the main objective of providing sufficient character information for identification purposes.

##### 3.3.1 Insect material

Pupal specimens of *T. leucotreta*, *C. pomonella*, *C. peltastica*, and *G. molesta* were generously donated from established South African laboratory colonies: *T. leucotreta* from XSIT, Citrusdal, and Rhodes

University, Grahamstown; *C. pomonella* from Entomon, Stellenbosch; *C. peltastica* from Bioriver Science, Addo; *G. molesta* from Embrapa Grape and Wine, Bento Gonçalves, Brazil and the Applied Entomology Department in the Institute of Agricultural Research, Eidgenössische Technische Hochschule, Zürich, Switzerland. Additional pupae of *C. peltastica* were collected from *Acacia saligna* and *A. pygnantha* galls. *T. batrachopa* pupae were received from Upotn farm, Umhlali. Larval specimens of *E. acerbella* were collected in the field and reared to adulthood for confirmation of pupal characters. One specimen of *L. capensana* was collected in an apple orchard at Oak Valley farm, Grabouw; other specimens were from the Entomological Museum of the Stellenbosch University (USEC), South Africa, which is also the depository of the voucher specimens of this study.

### **3.3.2 Preparations of specimens**

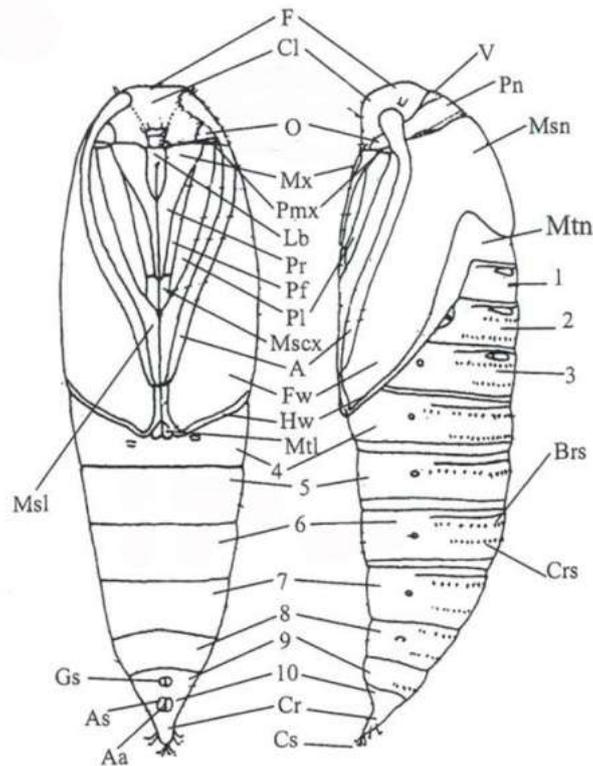
For reference material pupae were killed in alcohol and stored in Kahle's Fluid as preservative. Kahle's fluid was selected for its better colour retention of specimens.

### **3.3.3 Preparation of images**

Photos of pupae with a Leica MZ 16A automontage microscope for two dimensional image analyses with a Leica DFC 290 fixed digital camera and Leica Application Suite (LAS) v.2.7. software. Photos were edited in Adobe Photoshop Element v.9.0.0 (Adobe System Incorporated).

### **3.3.4 Nomenclature**

Nomenclature for pupal morphology follows that of Patočka & Turčáni (2005) (Fig. 34) and Timm *et al.* (2007, 2008). For uniformity, the style and format of the descriptions follow that of Timm *et al.* (2007, 2008). Setae are described for the left half of the pupae being a mirror image of the right.



**Figure 34:** General pupae; A. antennae; Aa. anal area; As. anal opening Brs. basal row of spines; Cl. clypeus; Cr. cremaster; Crs. caudal row of spines; F. frons; Fw. forewings; Gs. genital opening; Hw. hindwings; Lb. labium; Mscx. mesocoxa; Msn. mesonotum; Mtl. metatarsus; Mtn. metanotum; Mx. maxillae; O. eyes. Pf. prothoracic femur (not always visible); Pl. protarsus. Pmx. maxillary palpi. Pn. pronotum; Pr. maxillae; 1-10. 1<sup>st</sup> -10<sup>th</sup> abdominal segments (Taken and edited from Patočka & Turčáni, 2005; Fig B1).

### 3.3.5 Key development

Morphological details of pupae have not been used in the development of diagnostic keys due to minute difference in these structures not easily discernible to workers in the fruit industry. A summary was compiled using existing literature and own morphological assessments, in order to assist stakeholders in identification of pupae.

