



The mouthparts of adult Indian meal moths, *Plodia interpunctella* (HÜBNER, 1813) (Lepidoptera: Pyralidae)

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Abstract: The mouthparts of adult *Plodia interpunctella* (HÜBNER, 1813) (Pyralidae) were investigated using LM and SEM for the first time. Larvae of the Indian meal moths are regarded to be a common pest on stored food products. The adults are used as experimental organisms in laboratory since they are easily to breed without feeding the adults but it is doubtful whether they can feed at all. The mouthparts are similar to other higher Lepidoptera that exhibit a functionally intact feeding apparatus. The galeae form the proboscis measuring about half the body length. The distal proboscis exhibits an intake region near the tip that might lead fluid into the food canal. The proboscis bears numerous microtrichia and the characteristic sensillae of glossatan Lepidoptera, i.e. aporous trichoid sensilla, uniporous sensilla basiconica and sensilla styloconica in the tip-region, as well as a second type of sensilla basiconica inside the food canal. Two sets of internal galeal muscles, along with a nerve and tracheae are present inside the galeae. The labial palps feature a pit organ (“Von-Rath-Organ”) located subterminally in the third segment. Although adult moths never have been reported to feed under laboratory conditions, they possess a complete and fully equipped proboscis.

Keywords: Proboscis, morphology, sensilla, Lepidoptera

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Introduction

The pyralid moth *Plodia interpunctella* (HÜBNER, 1813), or Indian meal moth, is distributed worldwide, especially in households and warehouses, since the larvae feed on stored food products, such as grains, nuts, dried fruits, and vegetables. As concealed feeders, the larvae cause major damage to stored crops and are considered a cosmopolitan pest (HOPPE 1981, JOHNSON et al. 1992, NA & RYOO, 2000, FASULO & KNOX 2009). Adult moths of *Plodia interpunctella* live about 10 to 14 days but do not necessarily feed for reproduction. They can be reared over many generations in the laboratory without fluid supply for the adult moths (FASULO & KNOX 2009, Lewis pers. comm.).

The mouthparts of adult Lepidoptera are modified into a proboscis for fluid uptake, except for the most basal taxon of Lepidoptera which have biting / chewing mouthparts for pollen feeding (KRISTENSEN 2003, KRENN 2010) and several non-feeding taxa with rudimentary mouthparts (SCOBLE 1992). While various aspects of the morphology and

evolution of lepidopteran mouthparts have been studied in numerous species of butterflies and moths (e.g. EASTHAM & EASSA 1955, KRENN 1990, BÜTTIKER et al. 1996, PAULUS & KRENN 1996, KRENN et al. 2001, BAUDER et al. 2013, ZASPEL et al. 2013, XUE & HUA 2014), taxa that do not regularly feed have been neglected since they are assumed to have reduced mouthparts in adult stage.

Apart from the sensillum equipment, the mouthparts in the Glossata are rather uniformly shaped. They consist of a small labrum, greatly elongated galeae of the maxillae which form the proboscis, a pair of maxillary palpi and the labium bearing prominent three-segmented labial palpi (KRISTENSEN 2003). The labrum has lateral lobes, the piliferes, bearing bundles of bristles on their lateral edges (KRENN & KRISTENSEN 2000). The basal parts of the maxilla, the stipes and the cardo, form a hemolymph pump. They bear the elongated galeae, which compose the coilable proboscis that is linked by rows of cuticular processes, the legulae, on the dorsal and ventral sides. In this way the median walls constitute the food canal (KRENN & KRISTENSEN 2000). Each galea contains a trachea, a nerve, sensilla and a basal galeal muscle as well as two series of intrinsic galeal muscles inside the lumen (KRENN & KRISTENSEN 2000, 2004). In many taxa, the outer surface of the proboscis is covered with spine-like cuticular processes, referred to as microtrichia (KRENN & KRISTENSEN 2000).

Several types of sensilla occur on the lepidopteran proboscis. They are usually classified into trichoid sensilla, termed as sensilla chaetica (review FAUCHEUX 2013) or sensilla trichodea (review KRENN 2010), small cone-shaped sensilla basiconica (with various subtypes according to the number of pores) and the conspicuous sensilla styloconica (e.g. STÄDLER et al. 1974, FAUCHEUX 1991, PAULUS & KRENN 1996, WALTERS et al. 1998, FAUCHEUX 2013, ZASPEL et al. 2013, XUE & HUA 2014). The sensilla on the cephalic appendages of Lepidoptera have been studied in several families including some species of the Pyralidae (HONDA & HANYU 1989, FAUCHEUX 1991, 1995). The presence of the labial palp pit organ or von-Rath-organ on the third segment of the labial palpi was described by FAUCHEUX (1991, 1995) in two species of Pyralidae.

Plodia interpunctella has been the subject of many studies concerning development and reproduction such as, insect mating success, sexual selection related to sperm-polymorphy (e.g. SAVOV 1973, HOPPE 1981, JOHNSON et al. 1992, COOK 1999, INGLEBY et al. 2010, LEWIS et al. 2011, 2013) or the effects and the production of ultrasound (TREMATERRA & PAVAN 1995, HUANG & SUBRAMANYAM 2004). But no detailed investigations have been made on the morphology of the adult mouthparts, probably since they successfully reproduce under laboratory conditions without food supply for the adults. This poses the question whether the mouthparts of *Plodia interpunctella* actually are functionally intact and whether they possess the complete equipment of lepidopteran mouthparts. In general, little is known about the morphology of mouthparts in Lepidoptera, in which imagines do not necessarily ingest food and totally rely on nutrients from the larval stage. This study investigates the morphology of the mouthparts with emphasis on the sensory equipment in adult *Plodia interpunctella* moths. The purpose of this study is to provide a detailed description in this species and ask whether there are any reductions of mouthpart structures.

Material and methods

Biometry and light microscopic measurements

The individuals of *Plodia interpunctella* (HÜBNER, 1813), which have been used for this study, were reared and kept at room temperature and 35% relative humidity in the Department of Integrative Zoology at the University of Vienna, Austria. The body size was measured using a caliper rule (n= 26). To measure the length of the proboscis, the thorax, abdomen and labial palpi of dried animals were removed under a Nikon SMZ-U stereo-microscope. The heads were placed in lactic acid for several days to uncoil the proboscis. Afterwards they were rinsed with alcohol (30%) and positioned on a microscopic slide with a drop of glycerin and a cover. To study the external morphology of the proboscis, these specimens were studied using a light microscope (Olympus CX41) with attached Olympus E330 digital camera. The photos were transferred to a computer, where the proboscis length was measured using ImageJ (U.S. National Institute of Health, Bethesda, USA).

