KEY TO THE IDENTIFICATION OF *HELICOVERPA ARMIGERA* SUSPECTS INTERCEPTED AT U.S. PORTS OF ENTRY

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In spite of the pest status of *H. armigera*, there appears to be few detailed larval morphological studies with complete setal maps (e.g. Chu et al. 1965). Various, often conflicted diagnoses, have been published; the major ones are reviewed here organized by geographical regions. Although complicated, listing the suite of characters used to identify *H. armigera* will result in a better understanding of morphological variation and provide backup characters that might be useful in doubtful cases. Neither Weisman (1986) nor Venette et al. (2003) treated larval identification of *H. armigera* at United States ports; there is certainly a need to address this topic in some detail.

Hardwick (1965) presented a morphometric key to *Helicoverpa* larvae based on origins. For Australia, he noted *H. armigera* usually had spiracles with dark brown rims and a central light or medium brown area. There was often orange shading around the D and SD pinacula, but no orange spot. The vertical diameter of SD1 on A7 was equal or less than the diameter of the corresponding spiracle in *H. armigera* from Australia (Kirkpatrick 1961). Bejakovich and Dugdale (1998), working in New Zealand, noted *H. armigera* has three longitudinal bands of microspines: one on the dorsal midline, one between D2 and L2 and a final one between L1 and L3. In addition, the rim of the spiracle is black in all instars, the microspines have a broad round base, the cuticle appears "cobblestoned" between the spines and microspines are present below SD1 on A1-8. Matthews (1999: figs. 415, 416) illustrated the cuticle texture of *H. armigera* on A1 and A9 with scanning electron micrographs. He noted late instar *H. armigera* often have "saddle markings" (enlarged pinacula) on A1 and A2. These tend to be absent in *H. punctigera* (Matthews 1999: plate 21). Another difference is prothoracic setae behind the head. These tend to be pale in H. armigera but dark in *H. puntigera*.

Chu et al. (1965), studying *Helicoverpa* in China, noted that *H. armigera* and *H. assulta* both have a small inner mandibular tooth. *Helicoverpa armigera* has cone shaped pinacula on A1 and A8 and more spines near the dorsal line on A1 and A8 than *H. assulta*. The spines of *H. armigera* are pointed, easy to see "inside the legs" and the head has P1 slightly higher than AF2. Gardner (1946) put *H. armigera* in his A IV group noting that these species have a trisetose SV group on A2, a bisetose SV group on A7, SD1 on A8 directly above the spiracle and microspines becoming hairlike ventrally. Gardner (1946) did not find an inner tooth on the mandible.

Hardwick (1965) used measurements and ratios to separate *H. armigera* from *H. assulta* in Africa without other morphological details. Ahola and Silvonen (2005) gave a detailed description of the mouthparts of *H. armigera*, but no keys to related species in northern Europe. Beck (1999: 291-293) did provide a key to European Heliothinae. He illustrated the chaetotaxy of the first abdominal segment, noted the D pinacula of A1 and A8 are joined by a black bar and that the D pinacula of A1 are relatively large and closely spaced (Beck 1999: 501b, Beck 2000:

174). He illustrated the mandible of *H. armigera* with a small inner tooth (Beck 1999: 512c). Sannino et al. (1993) included *H. armigera* in his study of Lepidoptera associated with tobacco. He called attention to the sinuate striations and well developed pinacula in *H. armigera*.

Given the documented larval variation in North American species of *Chloridea*, *Heliothis*, and *Helicoverpa*, we have little or no confidence in morphological identification of larval *H. armigera* in some parts of its range. Neunzig (1969: figs 9-12) showed that the pinacula height of both *H. zea* and *C. virescens* varies according to age within an instar. As a larva grows, the cuticle tightens which tends to stretch and shrink the pinacula. Obviously, it becomes hard to trust pinacula size as a key character, although several authors cite conical pinacula as a feature of *H. armigera*. Another problem is mandible wear. *Chloridea virescens* can have a well-developed inner tooth or just a scar (Neunzig 1969: figs 6, 7). This may explain why some authors see a tooth on *H. armigera* while others do not.

