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Description of the previously unknown sexual morphs of *Eucarazzia elegans* from Iran and Pakistan and the northernmost record of viviparous generation from Europe

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Abstract

The previously unknown morphs of the *Eucarazzia elegans* (Ferrari) (Hemiptera, Aphididae, Aphidinae, Macrosiphini) - the oviparous females, the apterous and alate males are described and illustrated, based on specimens collected in Iran and Pakistan. The first record of viviparous generation of *E. elegans*, collected in south Poland, which is the northernmost European record of the species, is also provided. Because *E. elegans* is a significant species associated with numerous aromatic herbs of economic importance, its distributional data is updated and ways that it is spread are discussed.

Key words: aphids, aromatic herbs, distribution, *Lavandula angustifolia*, sexuales.

Introduction

The Macrosiphini tribe (Hemiptera, Aphididae, Aphidinae) is the predominant group of aphids on herbaceous plants, comprising about 60% of the currently described aphid taxa, including many important pest species (Blackman and Eastop, 2000; 2018). Among them, *Eucarazzia elegans* (Ferrari), belonging to the monotypic genus *Eucarazzia* Del Guercio, is mostly associated with numerous aromatic herbs that are of economic importance belonging to Lamiaceae (or Labiatae), such as lavender (*Lavandula*), balm (*Melissa*), mint (*Mentha*), catmint (*Nepeta*), oregano (*Origanum*), sage (*Salvia*) or thyme (*Thymus*). The species, which is Mediterranean in origin, is now widely distributed outside its native area and has demonstrated the capacity to spread readily (Blackman and Eastop, 2018).

Eucarazzia is a very distinctive genus among other Macrosiphini. In particular, its alatae have extensive black dorsal abdominal markings, which comprise a large transverse patch across abdominal tergites IV and V, linking with large marginal sclerites on abdominal tergites V and VI. They also have fore wings that are pigmented with dark triangular spots at the ends of all of the veins. Both apterous and alate females have large, markedly swollen siphunculi with a swollen part dark and a cylindrical basal part that is paler in the alatae and entirely pale in apterae (Blackman, 2010). The life cycle of this quite common species is unknown as only the viviparous generation (apterous and alate females) has been described. Naumann-Etienne and Remaudière (1995) reported the existence of sexual morphs (oviparous females and apterous males) in Iran on *Nepeta* sp.; however, they have not been described up to date.

While working in the Aphididae collection in the Museum national d'Histoire naturelle in Paris (MNHN), France, specimens of undescribed sexual morphs of *E. elegans*, collected in Iran, were found. Moreover, undescribed alate males of this species, collected in Pakistan, were also found and descriptions of these morphs are presented in this paper. This study also provides the first record of viviparous generation of *E. elegans* in Poland, which is the northernmost European record of the species.

Materials and methods

Taxonomical study

Material examined. Iran, Fachand, 2000 m a.s.l. 4.XI.1955, 8 oviparous females, 7 apterous males, from *Nepeta* sp., (Remaudière leg.) MNHN (EH) 22395 and 24145-24147. Pakistan, Usho, 31.X.1985, 1 alate male, (Devaux leg.) MNHN (EH) 24330, Pakistan, Usho, 23.X.1986, 1 alate male, (Devaux leg.) MNHN (EH) 24326, Pakistan, Kalam, 23.X.1986, 1 alate male, (Devaux leg.) MNHN (EH) 24327, Pakistan, Kalam, 30.X.1986, 1 alate male, (Devaux leg.) MNHN (EH) 24329, Pakistan, Matiltan, 30.X.1986, 1 alate male, (Devaux leg.) MNHN (EH) 24328. Collection of the Muséum national d'Histoire naturelle, Paris, France (MNHN).

The morphological characters were examined using a Nikon Ni-U light microscope equipped with a phase contrast system. Pictures of the slide-mounted specimens and their measurements were taken with NIS-Elements D 4.50.00 64-Bit of a Nikon SMZ 25 stereoscopic microscope. The drawings of the morphological details were done freehand on a Nikon Ni-U light microscope using a camera lucida. Measurements are given in millimetres (table 1). For each drawing, a magnified view is provided. The terminology of the male genitalia follows Wieczorek *et al.*, 2011.

Field study - sampling procedure and species identification

Living specimens of a viviparous generation of *E. elegans* were collected from May to July 2018 on *Lavandula angustifolia* Miller (Katowice, Poland, 50°15'N 19°01'E). The aphids were collected directly from the host plants using a fine hairbrush and placed into Eppendorf tubes containing 70% ethanol. The location,

Table 1. Measurements (in mm) of oviparous females and apterous and alate males of *E. elegans*.