## 3.4 Results

### 3.4.1 *Thaumatotibia leucotreta*

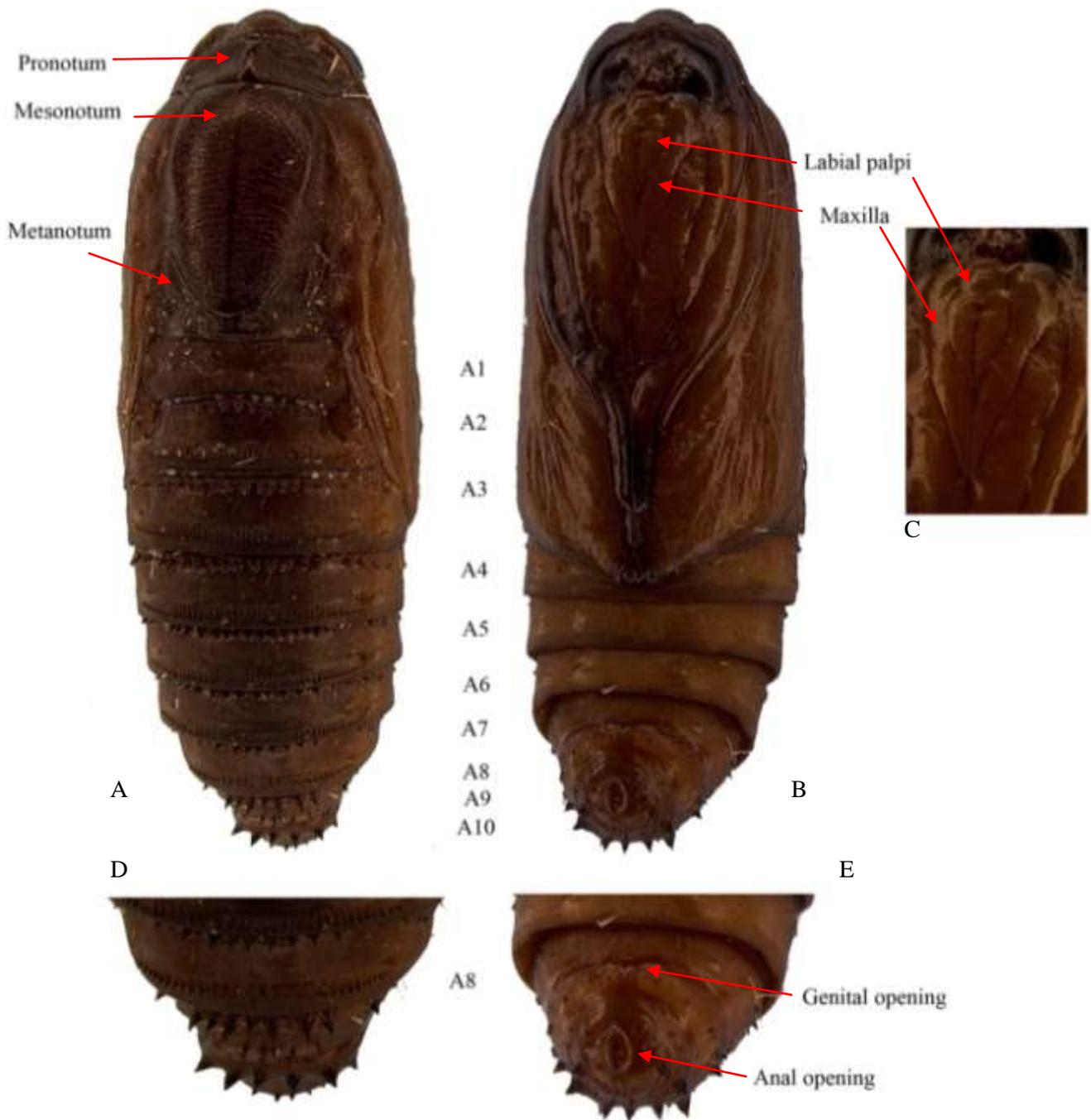
*Head* (Figs 35 A-C). Eyes darker and prominent in mature pupae. Two medial pairs of setae on clypeus, outer pair longer.

*Thorax* (Figs 35 A-B). Metatarsus extending beyond hindwing, in line with lower margin of forewing. Two pairs of setae on pro- and mesonotum: on pronotum, one lateral pair near forewing and medial pair close to mid-dorsal line. On mesonotum, one pair midway on alar furrow and one pair near mid-dorsal line. On metanotum, one pair of setae situated in anterior corners of the “M”-shaped hindwing.

*Abdomen* (Figs 35 A-B, D-E). Setae on lateral margin of ventral aspect: four setae on A4, one pair close to spiracle, and two single setae, one medio-anterior and one anterior, close to the mid-ventral line, single seta

sometimes concealed by hindwing. Seven setae on A5-A6, lateral group paired; one group of three, arranged in a triangular pattern, and two single setae; three outer setae longest. Six setae on A7, as for A5-A6, but group of three setae reduced to one pair. Four setae on A8, as for A5-A6, except group of three setae absent and all setae of similar length. Three setae spaced evenly on medio-lateral line on A9.

Dorsal aspect: A1 smooth without spines, single setae close to medial line. Double row of spines on A2-7, three single setae, one on the lateral margin and one close to medial line on anterior ridge, and single seta situated half way between lateral margin and medial line on posterior ridge. A2 anterior row with fewer spines than on other segments. Spines increasing in size on posterior abdominal segments. A8 with double row of dorsal spines in males, anterior row with 8-11 larger irregularly-sized spines, but smaller than on A9. One pair of setae on outer lateral margin and single seta close to mid-dorsal line. Posterior row with 6-8 minute, irregularly-sized spines. Single setae on lateral margins on posterior row of spines. A8 in females with single row of 9-10 larger, irregularly-sized spines, similar to spines on A9. A9 with 5-6 large irregularly shaped spines medially, occasionally with a few extra minute spines. A9 spines larger than those on A10. Distinct single seta laterally-caudal to row of spines. A10 with 2-3 medial small spines. Two larger spines on the lateral margins with a single seta posterior to each large spine.



