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Phorodon cannabis Passerini (Hemiptera: Aphididae), a newly recognized pest in North America found on industrial hemp

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Abstract. *Phorodon cannabis* Passerini (Hemiptera: Aphididae: Macrosiphini) is reported for the first time as a pest of *Cannabis* L. crops in North America. The insect has been confirmed from fields of industrial hemp in Colorado and Virginia and has been found present within greenhouses in at least several American states and one Canadian province. The generic position of the aphid species is discussed and other known members of the genus are ruled out. *Phorodon cannabis* is placed in genus *Phorodon* Passerini and subgenus (*Diphorodon* Börner). *Phorodon persifoliae* Shinji is transferred to *Hyalopterus* Koch as a *nomen dubium*.

Key words. *Cannabis*, Sternorrhyncha.

Introduction

North American cultivation of industrial hemp for ship rigging and other cordage dates to the Colonial period (Purvis 1999). However, interest and production of various species of *Cannabis* L. (Cannabaceae) (hemp, marijuana) crops in the United States has increased greatly in recent years, stimulated in large part by language in the 2014 Farm Bill that provided a means for legal production of industrial hemp and has been adopted in various forms by a majority of states. As production has increased and regulation changed, there are opportunities to better document the insects that are associated with these crops.

In Colorado, a state that has had extensive outdoor production of hemp since 2015, a widespread and potentially damaging species is *Phorodon cannabis* Passerini (Hemiptera: Aphididae), variously

known as the “cannabis aphid”, “hemp aphid”, or “bhang aphid” (McPartland et al. 2000; Anonymous 2017). Long known from central and southwest Asia, central and southern Europe, and North Africa (Blackman and Eastop 2006, 2018), where the host plants are native or have had long history of culture, *P. cannabis* only recently has been confirmed from North America (Halbert 2016).

This paper reports the aphid species as new to North America, rules out other species in the genus, discusses the generic placement, provides identification information, and reports the known distribution of the species in outdoor situations in Colorado and elsewhere in North America in greenhouses.

Materials and Methods

After the initial discovery of *P. cannabis*, field visits were expanded in 2017 to include an expanded survey of commercial hemp fields in eastern Colorado conducted in 2016–2017 by the first author. Specimens were preserved in ethanol and sent to the Florida Department of Agriculture and Consumer Services, Division of Plant Industry (DPI) (S. E. Halbert) for identification. Voucher specimens from this field survey are deposited at the Florida State Collection of Arthropods (FSCA) and at the National Aphidomorpha Collection, United States National Museum of Natural History (NMNH). A separate field collection of *P. cannabis* made on September 27, 2017 (K. E. Britt) from a hemp field in Blacksburg, Virginia was subsequently confirmed (G. L. Miller), and voucher specimens are deposited at NMNH. Additional specimens of greenhouse-collected material are deposited at the NMNH (confirmed by G. L. Miller) and the Ouellet-Robert Entomological Collection at the University of Montreal (QMOR). The cannabis aphid also has been observed on several occasions on indoor/greenhouse-grown *Cannabis* in Colorado, Oregon (Anonymous 2017), and Ontario, Canada (confirmed by C. Favret). Representative samples of natural enemies found associated with *P. cannabis* in Colorado will be deposited in the C.P. Gillette Museum of Arthropod Diversity at Colorado State University.

Our taxonomic identifications are based on comparisons of North American specimens from *Cannabis* and *Humulus* L. (Cannabaceae) in association with original descriptions and other relevant literature for all species of *Phorodon*. Our goal is to rule out other described species and to document efforts leading to our identification. Photographs of microscope slide-mounted specimens were taken using a Zeiss Axio Image.M1, line drawings were outlined using a camera lucida on a Nikon E600, and plates were constructed using GIMP 2.8.22.

Results and Discussion

Field observations. *Phorodon cannabis* has been observed in Colorado since 2015 when significant outdoor hemp production began in the state (Fig. 1). The original confirmed identification (Halbert 2016) consisted of aphids collected in September 2016 from a >20 ha hemp field located in Eaton, Colorado (Weld County). Subsequently, expanded surveys of hemp fields in 2017, including fifteen field sites, found it to be present in all eastern Colorado counties surveyed for this insect (Denver, Larimer, Otero, Pueblo, Weld). The common occurrence of the aphid on a crop that had little prior production suggests that *P. cannabis* can rapidly spread.