Scanning electron microscopy

The samples for scanning electron microscopy (SEM) were prepared and studied at the Core Facility of Cell Imaging and Ultrastructure Research (University of Vienna, Austria). The specimens used for SEM were fixed in alcoholic Bouin's solution for 48 hours and afterwards stored in 70% ethanol. The head and thorax were dehydrated in 95% ethanol two times for 30 minutes and subsequently in 100% ethanol two times for 30 minutes. They were chemically dried using Hexamethyldisilazane (30 minutes) and left to air-dry overnight under the fume hood. The protocol followed a standard procedure which was already proven to be useful in studies of lepidopteran mouthparts (e.g. KRENN et al. 2001). In some specimens the scales of the labial palpi, the maxillary palpi and the proboscis were removed under the binocular using adhesive tape. In others the proboscis and/or the labial palpi were completely removed in order to view the basal structures of the mouthparts. The prepared heads, several proboscides and labial palpi were mounted on aluminum stubs using carbon foils and conductive silver, left to dry for several hours and were then sputter coated with a thin layer of gold (Agar sputter coater, for 200 seconds). SEM-micrographs were taken using a Philips XL 20 SEM and Philips XL 30 ESEM, with an acceleration voltage of 15 kV. The photos were processed using Adobe Photoshop CS6. Contrast enhancement and brightness adjustments were performed in several photos. ImageJ (U.S. National Institute of Health, Bethesda, USA) was used for length measurements.

Histological sections

The specimens were fixed in alcoholic Bouin's solution for 48 hours (ROMEIS 1989), afterwards dehydrated in ethanol (70%, 90%, 96%, three times 100% for 30 min each) and acetone (three times for 30 min). Following an embedding protocol modified after PERNSTICH et al. (2003), the specimens were transferred to Agar Low Viscosity Resin. Dehydration and embedding were conducted at room temperature on a shaker platform. The polymerization was proceeded at 70° C within 24 h. Sections of 1 µm thickness were cut with a Reichart ultramicrotome using a Histo-Jumbo diamond knife (Diatome AG, Biel; Switzerland). Sections were transferred onto microscopic slides where they were

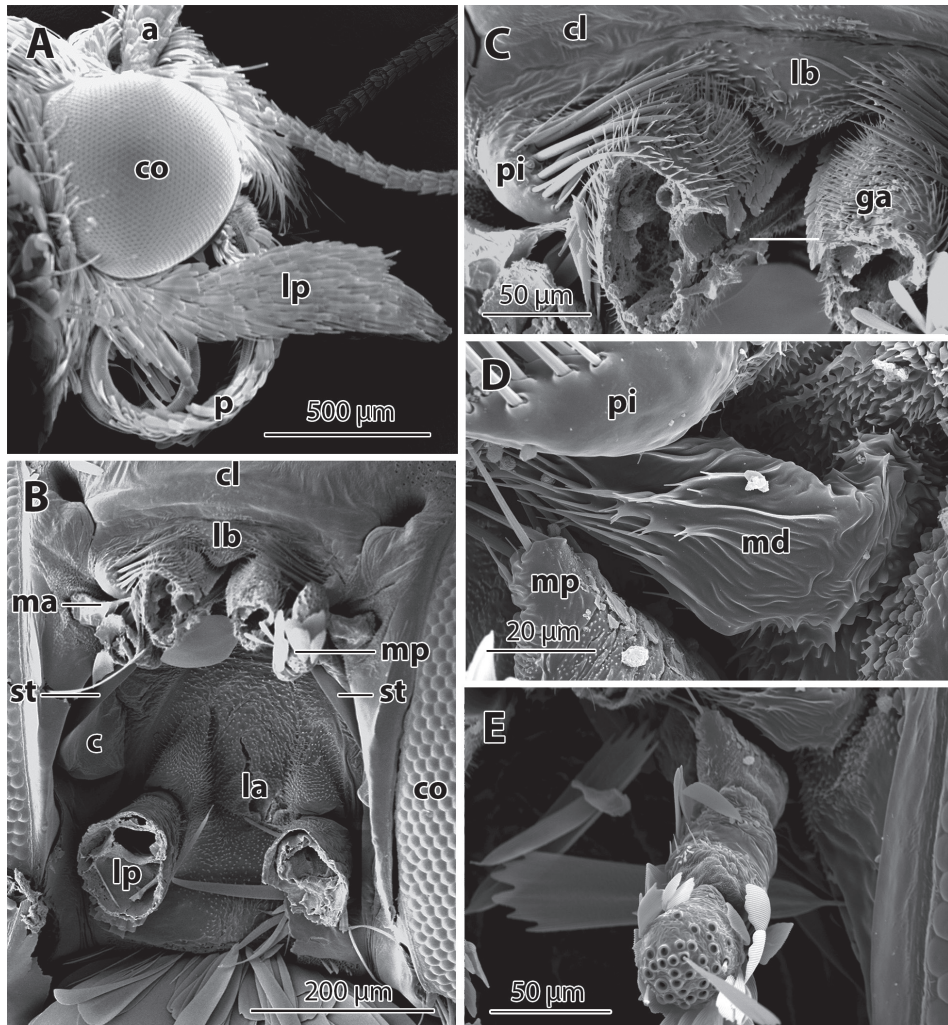


Fig. 1: Head and mouthparts of the moth *Plodia interpunctella* (Pyralidae) (SEM). A. Head and coiled proboscis (p) in lateral view; antenna (a), complex eye (co), labial palpus (lp). B. Ventral side of the head formed by labium (la); proboscis and labial palpi removed to show the position of the labrum (lb), the basal parts of the maxillae, i.e., cardo (c), stipes (st), and maxillary palpus (mp). C. Labrum (lb) and piliferes (pi); the bristles of the piliferes are in contact with the basal region of the galea (ga). D. Rudimentary mandible (ma) lies between maxillary palpus (mp) and pilifer (pi). E. Maxillary palpus; scales of third segment removed.

stained in a mixture of azure II and methylene blue in hydrous borax solution (1%) at 40° C for 20 seconds. The sections were studied using an Olympus CX41 light microscope (LM).