**Figure 35:** *Thaumatotibia leucotreta*. A. Dorsal view, B. Ventral view, C. Close up of maxilla and labial palpi, D. Dorsal view of A8-10, E. Female ventral view of A8-A10.

### 3.4.2 *Cydia pomonella*

*General.* Frontal and caudal area dark brown, dorsal side darker than ventral. Cremaster absent. Pupation takes place under the bark on trees or in plant litter, usually in a cocoon formed from soil particles and debris (Higbee *et al.*, 2001).

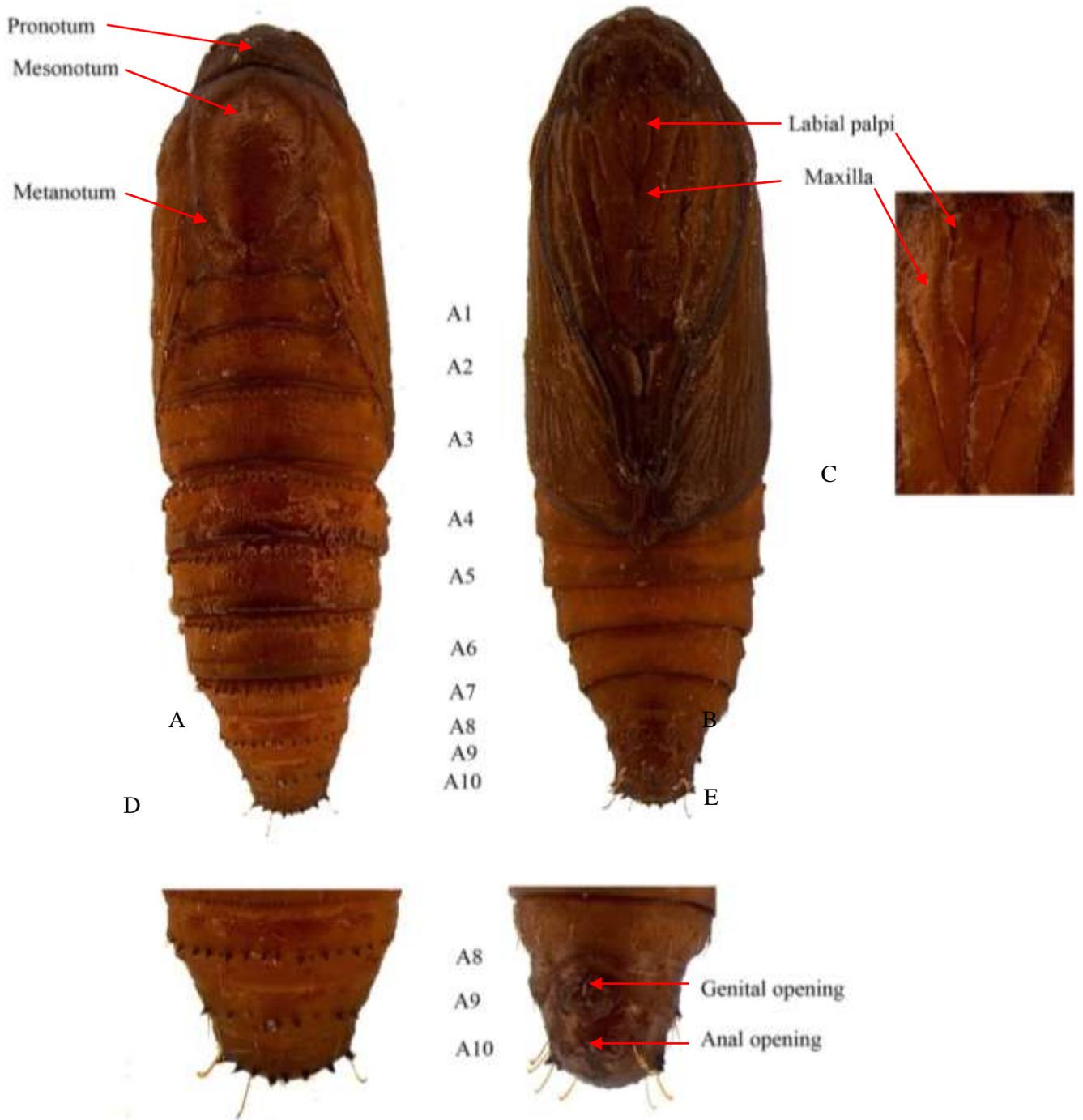
*Head* (Figs 36 A-C). Frons smoothly rounded, with one pair of setae. Eyes darker and prominent in mature pupae. Two medial pairs of setae on clypeus, inner pair slightly shorter. Maxilla and proboscis along

midline about 1.5 times length of labial palpus. Structure of antenna sexual dimorphic: in females extending beyond the mesocoxa by a distance longer than the mesocoxa along the midline; in males thickened and prominent, extending past the mesocoxa to the tip of the mesotarsus.

*Thorax* (Figs 36 A-B). Segments dorsally well delimited. Hindwing concealed almost entirely by forewing, visible only at ventral posterior edge of forewing. Protarsus extending slightly beyond procoxa. Mesotarsus well developed, extending beyond forewing. Metacoxa slightly visible. Two pairs of setae on pronotum and mesonotum. Pronotum 4.0-4.5 times as long as vertex along midline. One lateral pair near forewing and one medial pair close to the mid-dorsal line on pronotum. On mesonotum, one pair of setae midway on alar furrow and one pair near mid-dorsal line. On metanotum, one pair of setae situated in anterior corners of the “M”-shape denoting the hindwing.