The observed incidence of *P. cannabis* in Colorado hemp fields during the past two years has varied considerably. In many fields the insect was rare, but extremely large populations of *P. cannabis* were observed in other fields during late August and September. Observations were consistent with the previously described life history of the species as monoecious on *Cannabis* and holocyclic (Blackman and Eastop 2006, 2018). In Germany, the overwintering eggs were laid on the lower stems of the plants in mid-October. Eggs also could be found in the seed heads (Müller and Karl 1976).

Although large numbers of the aphid were observed in hemp fields, accompanied by production of large amounts of honeydew, no obvious plant injury (e.g., wilting, yellowing) was apparent. The late-season outbreaks involved large, well-irrigated and well-established plants nearing maturity, conditions that favor plant tolerance of aphid injuries. Furthermore, numerous natural enemies have been observed with *P. cannabis* on hemp. These natural enemies were found to build populations that could effectively control the aphids present in the late-season outbreaks. Most important were

convergent lady beetle (*Hippodamia convergens* Guérin-Méneville) and multicolored Asian lady beetle (*Harmonia axyridis* (Pallas)) (Coleoptera: Coccinellidae), but at least four other lady beetle species were common in Colorado hemp fields. Three species of green lacewing (Neuroptera: Chrysopidae) were present, with *Chrysopa oculata* Say and *Chrysoperla plorabunda* (Fitch) the most common. Larvae of at least four species of hover fly (Diptera: Syrphidae) and *Aphidoletes aphidimyza* (Rondani) (Diptera: Cecidomyiidae) also were observed feeding on cannabis aphids in hemp fields. Parasitism by braconids (Hymenoptera: Braconidae) and entomopathogenic fungi has been observed but only infrequently. Numerous other generalist predators including the Hemiptera *Orius insidiosus* (Say) (Anthracoridae), *Nabis alternatus* Parshley (Nabidae), *Geocoris punctipes* (Say) (Geocoridae), and *Chlamydatus associatus* (Uhler) (Miridae), and undetermined species in the genera *Platypalpus* Macquart (Diptera: Hybotidae), and *Condylostylus* Bigot (Diptera: Dolichopodidae), are present in Colorado hemp and likely predaceous on *P. cannabis*.

Phorodon cannabis is one of two aphid species confirmed from indoor production in Colorado, the other being rice root aphid, *Rhopalosiphum rufiabdominale* (Sasaki) (unpublished observations by W.S. Cranshaw and S. E. Halbert). This latter species is known to be a pest on many plants grown in hydroponic cultivation.

Greenhouse-grown *Cannabis* is used for hemp cultivars grown as cloned transplants for later field production. In indoor production, absent natural enemies, *P. cannabis* has significantly greater potential to cause crop injury. In Ontario greenhouses, *P. cannabis* also has been exhibiting sexual reproduction with egg-laying in late December 2017 and early January 2018. Egg-laying began approximately four weeks after the greenhouses were switched from a 16/8 to a 12/12 light/dark day cycle. The change in photoperiod probably triggered the production of sexual forms.

Taxonomic information. Whenever an adventive aphid is found in North America, it is essential to determine its identity. To arrive at an identification, other species in the genus, sometimes obscure, must be ruled out. Unfortunately, sometimes original descriptions do not mention important diagnostic characters, or the available literature does not address all species. Thus, all the species must be evaluated using multiple characters from different resources. For future confirmation reference, we need to discuss the literature and characters that allowed us to exclude some species, leading to the conclusion this North American hemp aphid is *P. cannabis*.

The genus *Phorodon* includes seven valid species (Favret 2018) from the Palearctic and is characterized by protruding frontal tubercles, often with finger-like processes, especially on the apterae. Most species are associated with *Humulus* L. or *Cannabis*, and host-alternating species use species of *Prunus* L. (Rosaceae) as primary overwintering hosts (Blackman and Eastop 2018).

Phorodon cannabis Passerini (1860) (Fig. 2a–f; Fig. 3a–f) (cannabis aphid) is the only species placed in the subgenus *Diphorodon* Börner (1952), distinguished by flabellate setae on the body of apterous viviparae (Fig. 2f). On the alate viviparae, the flabellate character of the setae is less pronounced (Fig. 3f). *Diphorodon* was established originally as a subgenus of *Phorodon*. Heinze (1960) raised it to generic status. We have chosen to maintain Börner's (1952) original intent for *Diphorodon* to be a subgenus of *Phorodon*, due to its morphology and host plant relationships. Like most other members of the genus, it has processes on the antennal tubercles of the apterae and infests Cannabaceae during the summer growing season (Blackman and Eastop 2018).