Results

The mean body size of *Plodia interpunctella* is 6.1 mm (SD ± 0.8; n= 26). In resting position the wings are folded above the body. They proceed beyond the end of the abdomen.

The length from the anterior side of the head to the tip of the wings measures 7.8 mm (SD \pm 0.9; n= 26).

The mouthparts of *Plodia interpunctella* consist of the small labrum, rudimentary mandibles and the maxillae bearing the maxillary palpi, the plate-shaped labium and its large labial palpi (Fig. 1). No differences in the morphology and anatomy of the mouthparts could be found between the sexes.

The labrum is located beneath the clypeus and above the basal joint of the proboscis (Fig. 1B). It is reduced to a tiny triangle and entirely covered with microtrichia (Fig. 1C). The lateral lobes, also termed piliferes, are located at both sides. The piliferes bear numerous long setae, which are oriented towards the proboscis where they contact the dorsal side of the proximal end of each galea. Their mean length is 68.3 μ m (SD \pm 4.9; n= 7). The setae are striated and shorter on the edge of the piliferes becoming longer and thicker towards the medium side of each pilifer.

The mandibles are rudimentary, small, and triangular in shape. They are located below the piliferes. Their cuticle is deeply grooved. They bear prickle-shaped thorns of unknown function (Fig. 1D). The cuticle of the basal mouthparts, the labrum and the mandibles, is striated and spiny.

The basal parts of the maxillae, the stipes and cardo, are located on each side of the labium plate (Fig. 1B). The greatly prolonged galea originates from the anterior end of each stipes. The two galeae are interlocked on their dorsal and ventral sides forming the central food canal of the proboscis. The mean length of the proboscis is 3.3 mm (SD \pm 0.32; n= 16). In its resting position, the proboscis is coiled up between the labial palpi in 4 to 4.5 coils (Fig. 2A). The outermost coil is covered in scales on the dorsal sides of the galeae (Fig. 2A).

The cuticula of the proboscis is composed of vertical ribs (Fig. 2B). They are broader at the base (mean width 7.03 μ m, SD \pm 0.55 μ m; n= 10) and become continuously narrower toward the tip (mean width 5.08 μ m, SD \pm 0.59 μ m; n= 10). All cuticle ribs are covered with one row of spin-like microtrichia (Fig. 2). These cuticular processes are long and thin at the base of the galea where the setae of the piliferes are engaged (Figs. 1C, 2A). They are shorter and more thorn-shaped on the other regions of the proboscis (Fig. 2). The two galeae are held together by the legulae. The legulae of the dorsal and ventral side are interlocked with their counterparts on the other galea at the opposite side. The ventral legulae are tightly connected from the base to the tip of the proboscis by interlocking of cuticular hooks. The dorsal legulae are lancet shaped and less tightly interlocked with each other. In the distal region of the proboscis, the two rows of dorsal legulae merge to a single row. This region, the so called tip region (Fig. 2B), is characterized by larger dorsal legulae that form slits into the food canal between them. The tip region is about 0.2 mm long and corresponds to about 6.5% of the total proboscis length.

Several types of sensilla on the proboscis were distinguished according to their external morphology, i.e., trichoid bristle shaped sensilla (Fig. 2C) and 2 types of cone shaped sensilla: sensilla basiconica (Fig. 2D) and sensilla styloconica (Fig. 2E).

Aporous trichoid sensilla were found on the outside of the galeae. They are composed of a round socket and a sensory bristle of varying length. In the proximal region they are

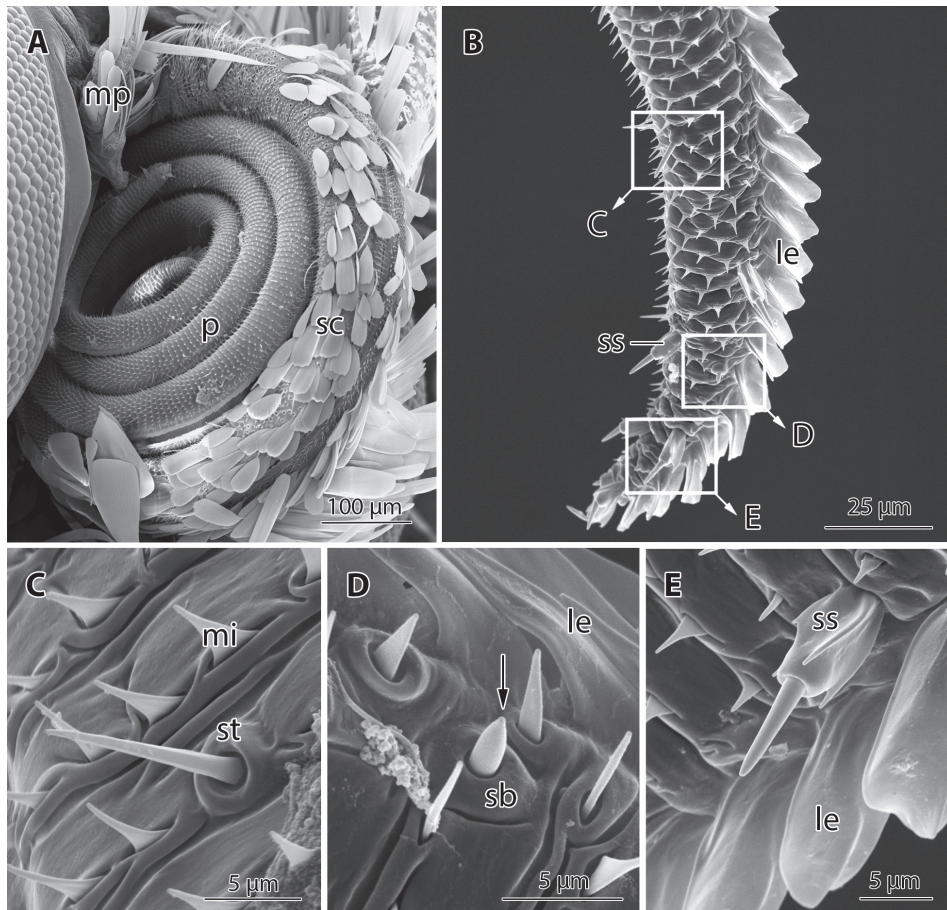


Fig. 2: Proboscis of *Plodia interpunctella* (Pyralidae) (SEM). A. Proboscis (p) coiled in resting position; scales (sc) on the dorsal side of the proximal region; maxillary palpus (mp). B. Tip region of the proboscis equipped with sensilla styloconica (ss), broad dorsal legulae (le) and microtrichia on the cuticle ribs. C. Aporous trichoid sensillum (st) and microtrichia (mi) on the lateral side of the galea. D. Uniporous sensillum basiconicum on the dorsal side (sb), arrow points to apical pore on the sensory cone. E. Sensillum styloconicum (ss) with cuticle ridges on the stylus and long sensory cone; dorsal legulae (le).