	Oviparous female	Apterous male	Alate male
Number of specimens	8	7	5
Body length	1.52-1.68	1.26-1.46	1.50-1.81
Maximal width of body	0.87-0.96	0.67-0.74	0.53-0.54
Head width across compound eyes	0.32-0.35	0.30-0.32	0.32-0.33
Length of antennae	1.69-1.75	1.38-1.65	2.11-2.26
Length of antennal segment III	0.42-0.49	0.43-0.47	0.53-0.57
Length of antennal segment IV	0.29-0.35	0.26-0.30	0.34-0.42
Length of antennal segment V	0.23-0.30	0.21-0.29	0.29-0.38
Length of antennal segment VIa base	0.11-0.13	0.09-0.13	0.14-0.20
Length of antennal segment VIb process terminalis	0.33-0.40	0.35-0.40	0.52-0.57
Length of rostrum	0.42-0.47	0.43-0.50	0.47-0.51
Length of apical segment of rostrum	0.10-0.11	0.09-0.11	0.12-0.17
Length of hind femora	0.49-0.64	0.56-0.61	0.61-0.76
Length of hind tibiae	0.88-0.92	0.86-0.97	1.03-1.26
Length of hind tarsi segment I	0.01-0.02	0.02-0.03	0.01-0.02
Length of hind tarsi segment II	0.07-0.10	0.08-0.10	0.09-0.11
Length of siphunculi	0.41-0.45	0.33-0.36	0.44-0.51
Maximal width of siphunculi	0.10-0.15	0.09-0.10	0.07-0.10
Length of cauda	0.09-0.15	0.05-0.08	0.11-0.12

sampling date and host plant name were recorded on the labels, which were placed on the tubes. Adult apterous or alate females were slide mounted using the method of Kanturski and Wieczorek (2012). The slides were examined using a Nikon Ni-U light microscope equipped with a phase contrast system. Samples were identified by K. Wieczorek based on their morphological diagnostic features using the standard literature-based keys (Blackman, 2010; Blackman and Eastop, 2006; 2018). Voucher specimens were deposited in the collection of the Department of Zoology, University of Silesia, Katowice, Poland (DZUS):

DZUS 20/5.18_150 *Eucarazzia elegans*, one alate viviparous female, one apterous viviparous female, Katowice, Poland, 20.V.2018, *Lavandula angustifolia*, K. Wieczorek leg.; DZUS 29/6.18_151 *Eucarazzia elegans*, one alate viviparous female, one apterous viviparous female, Katowice, Poland, 29.VI.2018, *Lavandula angustifolia*, K. Wieczorek leg.

Field photographs were taken using an iPhone 7 camera with the OlloClip Macro Pro Lens Set. The Figures were prepared using Corel Draw 17.1.0.572, 2014 Corel Corporation.

Results

Description of oviparous female (from 8 specimens) (figures 1a, 2a-e; table 1)

Colour of live specimens - unknown. Colour of mounted specimens: pale with apices of antennal segments (ant. segm.) III-V, antennal VI base, knee area and subgenital plate dusky (figure 1a). Body egg-shaped. Frons flat. Dorsal head chaetotaxy: 6 pairs of short, robust and pointed setae. Antennae 6-segmented (figure 2a), 1.04-1.11 times body length. Ant. segm. V-VI imbricated. Ant. segm. III longest, ant. segm. IV and V of similar length. Ant. segm. III with 9-15, ant. segm. IV with 8-10 rounded secondary rhinaria. Ant. segm. V with 0-2 secondary rhinaria and 1 primary rhinarium. Processus terminalis (VIb) 3.00-3.10 times base (VIa), with one rounded and ciliated rhinarium and 2-7 accessory rhinaria. Other antennal ratios: VI:III 0.69-0.71, V:III 0.55-0.61, IV:III 1.05-1.08. Antennal chaetotaxy: segm. I with 3 setae, segm. II with 3-4 setae, segm. III with 13-16 setae, segm. IV with 6-7 setae, segm. V with 5-7 setae. Ant. segm. VI with 2 basal and 3 apical setae. Antennal setae robust with slightly flattened apices, 0.01-0.02 mm long; the longest antennal seta III of similar length of basal articular diameter of this segment. Rostrum short, reaching segment III of thorax, apical segment of rostrum (ARS) long and pointed, with 6 pairs of accessory setae (figure 2b). ARS 0.24-0.22 times ant. segm. III and 0.11-0.12 times segment II of hind tarsus (HT II). Hind tibiae (figure 2c) slightly swollen in the proximal part, with 11-29 circular or irregular pseudosensoria, situated on the whole proximal and middle part of tibiae. First tarsal chaetotaxy 3:3:3. Abdomen without sclerites, slightly reticulated. Dorsal setae very few, pale, with flattened apices, 0.02-0.04 mm long. Siphunculi with distinctive smooth, large swollen in medial part and corrugated surface in basal and distal part, with 1-2 rows of reticulation below flange (figure 2d). Cauda short, triangular with 4 long and pointed setae and 2 short ones (figure 2e). Subgenital plate very well developed, sclerotized with fine and pointed setae.