Phorodon cannabis also has been placed in the genus *Paraphorodon* Tseng and Tao (e.g., Zhang et al. 1999). *Paraphorodon* was erected for *Paraphorodon omeishanensis* Tseng and Tao (1938), described from alatae on an unidentified species of *Rubus* L. in China. Eastop and Hille Ris Lambers (1976) synonymized *P. omeishanensis* with *P. cannabis*, which put *P. cannabis* in *Paraphorodon* as a subgenus of *Phorodon*, with *Diphorodon* as a junior synonym of *Paraphorodon*. However, Eastop and Blackman (2005) determined that *Paraphorodon omeishanensis* was a valid genus and species, which had the consequence of returning *P. cannabis* to the genus *Phorodon*, subgenus *Diphorodon* (Blackman and Eastop 2006, 2018).

Phorodon humuli (Schrank 1801) (Fig. 4a–f; Fig. 5a–f) is the hop aphid, adventive and widespread in North America at least since 1863 (Footitt et al. 2006). Apterous of *P. humuli* can be distinguished from those of *P. cannabis* by the absence of flabellate setae and by shorter setae on antennal segment III (Fig. 2b and 4b). This species is common and damaging on hops in North America, especially in the

Pacific Northwest and is not known from *Cannabis*. The aphids overwinter on *Prunus*, particularly ornamental purple leaf plum, *Prunus cerasifera* Ehrh (Rosaceae) (S. E. Halbert, personal observation).

Phorodon humulifoliae Tseng and Tao (1938) was described from specimens on *Humulus japonica* Siebold & Zucc. (Cannabaceae) in Chengdu, China. It can be separated from other species in the genus by its heavily sculptured integument and long, s-curved siphunculi. The original description says the setae are not pointed but it does not call them flabellate.

Phorodon japonensis Takahashi (1965) was described as a subspecies of *P. humuli*. The species is holocyclic, overwintering on *Prunus mume* Siebold & Zucc. It differs from *P. humuli* in having a shorter projection on the frontal tubercle of the aptera. The ratio of the lengths of the ultimate rostral segment and the second hind tarsal segment is larger in *P. japonensis* than in *P. humuli*. This aphid was treated at the species level by Zhang et al. (1999) and Blackman and Eastop (2006).

Phorodon lanzhouense Zhang et al. (1999) was described from five apterae on an unknown host. The process on the frontal tubercles is described as “rounded” but appears mostly lacking in the illustration. Zhang et al. (1999) state that *P. lanzhouense* most resembles *P. humulifoliae* but differs in the structure of the mesosternal furca (two parts connected in the middle like a thread, rather than a solid structure), has shorter caudal setae, and has slightly longer siphunculi relative to the length of the cauda. More work is needed to confirm the validity of this species and determine if it belongs in *Phorodon*.

Phorodon persifoliae Shinji (1922) was described from peach (*Prunus persica* (L.) Batsch) (Rosaceae) in Japan. The description mentions rhinaria on antennal segment III and a black head and thorax, indicating that the specimens were alate. The collection date is 30 May, suggesting that the aphid was described from spring migrants. The description indicates that the cauda and siphunculi are the same length, so this species cannot belong to *Phorodon*. In addition, the original specimens were yellowish green and covered in a waxy powder. Although the species was treated as valid by Eastop and Hille Ris Lambers (1976) and Remaudière and Remaudière (1997), Takahashi (1965) had previously proposed the species as a synonym of *Hyalopterus pruni* (Geoffroy). Given the host association and morphological description, we concur that the species is probably a member of *Hyalopterus* Koch. However, because the original description is based on alatae which at this time are not identifiable to species, it is currently impossible to place *P. persifoliae* in one of the valid species of the genus, *H. pruni* (Geoffroy), *H. arundiniformis* Gulamullah, or *H. amygdali* (Blanchard) (the first two are known to colonize peach). Regardless of which species with which *Phorodon persifoliae* may actually be synonymous, by the Principle of Priority (ICZN 1999), it would be considered the junior synonym of any of them. We here transfer *Phorodon persifoliae* to *Hyalopterus* in agreement with Takahashi (1965) but, per Favret et al. (2017) and pending an association with one of the three species of *Hyalopterus*, we consider it a *nomen dubium*.

Phorodon viburni Matsumura (1918) was collected from the underside of leaves of *Viburnum* sp. (Caprifoliaceae) at the Botanical Garden of the Agricultural College of Hokkaido in mid-July. Only alatae and alatoid nymphs were found. This species has not been found since the original description (Blackman and Eastop 2006). More study, and likely more collection records, are needed to determine the status of this species. The host relationship is unusual for *Phorodon*.