distributed between and beneath the scales. Some setae have a particularly long, fluted sensory bristle with a mean length of $37.2 \mu\text{m}$ ($\text{SD} \pm 1.87$; $n = 6$) that protrudes above the scales (Fig. 2A). Most other sensilla of the galea are shorter and have a mean length of $10.9 \mu\text{m}$ ($\text{SD} \pm 1.52$; $n = 21$). They are composed of a small socket and a shorter sensory bristle (Fig. 2C). They are scattered all over the surface of the proboscis but are absent in the food canal. The bristles are longer in the basal region of the proboscis (mean length $12.16 \pm 1.11 \mu\text{m}$; $n = 10$) and become shorter towards the tip (mean length $9.57 \pm 1.24 \mu\text{m}$; $n = 10$). No pores were detected in SEM.

Sensilla basiconica possess a small socket and a short blunt sensory cone with a pore on the apex. They are much less frequent and only present on the dorsal surface of the proboscis, where they are situated in a row near the dorsal legulae. Laterally in the tip region of the

proboscis a few sensilla basiconica have a much longer sensory cone than the ones more proximally on the galea. Their mean length is $7.3 \mu\text{m}$ ($\text{SD} \pm 0.86$; $n = 6$).

Sensilla basiconica type 2 only occurs inside the food canal. Sensilla basiconica found inside the food canal are shorter than that on the outside of the galea ($3.9 \pm 0.37 \mu\text{m}$; $n = 6$). They are scarce, and number only 11–13 per galea ($n = 6$). These sensilla are widely spaced in the proximal half of the proboscis and closer towards the tip. They have no socket and are composed only of the sensory cone, which bears a pore on the apex.

Sensilla styloconica are restricted to the tip region. They are only found on the most distal 5% of the proboscis. Their total mean length is $14.2 \mu\text{m}$ ($\text{SD} \pm 1.7$; $n = 17$). Compared to the other sensilla, the socket is long ($7.9 \pm 0.93 \mu\text{m}$; $n = 17$) and massive, with four pikes surrounding it (Fig. 2E). The sensory cone is shorter than the stylus measuring $6.2 \mu\text{m}$ ($\text{SD} \pm 0.87$; $n = 17$) in length and showing a pore on the apex. There are 9–10 sensilla styloconica per galea; they occur in the same pattern on each galea. A group of 7–8 sensilla are found close together at the apex. Another two sensilla are situated close to the dorsal legulae in the tip region (Figs. 2B, E).

The two galeae enclose the central food canal, the diameter of which decreases in the tip region. In cross-section each galea contains a nerve, a trachea and several intrinsic galeal muscles. The intrinsic galeal muscles can be divided into a series of lateral intrinsic galeal muscles, which are arranged along the lateral proboscis wall, and a second series of median intrinsic galeal muscles, which are arranged longitudinally along the ventral wall. The nerve and the trachea are suspended from a longitudinal septum. Whereas the nerve proceeds to the tip, no trachea could be found in the distal region of the proboscis.

The maxillary palpi are $172.1 \mu\text{m}$ long ($\text{SD} \pm 24.4$; $n = 10$) and consist of three segments (Figs. 1B, E). The first segment is short and tapers distally in the direction of the proboscis. This segment bears 2–4 sensilla trichodea, which are $48.5 \mu\text{m}$ long ($\text{SD} \pm 5.2$; $n = 7$). The second segment is longer than the first and has a triangular form. The third segment is oval shaped and similarly long as the second. No sensilla were found on the second and third segments. There are several microtrichia on the first and on the second segment. A few scales occur on the second, whereas the third segment is covered in numerous scales (Fig. 1B).

The labium is composed of the plate-shaped prementum and the huge labial palpi. The prementum constitutes the ventral side of the head (Fig. 1B). It forms a groove, which has numerous cuticular processes, in which the proboscis rests when it is in the recoiled position. The labial palpi consist of three segments (Fig. 3A). They measure 1.1 mm ($\text{SD} \pm 0.1$; $n = 6$) in total length. The second and third segments project upward in front of the head on both sides of the proboscis. The labial palpi are enormous compared to the head and surmount it (Fig. 1A). The first segment is short ($296.8 \mu\text{m}$; $\text{SD} \pm 34.7$; $n = 4$), followed by a much longer second segment ($575.9 \mu\text{m}$; $\text{SD} \pm 22.1$; $n = 4$), the third one is short again ($235.5 \mu\text{m}$; $\text{SD} \pm 46.7$; $n = 5$) and rounded (Fig. 3A).

The labial palpi are entirely covered by scales (Fig. 1A), which extend from a round cuticular socket. The scales are shorter and broader at the base but long and thin towards the tip. The outside of the labial palpi is more densely covered than the medial side facing the

