

Unusual Dark Forms of the *Solanum* Fruit Fly *Bactrocera latifrons* (Hendel) in Hawaii (Tephritidae: Dacini)

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Abstract. The *Solanum* fruit fly, *Bactrocera latifrons* (Hendel) is one of four invasive true fruit flies in Hawaii and primarily attacks peppers, tomatoes and other Solanaceae. The University of Hawaii Insect Museum collections hold a greater variation of forms than was described in the literature, which has likely led to some confusion regarding identification and may reflect greater morphological diversity across the range of the species. The abdomen of *B. latifrons* was initially described as orange-brown without dark markings and the femora were described as all fulvous. We found varying degrees of dark markings on the abdomen and legs in Hawaiian specimens. This variation is figured and we provide a differential diagnosis based on these new findings. We additionally discuss the consequences for diagnostics of this pest, and the possible synonymy with the Taiwanese endemic *B. parvula* (Hendel) and Indonesian *B. pectoralis* (Walker).

Key words: pest, invasive, tomato, pepper, eggplant, taxonomy

True fruit flies (Tephritidae) are among the most economically damaging of all fruit pests, known to attack over 400 different fruits and vegetables in Hawaii alone (Vargas et al. 2016). The family has four pest representatives in Hawaii, all introduced: the melon fly *Zeugodacus cucurbitae* (Coquillett) in 1895, the Mediterranean fruit fly *Ceratitis capitata* (Wiedemann) sometime before 1910, the Oriental fruit fly *Bactrocera dorsalis* (Hendel) in 1945, and the latest was the *Solanum* fruit fly *Bactrocera latifrons* (Hendel) in 1983. Although *C. capitata* was initially the most severe polyphagous pest, it was largely outcompeted soon after the introduction of *B. dorsalis*, which is now commonly found throughout the Hawaiian Islands. *Zeugodacus cucurbitae* and *B. latifrons* have a relatively more

specialized diet, feeding predominantly on Cucurbitaceae and Solanaceae, respectively, for which they are considered major pests (Liquido et al. 1994). *Bactrocera latifrons* can often be found feeding on bell or chili peppers (*Capsicum annuum*), tomato (*Solanum lycopersicum*) and eggplant (*Solanum melongena*) in gardens, agricultural settings and roadsides.

Bactrocera latifrons is native to South and Southeast Asia (White and Elson-Harris 1992, Liquido et al. 1994) and has been anthropogenically introduced to Tanzania, Kenya, and Hawaii (Vargas and Nishida 1985a, 1985b; Mwatawala et al. 2007). The genetic diversity between different regions and hosts is low, supporting a scenario of recent introductions (Meeyen et al. 2014). In the first few years following its arrival on Oahu in Hawaii,

it was reported to have a narrow range of host plants and remained confined to a single island (Vargas and Nishida 1985b), but it has since expanded to all major islands and utilizes a wider host range (McQuate et al. 2007). The University of Hawaii Insect Museum holds a time series of *B. latifrons* from 1987 to 2013 from different hosts and areas across Hawaii. Because we encountered morphological variations of *B. latifrons* outside of the scope of currently published descriptions of the species, we here provide a figured overview and updated differential diagnosis that should aid with the identification.

Material and Methods

Specimens in the University of Hawaii Insect Museum collections were collected from the islands of Oahu, Maui, and Kauai between 1987 and 2013 by various people using varying methods. Some were reared from fruit (usually “wild tomato” or “peppers” on the label), others were attracted to protein baits from trapping programs. Photographs of specimens were taken using a Nikon D7100 camera operated through Helicon Remote, attached to an Olympus SZX10 stereomicroscope. Photographs from different focal planes were stacked into a single image using Helicon Focus. For morphological terminology we follow White (2000), for systematic treatment we follow Doorenweerd et al. (2018).

Results

The majority of the 121 *Bactrocera latifrons* specimens in the UHIM collection have an orange-brown abdomen and no markings on the legs (Figs 1–3). Around 20% of them have dark markings on the abdomen and legs (Figs 4–15), and darker specimens are present among the oldest representatives (1987) as well as in more recent collections. Numbers were too low for statistical testing of any trends regarding the relative abundance of

unusual forms. Specimens that have not been treated with ethyl-ether to preserve the color may appear even darker (Figs. 13–15).