Description of apterous male (from 7 specimens) (figures 1b, 3a-e; table 1)

Colour of live specimens - unknown. Colour of mounted specimens: head dark brown. Antennae light brown with ant. segm. I, II, apices of ant. segm. III-V and base dark brown. Legs light brown with knee area and distal part of tibiae dark brown. Thorax and abdomen pale with rostrum, dorsal scleroites and siphunculi

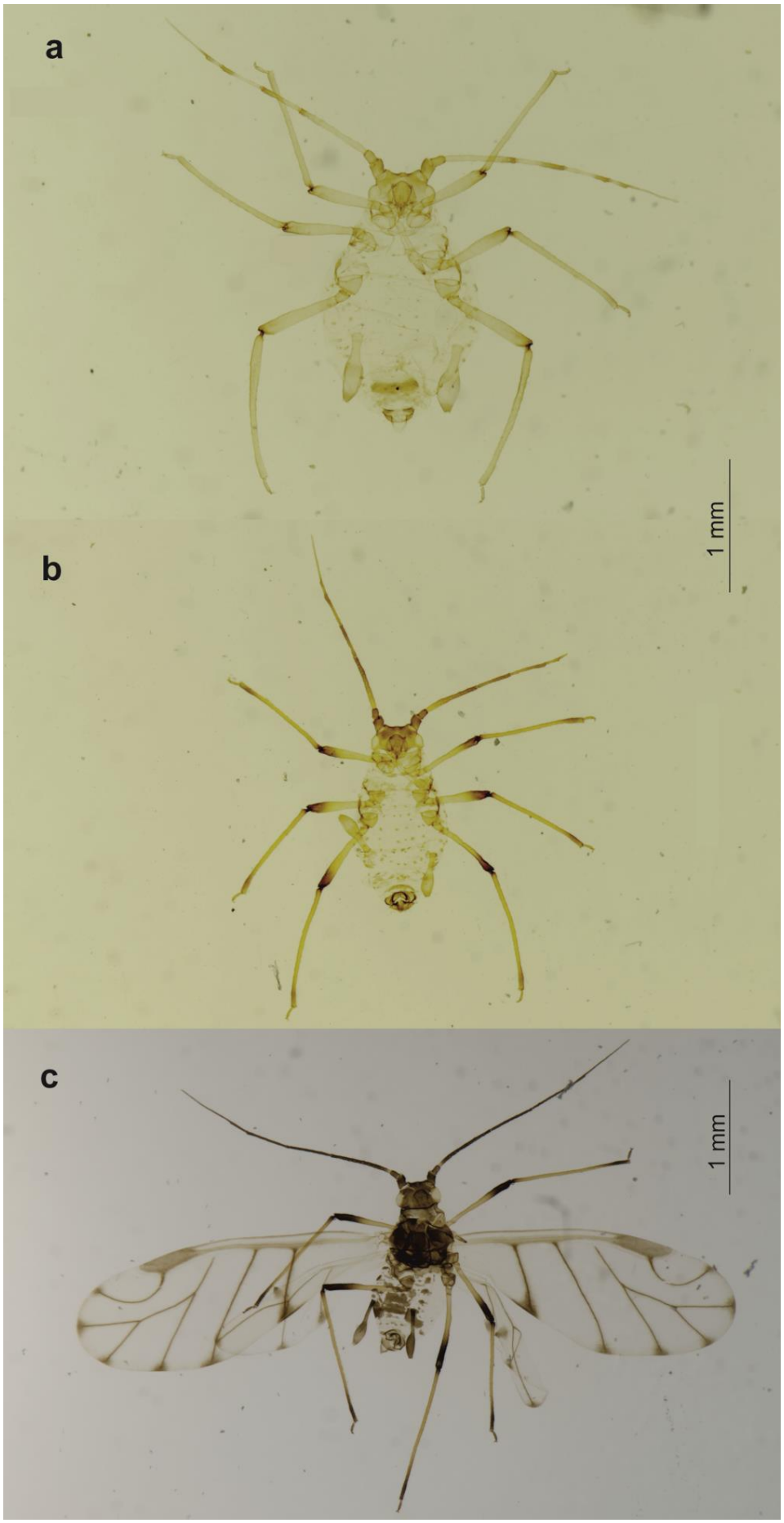

Figure 1. *E. elegans* slide-mounted specimen: **(a)** oviparous female, **(b)** apterous male, **(c)** alate male.