Based on the previously-discussed information, we can make an informed decision about the new North American species on hemp. The most widely used key to *Phorodon* species is in Blackman and Eastop (2006, 2018). It treats four of the species (*P. cannabis*, *P. humuli*, *P. humulifoliae*, and *P. japonensis*) on *Humulus*. The flabellate setae on the North American apterae will eliminate *P. humuli*, *P. humulifoliae*, and *P. japonensis*. *Phorodon lanzhouense* can be eliminated because it lacks finger-like processes on the antennal tubercles of the apterae (Zhang et al. 1999). *Phorodon viburni* can be eliminated because the description says that the antennae of alatae are longer than the body, with 12 small rhinaria on the outer side (Matsumura 1918). The antennae of the North American hemp aphid are slightly shorter than the body (antenna is 0.89 times body length; range: 0.80-0.95; n=11), and they have many more than 12 rhinaria (average 22; range: 18-28; n = 14), scattered around the circumference of the segment. Moreover, *P. viburni* was described from alatae on *Viburnum*, presumably a primary host. The aphids present on North American hemp are holocyclic on the crop. Finally, *P. persifoliae* can be eliminated because its cauda and siphunculi are the same length. Moreover, the North American hemp aphids do not host alternate, so forms on *Prunus* probably can be ruled out safely. Thus, our newly adventive aphid on hemp is *P. cannabis*.

Only two species of *Phorodon* are known to occur in North America, *P. humuli* (Fig. 4 and 5) on hops, and *P. cannabis* (Fig. 2 and 3) on hemp. The host associations and the presence (*P. cannabis*) or absence (*P. humuli*) of flabellate setae on the body should easily separate the apterae of these species. However, differences in shape of the siphunculi, and the shape of antennal projections also are diagnostic. The siphunculi of *P. cannabis* are slightly swollen, whereas the siphunculi of *P. humuli* are straight; the antennal projections on *P. humuli* apterae are more robust than those on *P. cannabis* apterae (Fig. 2 and 4). Although *P. cannabis* is listed in the key to aphids on hops in Blackman and Eastop (2018), there is no reference to *P. humuli* on *Cannabis*. The alatae of the two species are more difficult to separate because the setae are less flabellate in alate *P. cannabis* compared to the apterae.

A more readily observable character is needed for sorting alatae without host associations, such as those found in trap samples. We suggest using the relative lengths of the siphunculi and antennal segment III. In *P. humuli*, antennal segment III is 1.25 times (range: 1.09–1.45; $n = 14$) longer than the siphunculi, whereas in *P. cannabis*, antennal segment III is only 0.83 times the length of the siphunculi (range: 0.74–0.96; $n = 14$). The caudal length of alate *P. humuli* is 0.51 times (range: 0.43–0.57; $n = 11$) the length of antennal segment IV; in *P. cannabis*, caudal length is 0.75 times (range: 0.63–1.00; $n = 14$) antennal segment IV. Additionally, the central dorsal markings usually consist of a central patch on segments IV–VI in *P. humuli* and tend to be more extensive in *P. cannabis*, comprised of broad stripes on segments IV–VII (Fig. 2). However, the extent of the central patch of *P. humuli* can be variable.

A full taxonomic revision, including examination of primary types, is needed to determine the status of several of the species currently assigned to *Phorodon*. That task awaits further study and is beyond the scope of this paper.

Discussion. *Phorodon cannabis* is monoecious on *Cannabis*. The plant is grown as an annual, maturing in autumn, and does not survive through winter. Müller and Karl (1976) stated that a prerequisite for *P. cannabis* to survive successfully between seasons in Central Europe required live hemp plants in close proximity to wintering eggs laid on the previous crop at the beginning of the growing season. Such conditions plausibly could occur in some situations where volunteer plants are present by early spring. With hemp cultivars now grown for seed production, many seed heads shatter before harvest, and the seeds have been observed to germinate in late winter or early spring in Colorado. The plant has a fairly high cold tolerance, and some volunteer seedlings may be present when eggs laid on debris of the previous crop hatch. If eggs are laid on maturing stems, and fields remain unplowed, fundatrices that hatch from eggs could colonize the early-germinated seedlings. Where feral hemp is present, it may provide sites for successful overwintering of eggs. The site history of the infestation found at Blacksburg, Virginia suggests feral hemp to have been the likely original source of *P. cannabis*.