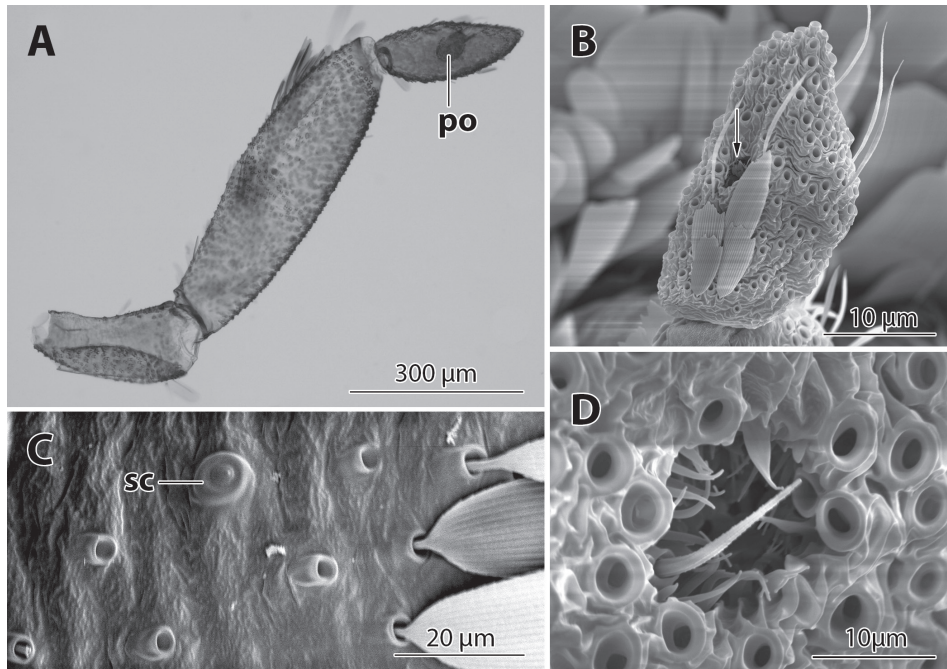


Fig. 3: Labial palpus of *Plodia interpunctella* (Pyralidae). A. Labial palpus composed of three segments (in light microscopy); scales and bristles removed showing the pit organ (po). B. Terminal segment (scales and bristles removed) bear subapical pit organs (arrow) (SEM). C. Sensillum campaniformium (sc) on the medial side of first palpus segment (SEM). D. Labial pit organ bears several types of small trichoid sensilla (SEM).

proboscis. Several types of sensilla were found on the labial palpi, i.e., trichoid sensilla, sensilla campaniformia and sensilla coeloconica inside the pit organ. The sockets of the trichoid sensilla resemble those of the scales, but they are smaller and much tighter around the base of the sensilla. The sensory bristles are long and striated. Greater numbers of sensilla were found on the second segment; their mean length is $68.2 \mu\text{m}$ ($\text{SD} \pm 11.42$; $n = 8$). On the third segment there are few and shorter sensilla ($60.9 \mu\text{m}$; $\text{SD} \pm 6.27$; $n = 10$). Some trichoid sensilla were found on the third segment near the apical pit organ (Fig. 3B). Sensilla campaniformia have a small socket with a dome shaped sensory cone barely surmounting it. They were found only on the medial side of the first segment (Fig. 3C). The labial palp pit organ is located in the middle of the inner side of the third palpus segment (Fig. 3B). The pit is oval shaped with a length of $17.2 \mu\text{m}$ ($\text{SD} \pm 0.99$; $n = 5$) and a width of $11.8 \mu\text{m}$ ($\text{SD} \pm 1.91$; $n = 5$). It contains a single long trichoid sensillum with a length of about $15.6 \mu\text{m}$, sensilla campaniformia, shorter sensilla coeloconica and several leaf-shaped sensilla around the edges (Fig. 3D).

Discussion

Although the adults of *P. interpunctella* (Pyralidae) never have been reported to ingest food neither under laboratory conditions nor in nature, the mouthparts do not exhibit discernible reductions. The external morphology is similar to other Pyralidae (FAUCHEUX

1991, 1995) and many other representatives of Ditrysia that regularly take up fluids (e.g. ALTNER & ALTNER 1986, WALTERS et al. 1998, KRENN & KRISTENSEN 2000, NAGNAN-LA MEILLOUR et al. 2000, XUE & HUA 2014). The proboscis of *P. interpunctella* has the complete equipment of sensilla (review FAUCHEUX 2013) and it also shows the typical internal anatomy of a ditryisian proboscis (KRENN & KRISTENSEN 2004). Indian meal moths can be raised under laboratory conditions over many generations without food supply for the imagines (JOHNSON et al. 1992, NA & RYOO 2000, FASULO & KNOX 2009, Lewis pers. comm.). Since this moth has a relatively short generation time and is easily to rear in the laboratory, *P. interpunctella* is well suited as a model organism for scientific research such as developmental biology in addition to the present use in reproduction biology of insects (e.g. LEWIS et al. 2011, 2013).

The mandibles of *P. interpunctella* are small, immovable, and rudimentary which is typical for the Glossata (KRISTENSEN 2003). The bristles of the piliferes touch the galea bases that have been functionally interpreted to detect proboscis movements (KRENN & KRISTENSEN 2000). Since piliferes are lost in many taxa with reduced mouthparts (KRENN & KRISTENSEN 2000), the presence of these structures in *P. interpunctella* indicates that the proboscis is moveable. The length and proportions of the proboscis approximates to the proboscis length of small butterflies (PAULUS & KRENN 1996, KRENN 2010, BAUDER et al. 2013). In the distal part of the proboscis, there is a region specialized for fluid intake in Lepidoptera, since slits between the legulae enable ingestion of fluid into the central food canal (KRENN & KRISTENSEN 2000). The tip region corresponds to 5–20% of the proboscis length in butterflies (PAULUS & KRENN 1996); the length of the intake region in *P. interpunctella* falls within this range.

As in many moths, the cuticle ribs of the galeae are covered with microtrichia giving the external sides of the proboscis a spiny appearance. Similar cuticle processes are present in various representatives of Ditrysia that regularly visit flowers to take up nectar or ingest fluids (e.g. KRENN 1990, FAUCHEUX 1991, WALTERS et al. 1998, KRENN & KRISTENSEN 2000, XUE & HUA 2014). At the base of the proboscis of *P. interpunctella*, the microtrichia are long and thin where they contact the setae of the piliferes as well as the sensilla of the first segment of the maxillary palpi. This contact might be important to determine the position of the proboscis relative to the head and to detect proboscis movements (KRENN & KRISTENSEN 2000). The proboscis linking structures, the dorsal and ventral legulae, are shaped as in other Ditrysia (KRENN & KRISTENSEN 2000). They interlock the two galeal parts of the proboscis in living moths.