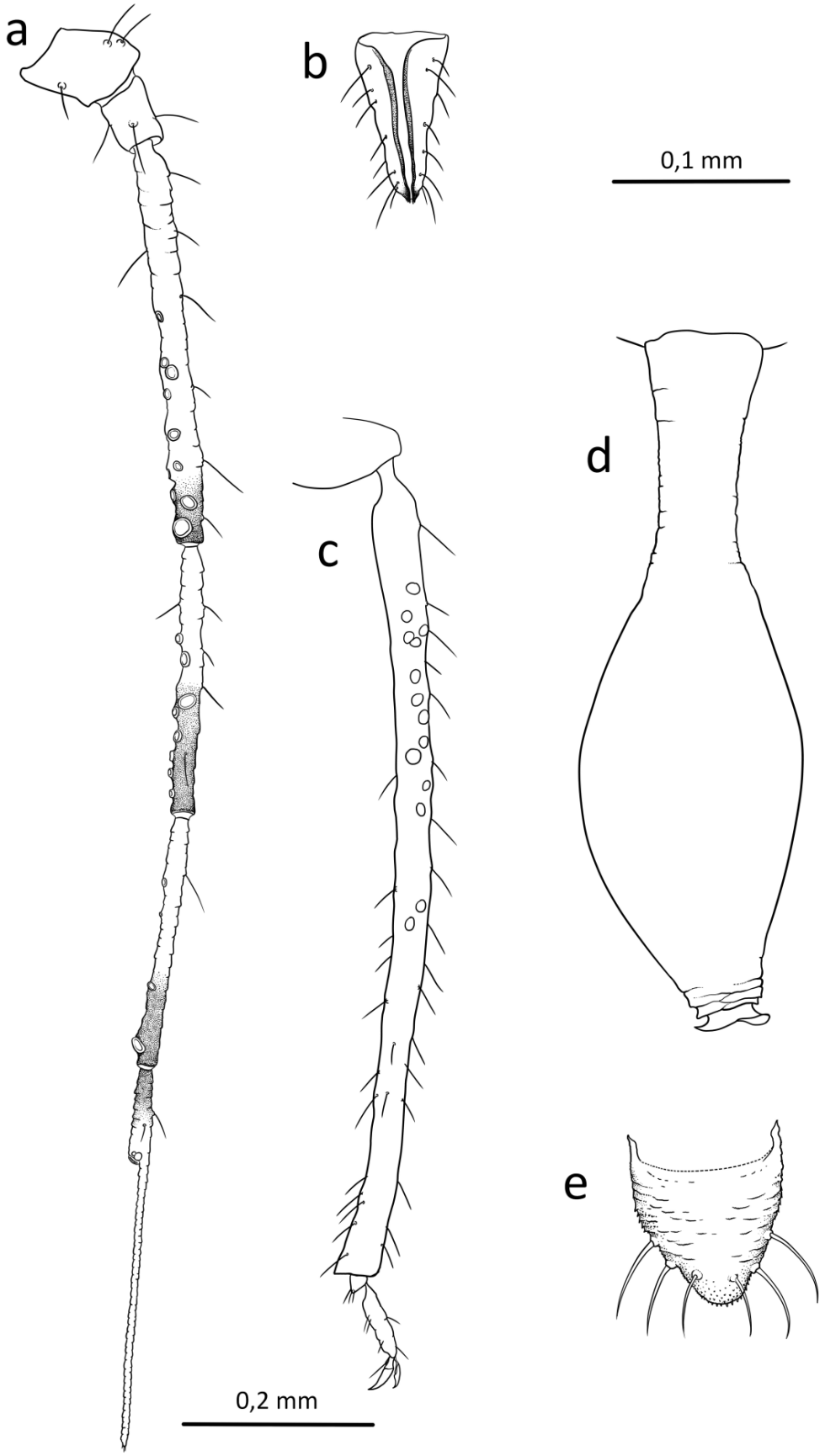

Figure 2. *E. elegans* oviparous female-morphological characters: **(a)** antenna, **(b)** apical segment of the rostrum, **(c)** hind tibia and tarsus, **(d)** siphunculus, **(e)** cauda.