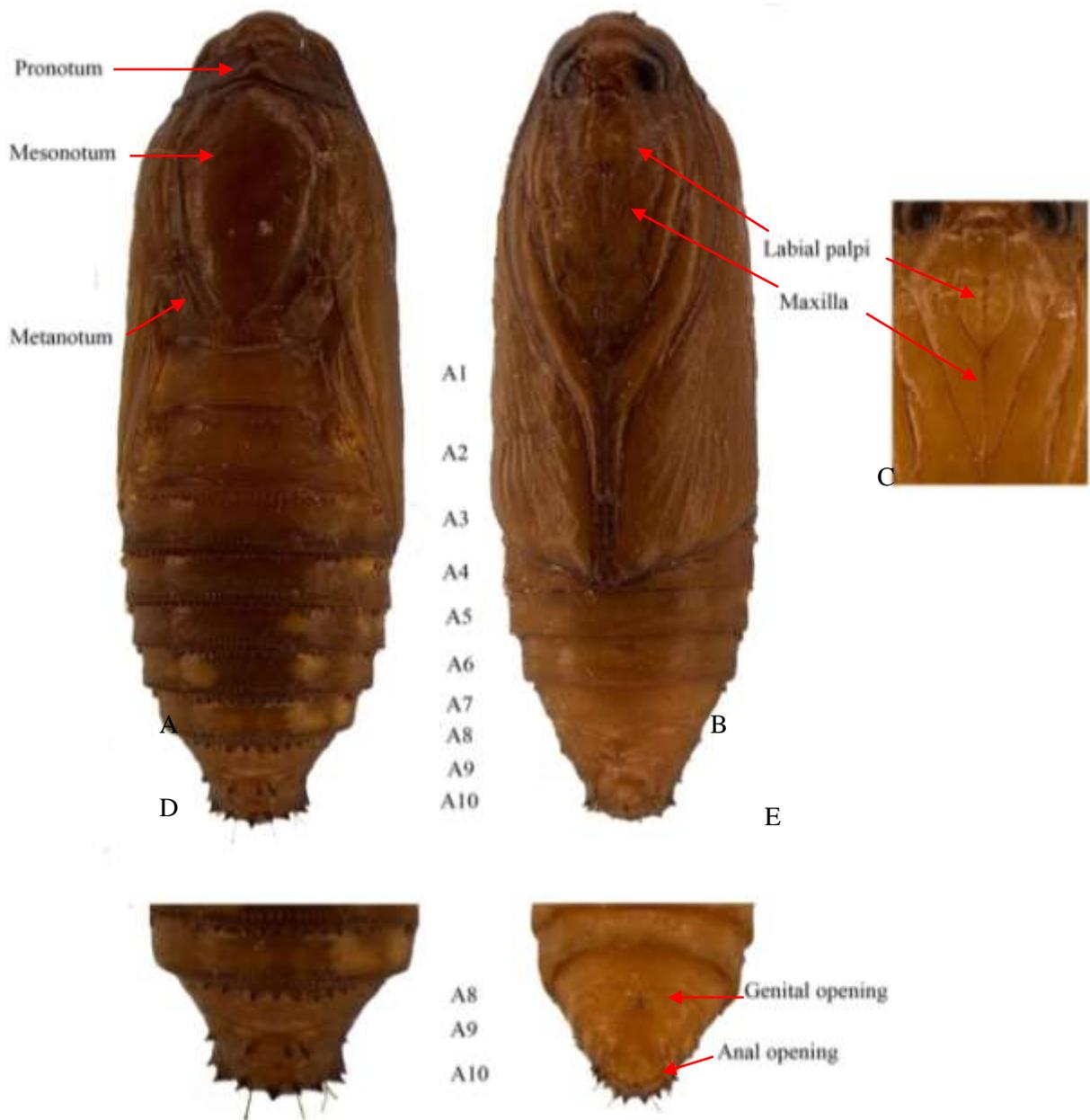
*Abdomen* (Figs 36 A-B, D-E). Spiracles oval, prominent. Setae positioned on lateral margin of ventral aspect: three to four setae on A4, one pair close to spiracle, single setae on medio-anterior to medial line, single seta sometimes concealed by hindwing. Seven setae on A5-A6, lateral group paired; one group of three, arranged in a triangular pattern, and two single setae; two outer setae longest. Six setae on A7, as for A5-A6, but group of three setae reduced to a pair. Lateral pair longest and two single setae shortest. Four setae on A8, as for A5-A6, except group of three setae absent; all setae of equal length. Three setae spaced evenly on medio-lateral line on A9. A10 with four pairs of thickened and distinct perianal and caudal setae. Anterior pair of setae, two on ventral side and two on dorsal side. Genital openings slit-like, ventromedially in females on A8, in males situated ventromedially on A9 with dome-like structures adjoining genital opening.

Dorsal aspect: A1 smooth without spines, single seta close to medial line. Double row of dorsal spines on A2-7, three single setae, one on the lateral margin and one close to medial line on anterior ridge, and single seta situated half way between lateral margin and medial line on posterior ridge. On A2 anterior row with fewer spines than other segments. On A4-A7 six to eight dorsal spines between anteromesad setae. A7 posterior row shorter than those on A2-A6. Spines increasing in size towards posterior abdominal segments. A8-A10 with single row of dorsal spines. Two pairs of setae on A8. A8 with 11-18 and A10 with 7-10 larger irregularly sized spines. A9 with three linear setae. One pair of perianal and one pair of caudal thickened curled setae.