Bactrocera (Bactrocera) latifrons (Hendel)

Chaetodacus latifrons Hendel, 1915: 425

Dacus amoyensis Froggatt, 1909: 36; nomen nudum

Dacus parvulus Hendel, 1912: 21; designated as synonym by White & Liquido (1995)

Chaetodacus antennalis Shiraki 1933: 56; designated as synonym of *D. parvulus* by Hardy (1973)

Dacus (Strumeta) latifrons (Hendel) Hardy 1968: 113

Bactrocera (Bactrocera) latifrons (Hendel) White & Liquido 1995: 251

Differential diagnosis. In Hawaii, *Bactrocera latifrons* is most similar to *B. dorsalis*, but can be distinguished by the absence of a distinct black T shape on the abdomen and the apical expansion of the costal band on the wing. Outside Hawaii, *B. latifrons* is most similar to *B. parvula* (Hendel) [known from Taiwan] and *B. citima* (Hardy) [known from Thailand and China], in having two lateral yellow vittae on the scutum, the absence of a medial vitta, an entirely yellow scutellum, absence of a clear dark T shape on the abdomen, wing with clear cells bc and c, costal band widening at the apex and usually crossing R_{2+3} . *Bactrocera latifrons* and *B. parvula* can be distinguished from *B. citima* by the mesopleural stripe ending midway between the anterior margin of notopleuron and anterior npl. seta dorsally in *B. citima* (Figure 16B), reaching anterior npl. seta dorsally in *B. latifrons* and *B. parvula* (Figure 16A). *Bactrocera citima* can further be distinguished by the needle-shaped ovipositor, which is trifurcate in *B. latifrons* and *B. parvula*



Figures 1–15. Lateral, dorsal views and abdomen close-ups of five specimens of Hawaiian *Bactrocera latifrons* with varying degrees of dark markings on the abdomen and the scutum and legs. 1–3: female collected on Oahu, Kahuku, Fukuyama farm, leg. S. Graham (no date on labels), with typical ‘textbook’ orange-brown abdomen and absence of dark markings. 4–6: UHIM2015.04242 male collected on Maui, Kula, Howard Harada coffee, 26.vii–4.viii.06. leg. L. Leblanc. 7–9: female collected on Oahu, 2017, leg. S. Graham. 10–12: UHIM2015.04243 collected on Maui, Kula, Flora Umeno’s coffee plot, 16–23.vi.06, leg. L. Leblanc. 13–15: UHIM2016.25466 female collected on Oahu, Ala Wai, garden, 5.ii.90 ex wild tomatoes, leg. M. M. Ramadan.

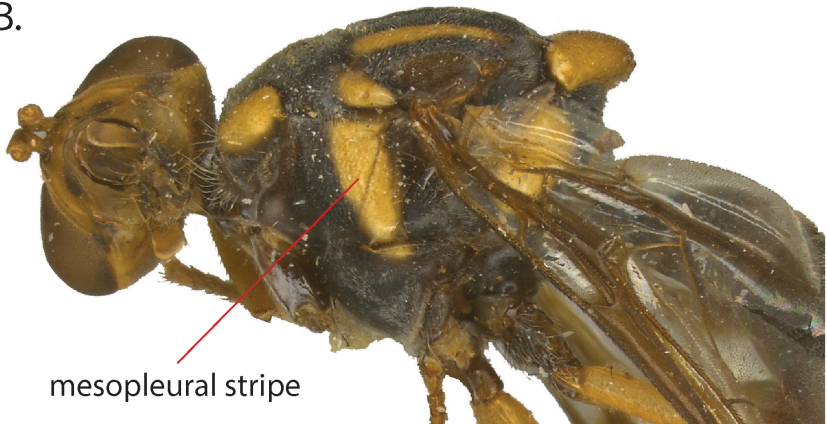
(Fig. 17). Whereas *B. citima* convincingly stands out as a distinct species, the distinction between *B. latifrons* and *B. parvula* is not as clear. The orange-brown abdomen variants of *B. latifrons* can readily be

distinguished from *B. parvula*. Darker specimens of *B. latifrons* with varying dark abdomen patterns can also have femora with black markings, as dots or rings, but these never extend fully around

A.



B.



mesopleural stripe

Figure 16. Lateral views showing the difference in the width of the mesopleural stripe. A. *Bactrocera latifrons* ex USDA fruit fly lab, Honolulu, Hawaii. B. Holotype of *B. citima*, Chiangdao, Chiangmai prov., Thailand.

the femur apex as (reported) in *B. parvula*.

Host plants. There has been some dispute in the literature on the theoretical (i.e. lab reared) and realized host range of *B. latifrons*. The commonly cited *Bactrocera* host overview by Allwood et al. (1999) lists 28 host plant species from ten plant families, and McQuate and Liquido (2013) reported 59 plant species from 14 families. The Center for Agriculture and Biosciences International (CABI) website lists *Solanum*, *Capsicum*, *Physalis*, *Diplocyclos*, *Lycopersicon* [Solanaceae] and

Citrullus lanatus [Cucurbitaceae] (CABI 2018). The predominant natural hosts are all Solanaceae, including tomatoes and peppers (White and Elson-Harris 1992, Liquido et al. 1994) and secondarily some Cucurbitaceae (Mziray et al. 2010). The UHIM collection holds reared material from the invasive devil's apple, *Solanum linnaeanum*, and from 'wild tomato'.