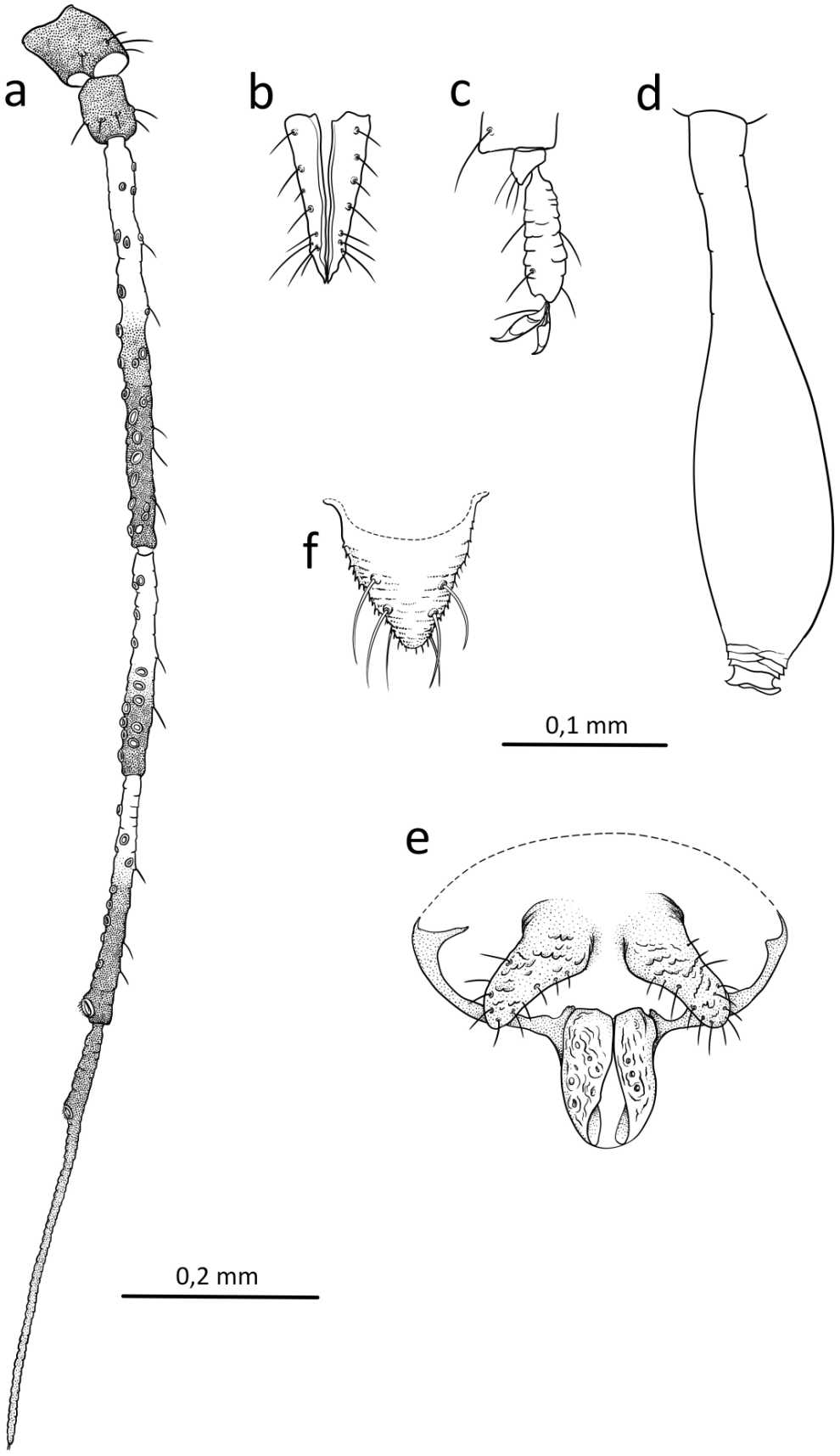

Figure 3. *E. elegans* apterous male-morphological characters: **(a)** antenna, **(b)** apical segment of the rostrum, **(c)** hind tarsus, **(d)** siphunculus, **(e)** genitalia, **(f)** cauda.