The sensory equipment of the mouthparts is similar to other Pyralidae (FAUCHEUX 1991, 1995) and many other Ditrysia in general (e.g. ALTNER & ALTNER 1986, KRENN & KRISTENSEN 2000, FAUCHEUX 2013). As in all studied Lepidoptera, aporous trichoid sensilla are the most frequent type of sensilla on the proboscis of *P. interpunctella*, they occur throughout the entire length of the proboscis. Assuming that these sensilla function as mechanosensilla (STÄDLER et al. 1974, ZACHARUK 1980, KRENN 1998), they might provide information on the depth of insertion into the flower during nectar feeding (KRENN 1998) or on the correct resting position since they contact the consecutive coils in the recoiled proboscis (KRENN 1990). Since trichoid sensillum were also found in moths with

rudimentary proboscis (FAUCHEUX 1980, GRANT et al. 2012), it must be assumed that they have additional functions, perhaps in water uptake which has been observed in some moths possessing only reduced mouthparts (SMEDLEY & EISNER 1995, GRANT et al. 2012). Sensilla basiconica possessing an apical pore occur only on the dorsal surface of the proboscis of *P. interpunctella*. As in glossatan Lepidoptera including Pyralidae, the sensilla basiconica occur on the outside of the proboscis as well as on the medial side that forms the food canal. They are considered to function as contact chemoreceptors having gustatory function (KRENN 1998). FAUCHEUX (1991, 1995) found multiporous sensilla basiconica on the proboscis of two species of Pyralidae in addition. FAUCHEUX (1991) suggested an olfactory function of these sensilla. All sensilla in the food canal of pyralid species as well as in other Ditrysia, are found to be uniporous. In *Plodia interpunctella*, both internal and external sensilla basiconica possess an apical pore. Contrary to the external sensilla, the sensilla of the food canal of *P. interpunctella* have no socket; they consist merely of the sensory cone. The higher density of these sensilla towards the tip could be explained by the fact that the tip of the proboscis is the first to contact the liquid when feeding. As those sensilla are hypothesized to provide information on the flow rates (STÄDLER et al. 1974, KRENN 1998), the proboscis of *P. interpunctella* is well equipped to detect fluid in the food canal.

Sensilla styloconica are the characteristic sensilla of the proboscis of Glossata (KRENN & KRISTENSEN 2000, KRENN et al. 2005, FAUCHEUX 2013). In *P. interpunctella*, the sensilla styloconica show only one terminal pore as it was found in most other studied species. They can be considered as chemo- and mechanosensilla (KRENN 1998, KRENN & KRISTENSEN 2000, FAUCHEUX 2013). The micromorphology of the stylus and the arrangement of sensilla styloconica in the tip region are nearly identical in other investigated Pyralidae (FAUCHEUX 1991, 1995). In the pyralid moth, *Homoiosoma electellum* (HULST, 1887), the sensilla styloconica likewise have pikes surrounding the socket (FAUCHEUX 1995). Also in *Pionea damastesalis* (WALKER, 1859) (Pyralidae), the sensilla look quite similar to those of *P. interpunctella* (BÜTTIKER et al. 1996), despite the fact that this moth is regularly found to take up lachrymal fluid from the eyes of mammals. However, another tear-feeding Pyralidae, *Filodes mirificales* (LEDERER, 1863) greatly differs in form and arrangement of the sensilla and the microtrichia on the proboscis (BÜTTIKER et al. 1996). This suggests diversity in the morphology and arrangement of the sensilla styloconica in representatives of Pyralidae that is not related to feeding preferences, as has been shown in nymphalid butterflies (KRENN et al. 2001) and, at least, some tear-feeding or piercing blood-sucking Noctuidae (BÜTTIKER et al. 1996, ZASPEL et al., 2007).

The internal anatomy of the proboscis *P. interpunctella* includes musculature, nerves and tracheae and represents the regular anatomy of representatives of Ditrysia (KRENN & KRISTENSEN 2004). The presence of muscles throughout the entire proboscis length indicates that the proboscis of *P. interpunctella* is movable.

The mouthpart appendages, i.e., the maxillary palpi and labial palpi exhibit the characteristic morphology of ditrysiian Lepidoptera (KRISTENSEN 2003). The sensory equipment of *P. interpunctella* shows only slight differences to other pyralid species. In *Homoiosoma electellum*, the three-segmented maxillary palpi bear several sensilla on the first and few

on the second segment (FAUCHEUX 1995). At the third segment of the labial palpi there is an assemblage of sensilla in a pit, the labial palp pit organ (FAUCHEUX 1991, 2008, KRISTENSEN 2003). Usually, this pit organ is located on the tip of the third segment (FAUCHEUX 1991, KRENN et al. 2004) whereas it is located in the middle of the inner side in *P. interpunctella*. In Sphingidae the labial palp pit organ seems to have olfactory function (KENT et al. 1986), in Pyralidae the function is not investigated.

Indian meal moths that obviously do not regularly feed in adult stage are nonetheless equipped with a complete and presumably functional proboscis. At least one individual was observed to take up water (KRENN unpublished), but it is unknown how regular and under which circumstances this behavior occurs. FASULO & KNOX (2009) reported that Indian meal moths were interested in fruit juice and sugar baits but did not report if feeding occurred. Thus further investigations are warranted on individuals in natural habitats regarding the necessity for water and/or mineral uptake. Since sodium uptake in non-nectar feeding butterflies has been shown to increase their reproduction (MOLLEMAN et al. 2004), water uptake would help to provide such mineral substances that might likewise be required in *P. interpunctella* to ensure optimal fecundity. At the same time, there are examples of adult Lepidoptera that possess only a short rudimentary proboscis, yet are able to take up fluid (SMEDLEY & EISNER 1995, GRANT et al. 2012). We conclude that the presence of fully developed mouthparts is not in itself an indication of regular feeding behavior in adult moths. *Plodia interpunctella* must be interpreted as an example of a capital breeding moth (TAMMARU & HAUKIOJA 1996) that does not necessarily take up food in the adult stage, although it possesses a fully intact proboscis equipped with all the characteristic sensilla and musculature.