**Figure 36:** *Cydia pomonella*. A. Dorsal view, B. Ventral view, C. Close up of maxilla and labial palpi, D. Dorsal view of A8-10, E. Male ventral view of A8-A10.





**Figure 37:** *Grapholita molesta*. A. Dorsal view, B. Ventral view, C. Close up of maxilla and labial palpi, D. Dorsal view of A8-10, E. Female ventral view of A8-A10.



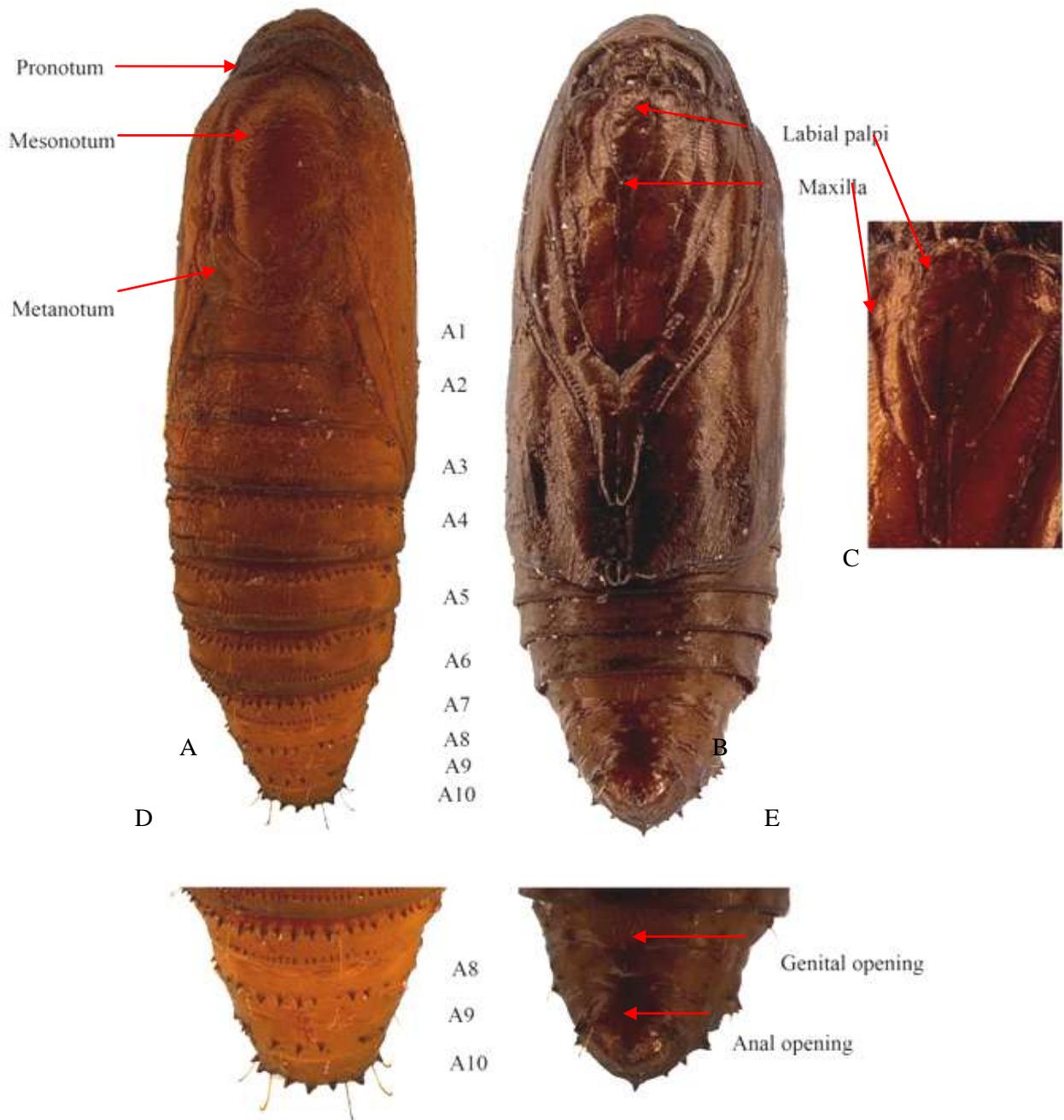


Figure 38: *Cryptophlebia peltastica*. A. Dorsal view, B. Ventral view, C. Close up of maxilla and labial palpi, D. Dorsal view of A8-10, E. Female ventral view of A8-A10.