light brown. Genitalia and cauda dark brown (figure 1b). Body egg-shaped. Frons flat. Dorsal head chaetotaxy: 6 pairs of short, robust and pointed setae. Antennae 6-segmented (figure 3a), 1.09-1.13 times body length. Ant. segm. VI-VI imbricated. Ant. segm. III longest, slightly narrower at base, with 19-23 rounded secondary rhinaria of variable size with sclerotic ring, distributed mostly on 2/3 length of the segment. Ant. segm. IV and V of similar length. Ant. segm. IV and V with 10-14 and 7-9 secondary rhinaria respectively, similar to those on ant. segm. III. Ant. segm. V with 1 rounded and ciliated primary rhinarium. VIb 3.08-3.89 times VIa; other antennal ratios: V:III 0.49-0.62, IV:III 0.60-0.64. Antennal chaetotaxy: segm. I with 2-5 setae, segm. II with 4-5 setae (in one row in middle of segment), segm. III with 5-8 setae, segm. IV with 4-5 setae, segm. V with 2-6 setae, segm. VI with 2 basal and 3-4 apical setae. Antennal setae pointed, robust, 0.01-0.02 mm long; the longest antennal seta III of similar length of basal articular diameter of this segment. Rostrum short, reaching segment III of thorax, ARS long and pointed, with 6 pairs of accessory setae (figure 3b). ARS 0.21-0.23 times ant. segm. III and 1.13-1.10 times HT II. First tarsal chaetotaxy 3:3:(2)3 (figure 3c). Abdomen with slightly visible reticulation. Dorsal side of abdomen covered with small, rounded sclerites in spinal, pleural and marginal position. Dorsal setae arising from these sclerites are pale, robust, pointed, very short; longest 0.02-0.04 mm long on last abdominal segment. Siphunculi smooth, with distinctive large swollen in medial part with 2-3 rows of reticulation below flange (figure 3d). Cauda short, triangular, with 2-4 long and pointed setae and short and pointed spinules (figure 3f). Genitalia well developed, strongly sclerotized with lobate parameres covered by numerous spine-like setae. Basal parts of phallus shortened, hooked-shaped with numerous setae (figure 3e).

Description of alate male (from 5 specimens) (figures 1c, 4a-g; table 1)

Colour of live specimens - unknown. Colour of mounted specimens: body pale with head, antennae (with exception of basal part of segm. III which is light brown), thorax, dorsal sclerites, genitalia brown. Legs light brown with knee area dark brown and distal part of tibiae and tarsi brown. Siphunculi brown with basal part dark brown. Cauda light brown (figure 1c). Body elongate. Frons flat. Dorsal head chaetotaxy: 4 pairs of short, robust and pointed setae. Antennae 6-segmented (figure 4a), 1.25-1.41 body length. Ant. segm. VI-VI imbricated. Ant. segm. III longest, slightly narrower at base, with 24-35 rounded secondary rhinaria of variable size with sclerotic ring, distributed mostly on dark pigmented part of the segment. Ant. segm. IV and V of similar length. Ant. segm. IV with 11-18, ant. segm. V with 7-11 secondary rhinaria, similar to those on ant. segm. III. Ant. segm. V with 1 rounded and ciliated primary rhinarium. VIb 2.85-3.71 times VIa; other antennal ratios: V:III 0.67-0.55, IV:III 0.64-0.73. Antennal chaetotaxy: segm. I with 2-6 setae, segm. II with 2-3 setae (in one row in middle of segment), segm. III with 7-15 setae, segm. IV with 6-7 setae, segm. V with 4-6 setae, segm. VI with 2 basal, 1 subapical and 3 apical setae. Antennal setae pointed, robust, 0.01-0.02 mm long; the longest antennal seta III of similar length of basal articular diameter of this segment. Rostrum short, reaching segment II of thorax, ARS long and pointed, with 6 pairs of accessory setae (figure 4b). ARS 0.23-0.30 times ant. segm. III and 1.33-1.55 times HT II. Wings with normal venation. Fore wings with pterostigma and veins dark, all ending in light brown triangles (figure 4c). First tarsal chaetotaxy 3:3:(2)3 (figure 4d). Dorsum with oval marginal sclerites on segments I-IV, large transverse patch across tergites IV-V (in some specimens partially fused between segments to form a central, dark patch perforated with "window"), linking with large marginal sclerites on abdominal tergites V and VI. Dorsal chaetotaxy: setae arranged in visible rows, pale, pointed, about 0.025 mm long, the longest ones about 0.04 mm long on abdominal segments VII-VIII. Basal part of siphunculi cylindrical, strongly elongated with surface corrugate, distal part smooth, with distinctive large swollen, with 1-2 rows of reticulation below flange (figure 4e). Cauda triangular with 6 long and pointed setae and short and pointed spinules (figure 4g). Genitalia well developed, strongly sclerotized with lobate parameres covered by numerous spine-like setae. Basal parts of phallus elongated, hooked-shaped with numerous setae and sclerotized arms distinct (figure 4f).