Zusammenfassung

Die Mundwerkzeuge adulter Dörrobstmotten, *Plodia interpunctella* (HÜBNER, 1813) (Pyralidae), wurden erstmals mit lichtmikroskopischen und elektronen-mikroskopischen Methoden untersucht. Die Raupen der Dörrobstmotten sind weltweit verbreitete Schädlinge an getrockneten Nahrungsvorräten. Die erwachsenen Motten werden vielfach als Laborinsekten für Experimente genutzt, weil sie leicht zu züchten sind und die adulten Insekten nicht mit Nahrung versorgt werden müssen. Es ist aber nicht klar, ob sie überhaupt Nahrung aufnehmen können. Die Mundwerkzeuge von *Plodia interpunctella* sind grundsätzlich so gebaut wie bei höheren Lepidoptera, die funktionsfähige Mundwerkzeuge besitzen und Nahrung aufnehmen. Das heißt, dass die beiden Galeae einen Rüssel bilden, der etwa die halbe Körperlänge besitzt. Der distale Rüssel bildet eine Einsaugregion nahe der Rüsselspitze, die Flüssigkeit in den Nahrungskanal aufnehmen kann. Die Rüsseloberfläche ist dicht mit Mikrotrichia besetzt und der Rüssel trägt die charakteristische Sensillenausstattung, die bei Glossata aus porenlosen borstenförmigen Sensillen, einporigen Sensilla basiconica und den Sensilla styloconica der Rüsselspitze besteht. Weiters tritt ein zweiter Typ von Sensilla basiconica im Nahrungskanal des Rüssels auf. Das Lumen jeder Galea enthält zwei Serien von Muskeln, eine Trachee und einen Nerv. Die großen Labialpalpen tragen ein subterminales Von-Rath-Organ („pit organ“). Obwohl bei diesen Motten niemals Nahrungsaufnahme dokumentiert werden konnte, besitzen sie voll ausgestattete und vermutlich funktionsfähige Mundwerkzeuge.

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References

- ALTNER H. & ALTNER I. 1986: Sensilla with both, terminal pore and wall pores on the proboscis of the moth, *Rhodogastris bubo* WALKER (Lepidoptera: Arctiidae). – Zoologischer Anzeiger 216: 129–150.
- BAUDER J.A.-S., HANDSCHUH S., METSCHER B.D. & KRENN H.W. 2013: Functional morphology of the feeding apparatus and evolution of proboscis length in metalmark butterflies (Lepidoptera: Riodinidae). – Biological Journal of the Linnean Society 110: 291–304.
- BÜTTIKER W., KRENN H.W. & PUTTERILL J.F. 1996: The proboscis of eye-frequenting and piercing Lepidoptera (Insecta). – Zoomorphology 116: 77–83.
- COOK P.A. 1999: Sperm numbers and female fertility in the moth *Plodia interpunctella* (HUBNER)(Lepidoptera; Pyralidae). – Journal of Insect Behavior 12: 767–779.
- EASTHAM L.E.S. & EASSA Y.E.E. 1955: The feeding mechanism of the butterfly *Pieris brassicae* L. – Philosophical Transactions of the Royal Society of London B 239: 1–43.
- FASULO T.R. & KNOX M.A. 2009: University of Florida Featured Creatures – Indian meal moth, *Plodia interpunctella* HÜBNER. – Download form http://entomology.ifas.ufl.edu/creatures/urban/stored/indianmeal_moth.htm: August 2014.
- FAUCHEUX M.J. 1980 : Les pièces buccales des adultes de cinq Lépidoptères Tinéides kérotophages communs dans l'Ouest de la France. III – Les récepteurs sensoriels des maxilles. – Bulletin de la Société des Science Naturelle de l'Ouest de la France (n.s.) 2 : 16–25.
- FAUCHEUX M.J. 1991: Morphology and distribution of sensilla on the cephalic appendages, tarsi and ovipositor of the European sunflower moth, *Homoeosoma nebulella* DEN. & SCHIFF. (Lepidoptera: Pyralidae). – International Journal of Insect Morphology and Embryology 20: 291–307.
- FAUCHEUX M.J. 1995: Sensilla on the antennae, mouthparts, tarsi and ovipositor of the sunflower moth, *Homoeosoma electellum* (HULSTER) (Lepidoptera, Pyralidae): a scanning electron microscopic study. – Annales des sciences naturelles, Zoologie et biologie animale 16 : 121–136.
- FAUCHEUX M.J. 2008: Mouthparts and associated sensilla of a South American moth, *Synempona andesae* (Lepidoptera: Neopseustidae). Revista de la Sociedad Entomologica Argentina 67: 21–33.

- FAUCHEUX M.J. 2013: Sensillum types on the proboscis of the Lepidoptera: a review. – *Annales de la Société entomologiques de France (N.S.)*, *International Journal of Entomology* 49: 73–90.
- GRANT J.I., DJANI D.M. & LEHNERT M.S. 2012: Functionality of a reduced proboscis: fluid uptake by *Phigalia strigataria* (MINOT) (Geometridae: Ennominae). – *Journal of the Lepidopterists' Society* 66: 211–215.
- HONDA H. & HANYU K. 1989: Scanning electronmicroscopy of antennal sensilla of the yellow peach moth, *Conogethes punctiferalis* (Guenee) and *Conogethes* sp. (Lepidoptera: Pyralidae). – *Japanese Journal of Applied Entomology and Zoology* 33: 238–246.
- HOPPE T. 1981: Nahrungswahl, Eiablage und Entwicklung der Dörrobstmotte (*Plodia interpunctella* HÜBNER) an verschiedenen Rohstoffen und Fertigprodukten der Schokoladeindustrie. – *Zeitschrift fuer Angewandte Entomologie* 91: 170–179.
- HUANG F. & SUBRAMANYAM B. 2004: Behavioral and reproductive effects of ultrasound on the Indian meal moth, *Plodia interpunctella*. – *Entomologia experimentalis et applicata* 113: 157–164.
- INGLEBY F., LEWIS Z. & WEDELL N. 2010: Level of sperm competition promotes evolution of male ejaculation allocation patterns in a moth. – *Animal Behaviour* 80: 37–43.
- JOHNSON J.A., WOFFORD P.L. & WHITEHAND L.C. 1992: Effect of diet and temperature on development rates, survival, and reproduction of the Indian meal moth (Lepidoptera: Pyralidae). – *Journal of economic entomology* 85: 561–566.
- KENT K.S., HARROW I.D., QUARTARARO P. & HILDEBRAND J.G. 1986: An accessory olfactory pathway in Lepidoptera: the labial pit organ and its central projections in *Manduca sexta* and certain other sphinx moths and silk moths. – *Cell and tissue research* 245: 237–245.
- KRENN H.W. 1990: Functional morphology and movements of the proboscis of Lepidoptera (Insecta). – *Zoomorphology* 110: 105–114.
- KRENN H.W. 1998: Proboscis sensilla in *Vanessa cardui* (Nymphalidae, Lepidoptera): functional morphology and significance in flower-probing. – *Zoomorphology* 118: 23–30.
- KRENN H.W. & KRISTENSEN N.P. 2000: Early evolution of the proboscis of Lepidoptera (Insecta): external morphology of the galea in basal glossatan moths lineages, with remarks on the origin of the pilifers. – *Zoologischer Anzeiger* 239: 179–106.
- KRENN H.W., ZULKA K.P. & GATSCHNEGG T. 2001: Proboscis morphology and food preferences in nymphalid butterflies (Lepidoptera: Nymphalidae). – *Journal of Zoology* 254: 17–26.
- KRENN H.W. & KRISTENSEN N.P. 2004: Evolution of proboscis musculature in Lepidoptera. – *European Journal of Entomology* 101: 565–575.