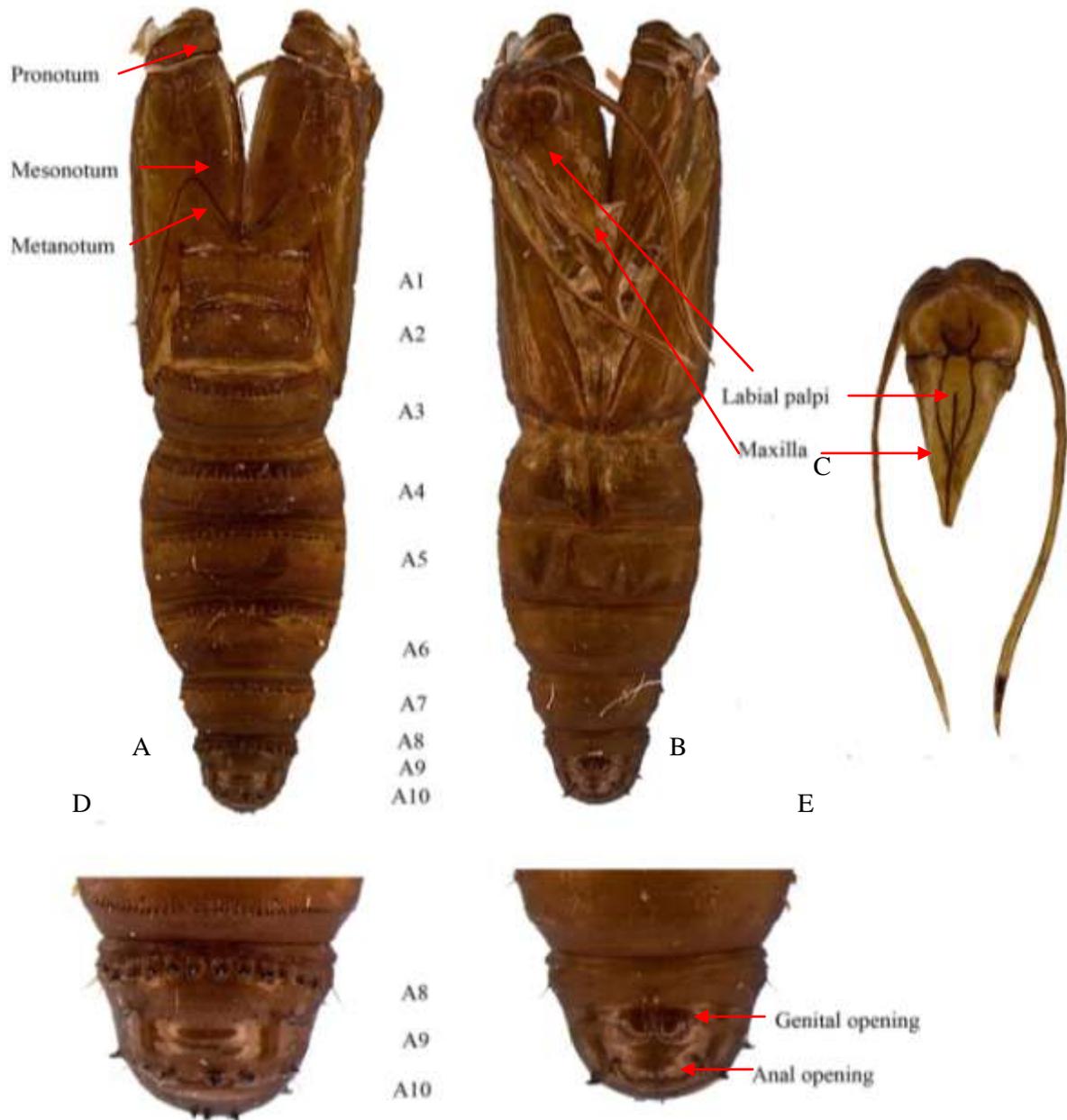
### 3.4.5 *Thaumatotibia batrachopa*

*Head* (Figs 39 A-C). Frontal region dark brown. Eyes darker and prominent in mature pupae. Two equally-sized medial pairs of setae on clypeus.

*Thorax* (Figs 39 A-B). Metatarsus extending beyond forewing. Hindwing concealed almost completely by forewing, extending only slightly at posterior edge. Two pairs of setae on pro- and mesonotum. On pronotum, one lateral pair near forewing and medial pair close to the mid-dorsal line. On mesonotum, one pair midway on alar furrow and one pair near mid-dorsal line. On metanotum, one pair of setae situated in anterior corners of the “M”-shaped hindwing.

*Abdomen* (Figs 39 A-B, D-E). Setae positioned as follows on lateral margin of ventral aspect: four setae on A4, one pair close to spiracle, and two single setae, one medio-anterior and one anterior. Seven setae on A5-A7, lateral group paired; one group of three, arranged in a triangular pattern, and two single setae. Four setae on A8, as for A5-A6, except group of three setae absent and all setae of similar length. Five setae on A8 and A9, two pairs, one lateral pair close to spiracle and one close to mid-ventral line, single setae between pairs. On A10, four pairs of spines, one pair lateral to anal pore, anterior spine larger. Posterior to anal pore: one medio-posterior pair and adjoining laterally two pairs of equal length.

Dorsal aspect, setae described as before (mirror image): A1 smooth, without spines, single setae close to medial line. Double row of dorsal spines on A2-7, three single setae, one on the lateral margin and one close to medial line on anterior ridge, and single seta situated half way between lateral margin and medial line on posterior ridge. A2 anterior row with spines reduced in number and size spines. Spines generally increasing in size on posterior abdominal segments except for A9, number and size reduced. A8 with a single row of dorsal spines, with approximately 10 spines irregularly sized with five setae, two pairs and single seta. A9 with about eight large irregularly shaped spines, with single seta anteromedial to spines. A10 with about four spines.