Field observations

Living specimens of a viviparous generation of *E. elegans* (adults and nymphs) were first observed on a cultivated *L. angustifolia* (figure 5a) in Katowice, Poland in late May. The plants were growing on a balcony and were purchased from one of the largest garden stores in the Upper Silesia region, Poland. The aphids had infested the undersides of the leaves on the lower parts of the plants and in early June caused serious defoliation. Later, the density of the population increased, caused drying of these leaves (figure 5b) after which the aphids (apterae, alatae and nymphs) were also observed on the undersides of the leaves on the upper parts of the plants, stems and inflorescences (figure 5c). At the beginning of July, the colonies disappeared, probably due to high temperatures that prevailed at the beginning of summer. The lavender seedlings, despite being partially dried out, survived on the balcony until the end of November, but the aphids did not reappear on them. The source of the aphid occurrence is unknown. They could have been present on the plants at the time of purchase; however, it is worth emphasizing that the lavender seedlings from the store had not imported, but had been grown locally. Because the individuals are very small, they may have been overlooked and were only noticed when the colonies became dense. It is also possible, that the plants were infested independently by winged viviparae. Regardless of the source of the infestation, it was the first field observation of *E. elegans* (i.e. aphids feeding on the host plant) the northernmost in Europe.

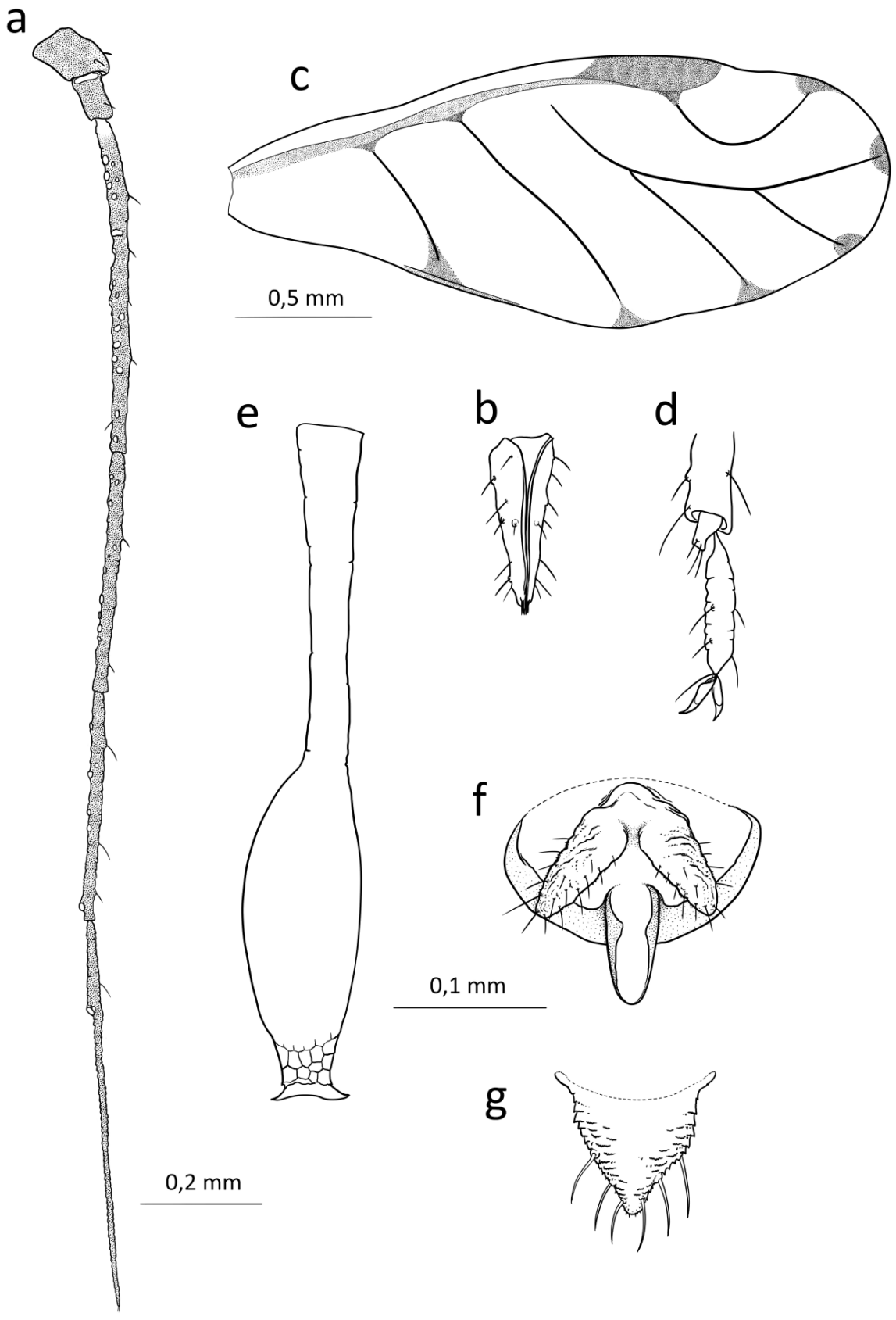

Figure 4. *E. elegans* alate male-morphological characters: **(a)** antenna, **(b)** apical segment of rostrum, **(c)** fore wings; **(d)** hind tarsus, **(e)** siphunculus, **(f)** genitalia, **(g)** cauda.

Figure 5. *E. elegans* in the field: **(a)** apterous and alate viviparous females on inflorescences of *L. angustifolia*, **(b)** damage caused by feeding aphids, **(c)** colony on the undersides of leaves and stems of *L. angustifolia*.

Discussion

The life cycle of aphids depends on the environmental conditions (Dixon, 1998; Wieczorek *et al*., 2013; Depa *et al*., 2015). In warm and humid climates, *E. elegans* is an anholocyclic species, reproducing parthenogenetically throughout the year. Faszand (Fachand) in Iran is located about 2000 m above sea level in the foothills of the Alborz mountain range. The area has an arid climate with a hot summer and cold winter. This type of climate is favourable for the occurrence of the sexual morphs of aphids. Thus, both apterous males and oviparous females of *E. elegans* have been recorded in this location. Similarly, in the Kalam Valley in Pakistan, which is also located at about 2000 m above sea level, alate males of this species have been recorded in the foothills of the Hindu Kush mountains. In this way, under some conditions (temperature and geographical location), they can be holocyclic with a sexual phase during part of their life cycle. In Iran, the aphids have been