Another likely source of many field infestations is indoor-grown transplants that are produced in the absence of natural enemies. Now the majority of hemp produced in Colorado involves use of all-female clones from greenhouse-produced transplants. In this system there is no seed production and, subsequently, volunteer plants are absent. All three hemp fields where outbreaks of *P. cannabis* were observed in 2017 were produced from transplants in fields free of volunteer hemp. The present extensive use and transport of cloned plants in many hemp production systems affords a means for *P. cannabis* to survive year-round and to spread with human assistance.

Final comments. The 2016 record (Halbert 2016) seems to be the first formal confirmation of the presence of *P. cannabis* in North America, although McPartland et al. (2000) made passing reference that it “now lives in North America”. In this regard, it may be notable that *P. cannabis* (or any other aphid) was absent from Lago and Stanford’s (1989) insect inventory of outdoor-grown marijuana in Mississippi. However, the widespread occurrence of *P. cannabis* in Colorado and its recently reported discovery on both coasts and in Canada suggest that the species now is likely present in many areas of North America, at least in areas associated with some indoor production of host plants.

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Figure 1. *Phorodon cannabis* Passerini. **a)** Apteræ with color form exhibited indoors and outdoors through midsummer. Photograph taken on August 4, 2017. **b)** Hemp leaf heavily infested with *P. cannabis*. Photograph taken on September 11, 2017. **c)** Mixed stages, including alate forms. Photograph taken on August 28, 2017. **d)** Aphids developing on stem of hemp. Photograph taken on September 31, 2017.