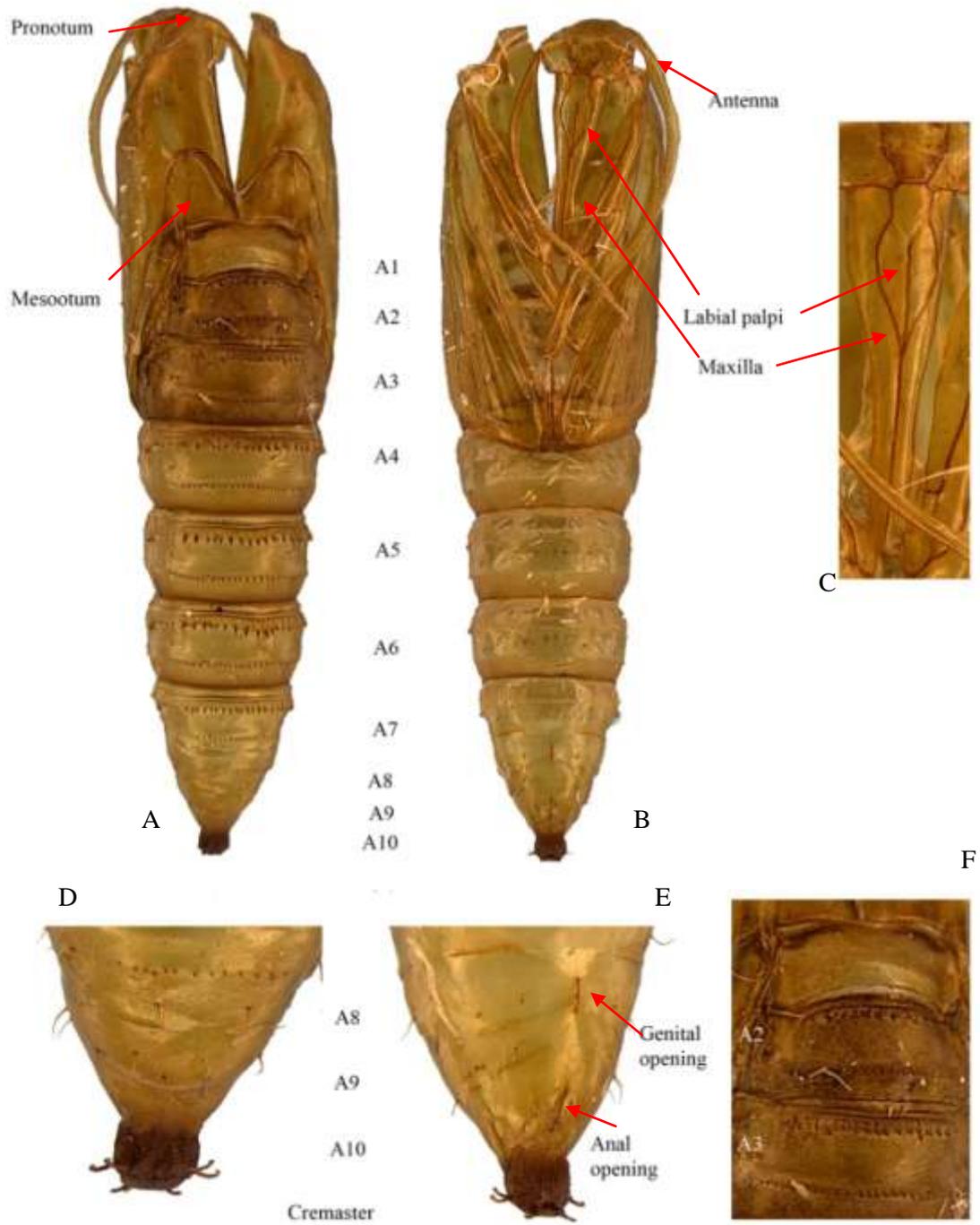
**Figure 39:** *Thaumatotibia batrachopa* A. Dorsal view, B. Ventral view, C. Close up of maxilla and labial palpi, D. Dorsal view of A8-10, E. Ventral view of A8-A10.

### 3.4.6 *Epichoristodes acerbella*

*Head* (Figs 40 A-C). Two medial pairs of setae on clypeus, inner pair slightly shorter than outer pair. Labial palpus short with a distinct concave bulge.