collected directly from their host plants (*Nepeta* sp.), while in Pakistan, they were collected from yellow trays. However, because the sexuales were simultaneously collected with apterous (Iran) or alate (Pakistan) females at both locations (material deposited in the MNHN collection), the described morphs without a doubt belong to the genus *Eucarazzia*. Among Macrosiphini, the presence of both holocyclic and anholocyclic populations is common in numerous species such as the presence of apterous and alate males of the same species (Blackman, 2010). Thus, *E. elegans* is not an exception here.

E. elegans is widely distributed in the Mediterranean region, also known from the archipelagos of Macaronesia, the Middle East and Central Asia, Pakistan and India (Himachal Pradesh, north-west Himalayas), Africa south of the Sahara, western USA, South America and Australia (Stoetzel, 1985; Hales *et al*., 2009; Holman, 2010; Blackman and Eastop, 2018). However, in the higher latitudes of Europe, alatae of this species has only been trapped in Great Britain (Blackman, 2010) and apterous and alatae have been found feeding on the host plant (lavender) in southern Poland (present study).

The winged aphids, as part of the aeroplankton, are easily spread over long distances. That is why the alatae of *E. elegans* have been caught up in various kinds of traps (suction trap, Moericke water trap, yellow pan trap, yellow sticky board, yellow trays), far beyond the range of its natural occurrence and have also been collected from numerous unrelated host plants (Stoetzel, 1985; Nieto Nafría *et al*., 2016). Another source of the spread of this species is transport with their host plants. As apterae are rather small, green aphids, they can easily be overlooked. For example, in 1998 in the UK, *E. elegans* was intercepted on *Melissa officinalis* L. from Italy (Cannon *et al*., 1999). This aphid species is a well-known pest of ornamental herbs, especially in the Middle East (Zarkani *et al*., 2017). However, in new areas, the species is usually widely established but is unlikely to become a significant pest. On the other hand, it should be considered as a risk to any ornamental Lamiaceae that is being grown under protection or other native plants from this family, Peronti and Sousa-Silva (2002) reported that *E. elegans* feeds on the native species *Salvia splendens* Sellow ex Roemer et J.A. Schultes in Brasil.

Climate change clearly affects the distributional ranges of plants and the insects that are associated with them (Parmesan and Hanley, 2015; Warren *et al*., 2018). Lavender (primarily species that are resistant to winter conditions such as *L. angustifolia*) is currently one of the most popular ornamental plants in the higher latitudes, and is also cultivated commercially (especially for its essential oils, Cristea and Boros-Iacob, 2017), including in Poland (Borkowska, 2018). Therefore, it can potentially be a food source for an established population of *E. elegans*, thereby contributing to the spread of this species.

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