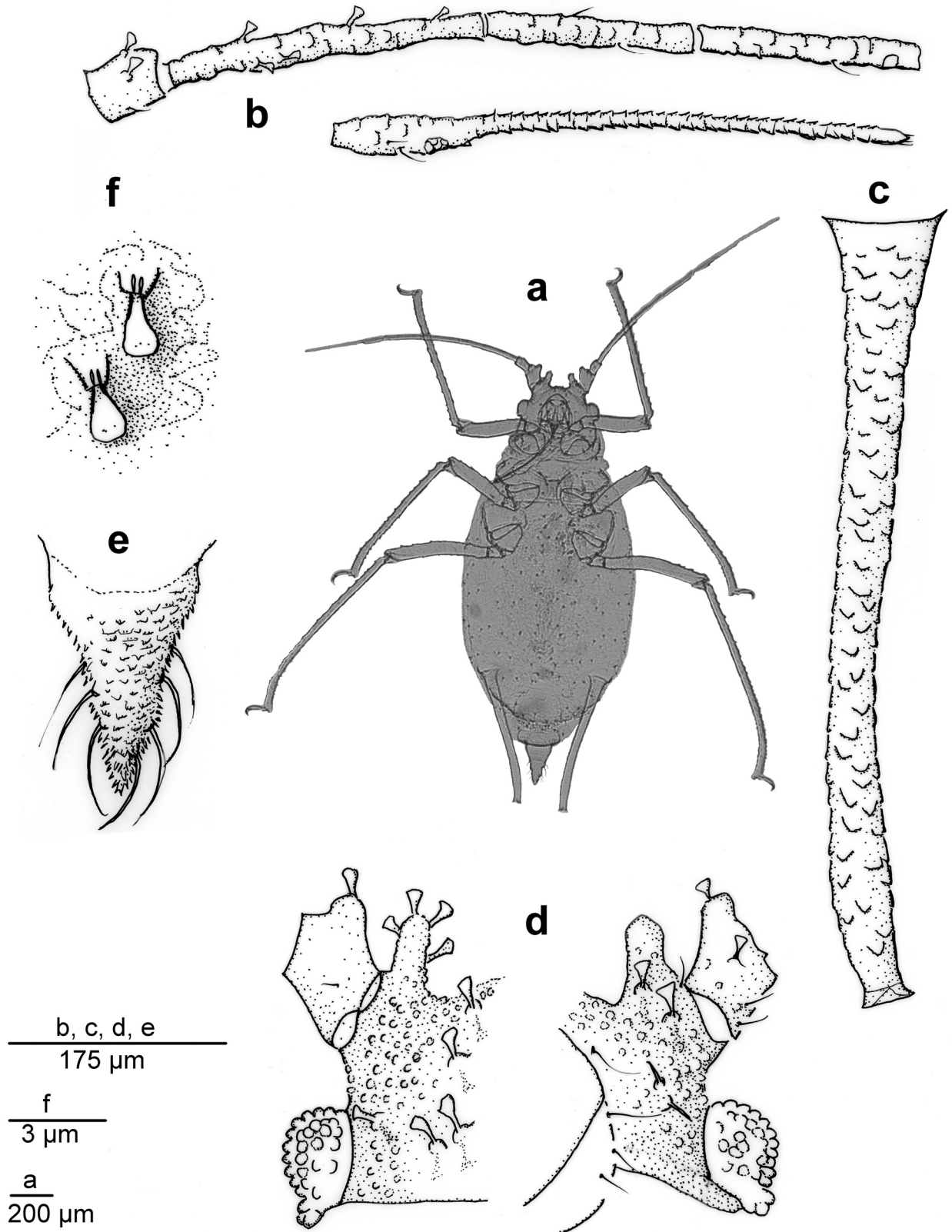


Figure 2. *Phorodon cannabis* Passerini. **a)** Apterous vivipara photomicrograph. **b)** Antennal segments II–VI. **c)** Siphunculus. **d)** Head and antennal segment I (left side dorsum; right side venter). **e)** Cauda dorsum. **f)** Enlargement of dorsal abdominal spatulate setae.