Unfortunately, the quarantine significance of *H. armigera* forces us to evaluate conflicting literature and attempt a diagnosis. In New Zealand, the black spiracles and three bands of microspines will separate *H. armigera* from *H. puntigera* (with brown spiracles) and *H. assulta* (with microspines not in obvious bands) (Bejakovich and Dugdale 1998: 10, 11). Kirkpatrick (1961) was unable to separate *H. armigera* from *H. punctigera* in Australia, and given doubt about the spiracular color of *H. armigera* being black or brown in areas outside of New Zealand, it is better to stop at genus for interceptions in Australia. Color characters (saddle markings, etc.) will be a clue but are not definitive.

For European interceptions, when present, large conical pinacula will separate *H. armigera* from related genera of Heliothinae, but not all specimens are expected to show this character. Perhaps scattered spines on the distal region of the hypopharyngeal complex (Ahola and Silvonen 2005: fig. 1106) is the most distinctive mouthpart character for *H. armigera* in northern Europe. The final problem is separating *H. armigera* from *H. assulta*. *Helicoverpa assulta* is normally associated only with only Solanaceae (but see Mathews 1999: 117, 118) whereas *H. armigera* is polyphagous. Differences in cuticular texture will separate the two species on solanaceous hosts.

At the current time (January, 2014), we are unaware of any occurrences of *Helicoverpa armigera* in the New World outside of Brazil. Because we currently do not know any reliable morphological characters to separate *H. zea* from *H. armigera*, interceptions from Brazil will require molecular methods. There is also occasional evidence of Old World cargo or produce going through Mexico to the United States. This is another potential pathway for introduction of *H. armigera* into the U.S.

A second problem area is Australia and New Zealand. Do not identify *H. armigera* to species in Australia and do so in New Zealand only with caution using well preserved mature larva. *Helicoverpa puntigera* is restricted to Australia and therefore it is not a consideration when identifying *H. armigera* from other regions.

For quarantine purposes, it may be best to assume *H. assulta* eats only Solanaceae until more records from other plant families are published from regions outside of Australia. Therefore, we can assume *Helicoverpa* interceptions from non-solanaceous plants are more likely to be *H. armigera* than *H. assulta*.

Identification of *H. armigera* from Europe and Northern Africa is relatively straightforward. The literature is good and sibling species like *H. assulta* do not occur in those regions. Netherlands vegetables are assumed to be grown in country, other hosts are of uncertain origin and therefore it is best not to attempt a species identification for *Helicoverpa* from this pathway. Sibling species of *Helicoverpa* in Central Africa prevent recognition of *H. armigera* in that part of the world.

The above information is summarized in the key (below) for identification of *Helicoverpa armigera* suspects at US ports of entry. This key assumes the larva in question has most of the characters associated with *H. armigera* as defined in the first couplet. Rare species unlikely to be intercepted at US ports are in brackets.

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1. D setae of A1-8 inserted on large conical chalazae, those of A1, A2 or A8 often larger than the rest; body color highly variable, but usually with lines and stripes and sometimes a black bar joining the D setae of A1 or A2; if the setal bases are small, then the mandible has a minute tooth on the inner rib and no large retinaculum ..... 2 (*H. armigera* suspect)
1'. D setae of A1-8 not inserted on large conical chalazae, those of A1, A2 or A8 often equal in size to the other setal bases; body color highly variable, but usually without lines and stripes and not with a black bar joining the D setae of A1 or A2; mandible lacks a minute tooth on the inner rib ..... not an *H. armigera* suspect

2. From Africa 3
2'. From other parts of the Old World (including Hawaii) 6
2". From Central America, South America, or the Caribbean 18