Lure response. *Bactrocera latifrons* is not attracted to methyl eugenol or cue lure, which are highly attractive to *B. dorsalis* and *Zeugodacus cucurbitae*, respectively.

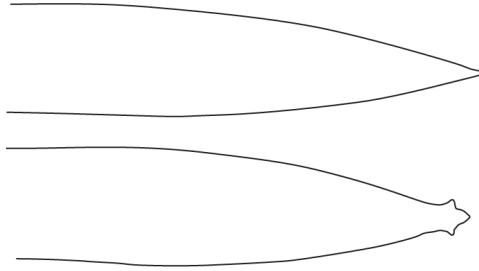


Figure 17. Dorsal view drawing of the aculeus (piercer) of the ovipositor, which is needle shaped (above) in *Bactrocera citima* and trifurcate (below) in *B. latifrons* and *B. parvula*.

There is a specific lure developed for *B. latifrons* called ‘latilure’ (alpha-ionol), sometimes used in combination with cade oil, but this is only slightly attractive (McQuate et al. 2004). Recent studies have discovered ionol analogue compounds that have promise for being more effective (McQuate et al. 2018). Protein baits can be used to attract females, but rearing the species from infested fruit appears to be, at present, the most effective collecting and surveying method (Liquido et al. 1994, Mziray et al. 2010).

Discussion

The variation we encountered in *Bactrocera latifrons* is not unlike that of other species in the genus, which can have a wide variety of dark patterns on both the scutum and the abdomen (San Jose et al. 2013, Leblanc et al. 2015). At present, we have not studied larger series of specimens from outside Hawaii and the variation in *B. latifrons* may not be present throughout its range. The main consequences of our findings are in the species diagnostics and in what should be considered its distributional range. *Bactrocera parvula*, a Taiwanese endemic, has been synonymized with *B. latifrons* in the past, and precedence for the name *B. latifrons* over *B. parvula* was requested based on its predominant use in literature and its pest attribution (White and Liquido

1995). Both species were originally described from Taiwan. White and Liquido (1995) acknowledged that the specimens of *B. parvula* were slightly smaller than *B. latifrons*, but state that the dark markings fall within the range of variation in *B. latifrons*. They additionally placed a confusing statement on a specimen of *B. parvula*, likely identified by Hendel, where they suggest to have assumed that the trifurcate aculeus would be a character to differentiate the two species. The status of *B. parvula* as a separate species was revived by Drew and Romig (2013), whom studied the original type series of five specimens, and re-identified a co-type of *B. parvula* as *B. latifrons*. The argued differentiating characters are the dark leg and abdomen markings, of which the latter and partly the former are here shown to be variable in *B. latifrons*. To further add to this quagmire, *B. antennalis* (Shiraki) was synonymized with *B. parvula* by Hardy (1977) but is considered a junior synonym of *B. latifrons* by Drew and Romig (2013). Finally, the Indonesian *B. pectoralis* has been suggested to be a synonym of *B. parvula* by Hardy (1968) but is distinct from the latter by having short and narrow lateral vittae and having colored cells bc and c (Drew and Romig 2013).

If *B. parvula* and *B. latifrons* species are distinct, we cannot fully exclude the possibility that the darker forms in

Hawaii are *B. parvula*. However, because both forms have been present since the earliest collected specimens and because the intensity of dark markings appears to be gradual, we find it unlikely that there would be any species confused with *B. latifrons* in Hawaii. Tseng et al. (1992), in their checklist of Dacini of Taiwan, indicated that *B. latifrons* is frequently found throughout Taiwan but did not cite the number of specimens actually examined, and only report examining five specimens of *B. parvula*. With the broad variation observed in *B. latifrons* in Hawaii and the apparently small series of specimens ever collected and studied for *B. parvula*, the difference between the two appears minor. We refrain from (re-)synonymizing at this point because we did not study any *B. parvula* specimens morphologically, nor *B. latifrons* from Taiwan, and because *B. parvula* has not been included in any molecular studies. In fact, there are no published collecting records of *B. parvula* in the past 25 years (Tseng et al. 1992, Drew and Romig 2013). Neither species has been included in any molecular studies yet, which is particularly important in complex situations such as the case at hand and can bring robust conclusions from an integrated taxonomic approach (e.g. Schutze et al. 2015). Hopefully our findings will spark renewed interest in this taxonomic puzzle and instigate collecting efforts of *B. parvula* in Taiwan and *B. pectoralis* in Indonesia.

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