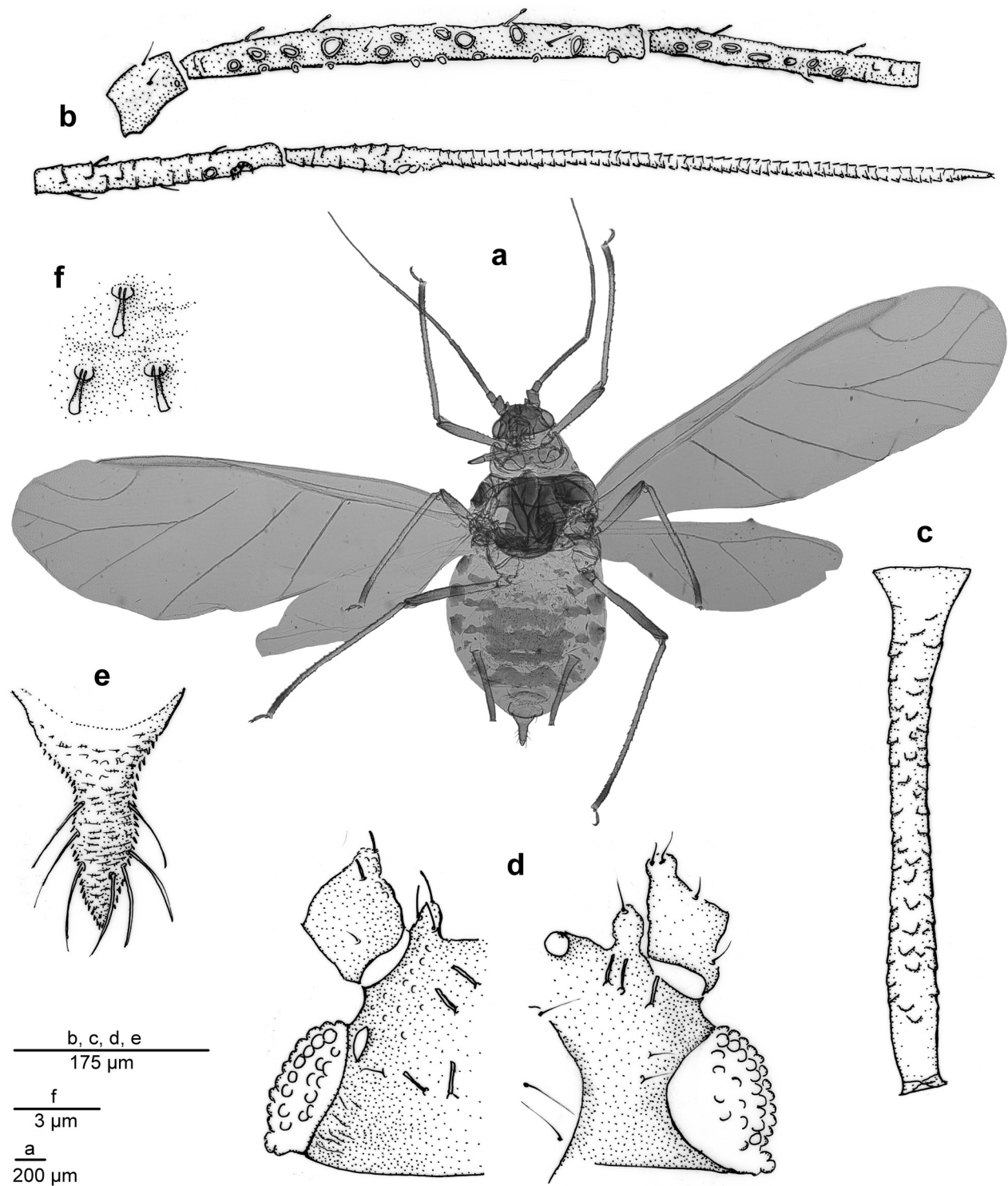


Figure 3. *Phorodon cannabis* Passerini. **a)** Alate vivipara photomicrograph. **b)** Antennal segments II-VI. **c)** Siphunculus. **d)** Head and antennal segment I (left side dorsum; right side venter). **e)** Cauda dorsum. **f)** Enlargement of dorsal abdominal spatulate setae.

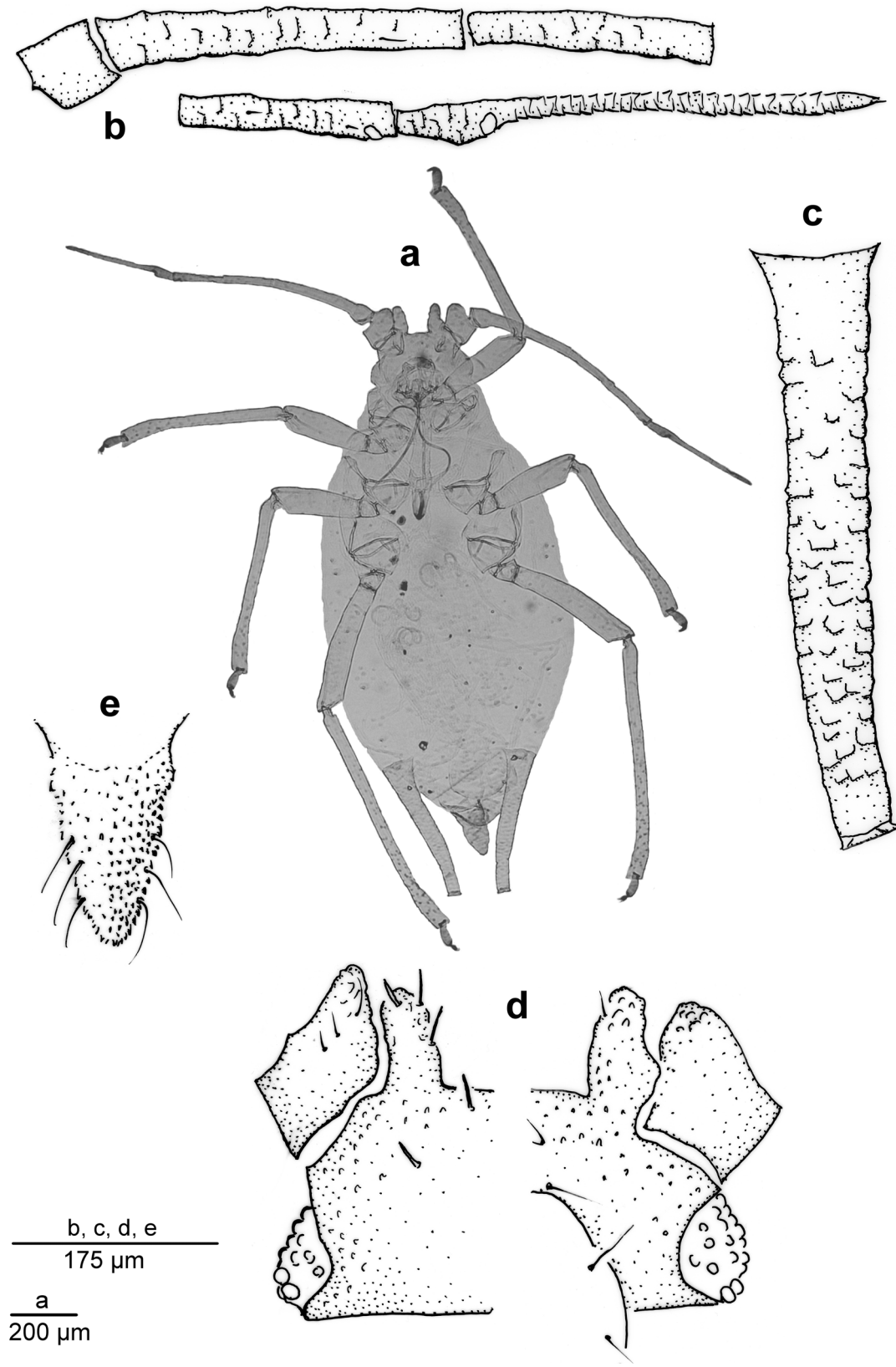


Figure 4. *Phorodon humuli* (Schrank). **a)** Apterous vivipara photomicrograph. **b)** Antennal segments II–VI. **c)** Siphunculus. **d)** Head and antennal segment I (left side dorsum; right side venter). **e)** Cauda dorsum.