3. From North Africa countries bordering the Mediterranean Sea 4
3'. From central and southern Africa 5

4. From Solanaceae, dorsal and subdorsal areas of A1-8 with fine spines evenly distributed (Sannino et al. 1993: fig. 5) ..... *H. assulta*
4'. From other hosts, including Solanaceae; dorsal and subdorsal areas of A1-8 in sinuate longitudinal bands (Bejakovich and Dugdale 1998: fig. 34) ..... *H. armigera*

5. Pinacula with microspines on A9 (Mathews: fig. 740); from Suden, Niger, Nigeria, Ghana, or Senegal ..... [*H. fletcheri*]
5'. Pinacula without microspines on A9; from central or southern Africa .... *Helicoverpa* sp. ([*H. toddi*], *H. armigera*, or *H. assulta*)

6. From Europe, the Middle East and western Russia 7
6'. From other parts of the Old World 9

7. From the Netherlands 8
7'. From other areas of Europe, the Middle East or western Russia ..... *H. armigera*

8. From Netherlands vegetables ..... *H. armigera*
8'. From Netherlands cut flowers (doubtful orgin) .....*Helicoverpa* sp.

9. From the Pacific Islands (including Hawaii) 10
9'. From Asia and Australia 12

10. From any Pacific Island except Hawaii or Jarvis Island 11
10'. From Hawaii or Jarvis Island ....*Helicoverpa* sp. ([*H. confusa, H. hawaiiensis, H. minuta, H. pallida*], *H. zea*, or [*H. pacifica*])

11. From Solanaceae, dorsal and subdorsal areas of A1-8 with fine spines evenly distributed (Sannino et al. 1993: fig. 5) ..... *H. assulta*
11'. From other hosts, including Solanaceae; dorsal and subdorsal areas of A1-8 in sinuate longitudinal bands (Bejakovich and Dugdale 1998: fig. 34) ..... *H. armigera*

12. From New Zealand (from Bejakovich and Dugdale 1998) 13
12'. From another part of Asia 15

13. Segments A1-A7 with SDl and L2 pinacula large and closely spaced; microspines in irregular patches around D, SD and L pinacula ..... *H. assulta*
13'. Segments A1-A7 with SDl and L2 pinacula not closely spaced; microspines in wide longitudinal bands on dorsal midline, between setae D2 and L2, and between setae L1 and L3 14

14. Peritreme of spiracle usually pale brown in late instars; microspines absent below ventral margin of seta SDl on segments Al-A6; platelets between microspines sparse .....*H. punctigera*
14'. Peritreme of spiracle black in all instars; microspines present below ventral margin of seta SDl on segments Al-A6; platelets between microspines dense, giving a cobbled appearance .... *H. armigera*

15. From Australia .....*Helicoverpa* sp. (*H. assulta*, *H. armigera*, *H. punctigera*, [*H. prepodes*])
15'. From another region of Asia 16

16. From Tibet .....*Helicoverpa* sp. (*H. armigera*, *H. assulta*, [*H. tibetensis*])
16'. From the rest of Asia except New Zealand, Australia, or Tibet 17

17. From Solanaceae, dorsal and subdorsal areas of A1-8 with fine spines evenly distributed (Sannino et al. 1993? lepintercept lists 1995?: fig..... *H. assulta*
17'. From other hosts, including Solanaceae; dorsal and subdorsal areas of A1-8 in sinuate longitudinal bands (Bejakovich and Dugdale 1998: fig. 34) ..... *H. armigera*

18. Pinacula of A1, A2 and A8 covered with microspines .....*Chloridea* sp. (= *Heliothis*)
18'. Pinacula of A1, A2 and A8 lacks microspines, or at most, with only a few around the edges 19

19. From Central America, Ecuador, Colombia, Venezuela, or the Caribbean ..... *H. zea*
18'. From the rest of South America (including Brazil)..... .....*Helicoverpa* sp. (*H. zea*, *H. armigera*, *H. gelotopoeon*, etc.)

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