- KRENN H.W., PLANT J.D. & SZUCSICH N.U. 2005: Mouthparts of flower-visiting insects. – *Arthropod Structure & Development* 34: 1–40.
- KRENN H.W. 2010: Feeding mechanisms of adult Lepidoptera: structure, function, and evolution of the mouthparts. – *Annual review of entomology* 55: 307–327.
- KRISTENSEN N.P. 2003: Skeleton and muscles: adults. In *Lepidoptera, Moths and Butterflies Volume 2: Morphology, Physiology, and Development*, ed. N.P. Kristensen, pp. 39–131. – In: *Handbook of Zoology, Volume 4, Arthropoda: Insects Part 36*, ed. M. Fischer, Berlin, New York: Walter de Gruyter.
- LEWIS Z., WEDELL N. & HUNT J. 2011: Evidence for strong intralocus sexual conflict in the Indian meal moth, *Plodia interpunctella*. – *Evolution* 65: 2085–2097.
- LEWIS Z., LIZÉ A. & SCHMIDT B.A. 2013: The interplay between different stages of reproduction in males of the moth *Plodia interpunctella*. – *Animal Behaviour* 86: 917–922.
- MOLLEMANN F., ZWAAN B.J. & BRAKEFIELD P.M. 2004: The effect of male sodium diet and mating history on female reproduction in the puddling squinting bush brown *Bicyclus anyana* (Lepidoptera). – *Behavioral Ecology Socialbiology* 56: 404–411.
- NA J.H. & RYOO M.I. 2000: The influence of temperature on development of *Plodia interpunctella* (Lepidoptera: Pyralidae) on dried vegetable commodities. – *Journal of Stored Products Research* 36: 125–129.
- NAGNAN-LE MEILLOUR P., CAIN A.H., JACQUIN-JOLY E., FRANCOIS M.C., RAMACHANDRAN S., MAIDA R. & STEINBRECHT R.A. 2000: Chemosensory proteins from the proboscis of *Mamestra brassicae*. – *Chemical Senses* 25: 541–553.
- PAULUS H.F. & KRENN H.W. 1996: Vergleichende Morphologie des Schmetterlingsrüssels und seiner Sensillen: Ein Beitrag zur phylogenetischen Systematik der Papilionoidea (Insecta, Lepidoptera). – *Journal of Zoological Systematics and Evolutionary Research* 34: 203–216.
- PERNSTICH A., KRENN H.W. & PASS G. 2003: Preparation of serial sections of arthropods using 2, 2-dimethoxypropane dehydration and epoxy resin embedding under vacuum. – *Biotechnic & Histochemistry* 78: 5–9.
- ROMEIS B. 1989: *Mikroskopische Technik*. 17th edition. – Urban & Schwarzenberg, Wien, 667 pp.
- SAVOV D. 1973: Development of *Plodia interpunctella* HB (Lepidoptera: Pyralidae) in the optimum temperature range. – *Horticultural and Viticultural Science* 10: 33–40.
- SCOBLE M.J. 1992: *The Lepidoptera. Form, Function and Diversity*. – Oxford University Press, Oxford, UK, XI+404 pp.
- SMEDLEY S.R. & EISNER T. 1995: Sodium Uptake by Puddling in a Moth. – *Science* 270: 1816–1818.

- STÄDLER E., STÄDLER-STEINBRÜCHEL M. & SEABROOK W.D. 1974: Chemoreceptors on the proboscis of the female eastern spruce budworm. Morphological and histological study. – *Mitteilungen der Schweizer Entomologischen Gesellschaft* 47: 63–68.
- TAMMARU T. & HAUKIOJA E. 1996: Capital breeders and income breeders among Lepidoptera – consequences to population dynamics. – *Oikos* 77: 561–564.
- TREMATERRA P. & PAVAN G. 1995: Ultrasound production in the courtship behaviour of *Ephestia cautella* (WALK.), *E. kuehniella* Z. and *Plodia interpunctella* (Hb.) (Lepidoptera: Pyralidae). – *Journal of Stored Products Research* 31: 43–48.
- WALTERS B.D., ALBERT P.J. & ZACHARUK R.Y. 1998: Morphology and ultrastructure of sensilla on the proboscis of the adult spruce budworm, *Choristoneura fumifereana* (CLEM.) (Lepidoptera: Tortricidae). – *Canadian Journal of Zoology* 76: 466–479.
- XUE S. & HUA B. 2014: Proboscis sensilla of the black cutworm *Agrotis ypsilon* (Rottemberg) (Lepidoptera: Noctuidae). – *Journal of Asian-Pacific Entomology* 17: 295–301.
- ZACHARUK R.Y. 1980: Ultrastructure and function of insect chemosensilla. – *Annual review of entomology* 25: 27–47.
- ZASPEL J.M., KONONENKO V.S. & GOLDSTEIN P.Z. 2007: Another blood feeder? Experimental feeding of a fruit-piercing moth species on human blood in the Primorye territory of far eastern Russia (Lepidoptera: Noctuidae: Calpinae). – *Journal of Insect Behavior* 20: 437–451.
- ZASPEL J.M., COY S., HABANEK K. & WELLER S.J. 2013: Presence and distribution of sensory structures on the mouthparts of self-medicating moths. – *Zoologischer Anzeiger* 253: 6–10.

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