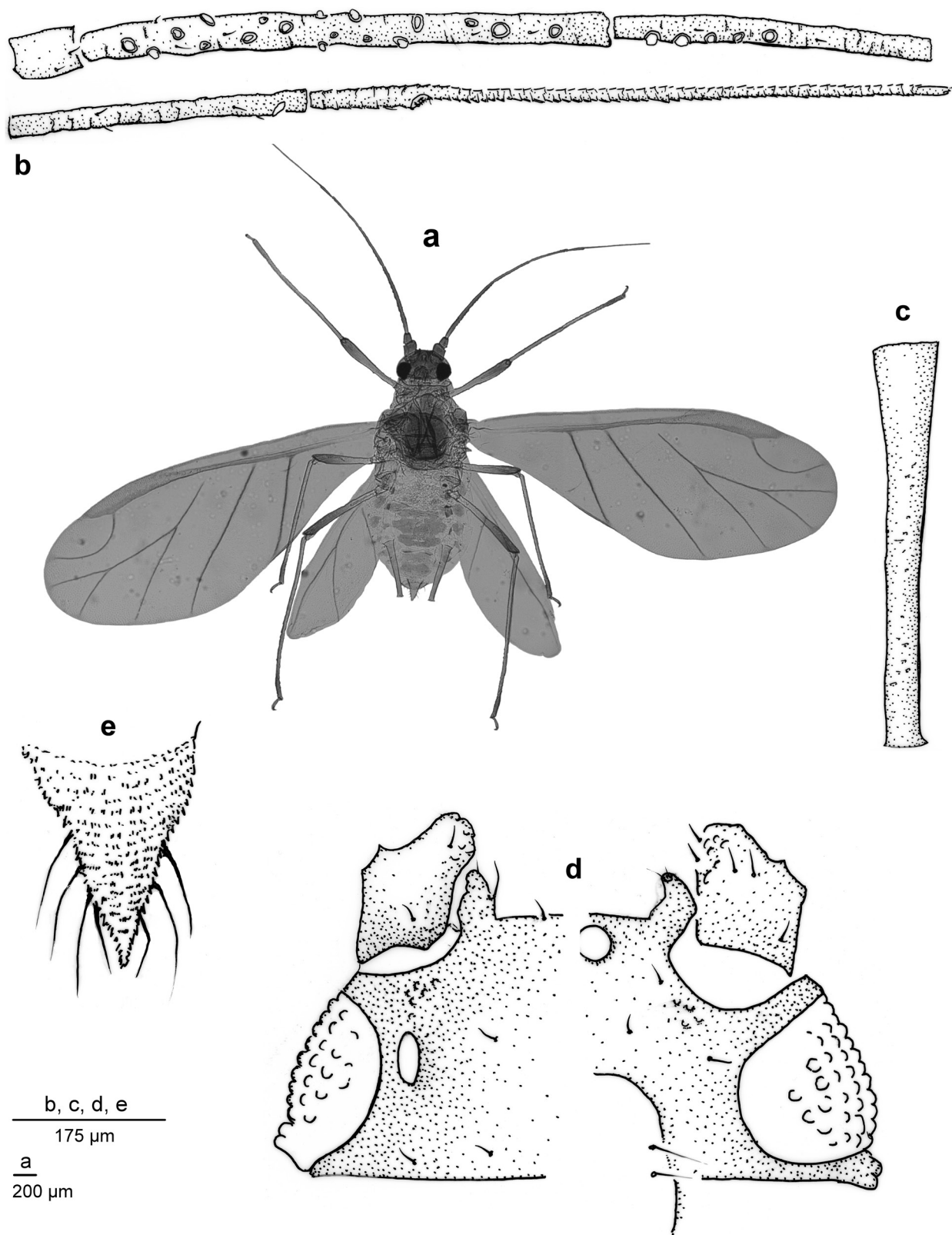


Figure 5. *Phorodon humuli* (Schrank). **a)** Alate vivipara photomicrograph. **b)** Antennal segments II–VI. **c)** Siphunculus. **d)** Head and antennal segment I (left side dorsum; right side venter). **e)** Cauda dorsum.