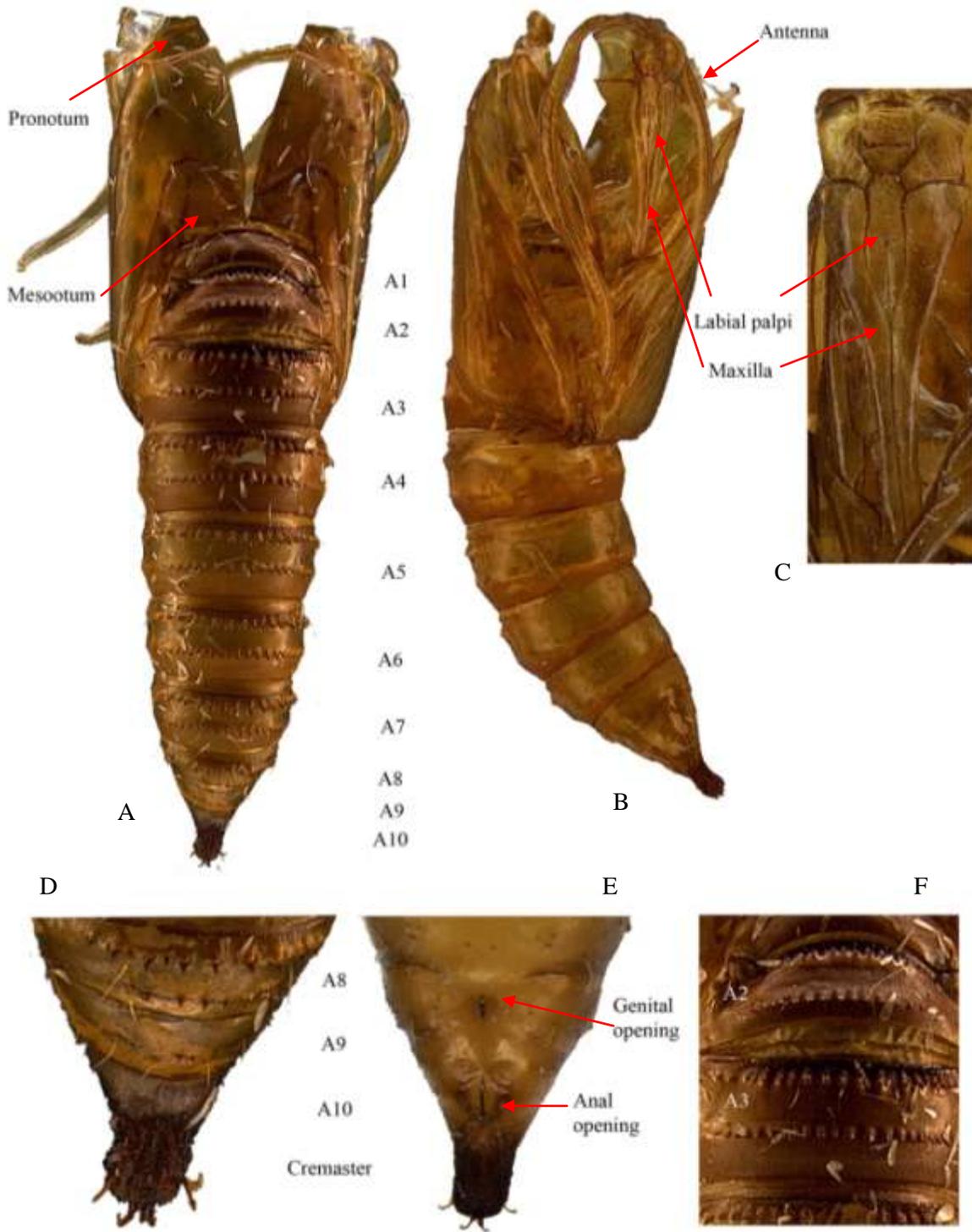
*Thorax* (Figs 40 A-B, F). Metatarsus in line with caudal margin of forewing. Hindwing concealed almost entirely by forewing, extending only slightly beyond it at posterior edge. Two pairs of setae on pro- and mesonotum. On pronotum, one lateral pair near forewing and medial pair close to the mid-dorsal line. On mesonotum, one pair midway on alar furrow and one pair near mid-dorsal line. On metanotum, one pair of setae situated in anterior corners of the “M”-shaped hindwing.

*Abdomen* (Figs 40 A-B, D-E). Distinct darker lateral line along spiracles. Setae positioned as follows on lateral margin of ventral aspect: two single setae on A4, one close to spiracle, the other medio-anterior to medial line. Seven setae on A5-A7, lateral group paired, one group of three, arranged in a triangular pattern, and two single setae. Five setae on A8 and A9, two pairs, one lateral pair close to spiracle and one close to mid-ventral line, single setae between pairs. Anal rise smooth. Genital openings slit-like, in males situated ventromedially on A9; in females on A8. Dorsal aspect, setae described as before (mirror image): A1 smooth, without spines, single setae close to medial line at border of the metanotum. Double row of dorsal spines on A2-A8, spines on anterior ridges facing posteriorly, posterior row of spines smaller than anterior row. On A2-A8, three single setae, one on the lateral margin and one close to medial line on anterior ridge, and single seta half way between lateral margin and medial line on posterior ridge. A2 anterior row with fewer spines than on other segments. Spines on A2 small, on A3-A7 large and equally sized, and on A8 very small, reduced in numbers. Anterior row A8 with 10-16 smaller spines and posterior row with zero to nine minute spines, both rows irregularly sized. A9-A10 smooth, without spines. A9 with three setae, one pair and a single seta close to medial line.



**Figure 40:** *Epichoristodes acerbella* A. Dorsal view, B. Ventral view, C. Close up of maxilla and labial palpi, D. Dorsal view of A8-10, E. Female ventral view of A8-A10. F. Dorsal view of A2-A3.





**Figure 41:** *Lozotaenia capensana* A. Dorsal view, B. Ventral view, C. Close up of maxilla and labial palpi, D. Dorsal view of A8-10, E. Female ventral view of A8-A10. F. Dorsal view of A2-A3.

### 3.5 Summary of literature and morphological study

A summary of characters abstracted from literature (see Appendix) (white boxes) and own morphological study (green boxes) is given in Table 5.



























































































### **Future investigations**

Further research should focus on obtaining details on the larval morphology of *L. capensana*. In terms of speciation of *T. leucotreta*, cross-mating trials and or more geometric morphometric analyses using different sections of the genitalia might be of benefit. *Epiphyas postvittana* and *Lobesia botrana* are of utmost concern to the South African fruit industry as potential invasive species and extensive monitoring for these two tortricids should be carried out and maintained.









