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STUDIES IN HAWAIIAN FRUIT FLIES¹

(DIPTERA, TEPHRITIDAE)

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This paper represents a comparative study of the fruit flies of economic importance to fruits and vegetables in Hawaii. There are only three species of fruit flies which cause damage in the Islands; they are: (1). *Dacus* (*Strumeta*) *dorsalis* Hendel, the oriental fruit fly; (2). *D.* (*Strumeta*) *cucurbitæ* Coquillett, the melon fly; and (3). *Ceratitis capitata* (Wiedemann), the Mediterranean fruit fly. The adult characters of these species are rather well known and have been, for the most part, adequately described in the literature. The immature stages, however, have been insufficiently understood and the existing descriptions have not treated many of the characters which are of importance in distinguishing the species. The main purpose of this paper is to present drawings and descriptive information which will aid in the identification of these species in the various stages of their life cycle. It deals chiefly with those characters which are considered of most importance in comparing these species.

GENERAL CONSIDERATIONS

*Dacus*² (*Strumeta*) *dorsalis* Hendel³

The oriental fruit fly is widespread and abundant throughout the Hawaiian Islands. It is one of the most euryphagous of the fruit flies and has been recorded from 109 different hosts in Hawaii. This species will apparently attack almost all types of fruits and many vegetables and other plants.

Dacus dorsalis was first recorded in Hawaii on May 10, 1946, when specimens were reared from mango fruits collected in Honolulu. Later a single female specimen was found in a collection of some 22,500 fruit flies which had been collected, or reared, in Honolulu by O. C. McBride between April and

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²The name *Dacus*, sens. lat., is used pending clarification of the generic classification of the Dacinae.

³1912, Suppl. Ent. 1:18. (*Dacus*).

July 1945. It is believed that this fly was imported from Saipan by returning troops and that it possibly arrived as early as the late summer of 1944. In the absence of its natural enemies and with the ideal ecological conditions in Hawaii the species has been able to build up surprisingly large populations in a relatively short time. It is by far the most serious pest of fruits which has become established in Hawaii. Because of *dorsalis* it is now impossible to raise many fruits fly-free without bagging each individual fruit or protecting them by very frequent and thorough applications of insecticides.

***Dacus (Strumeta) cucurbitae* Coquillett⁴**

The melon fly was brought into Hawaii around 1895 by immigrants from the Orient. It is now widely spread throughout all of the vegetable growing areas in Hawaii and has a devastating effect upon cucurbits, tomatoes, and many other vegetable crops. In Hawaii, the melon fly has been recorded as attacking thirty-six different kinds of plants belonging to twelve families. It is by far the most serious pest with which the vegetable growers have to contend.

***Ceratitis capitata* (Weidemann)⁵**

Prior to the establishment of *Dacus dorsalis* in Hawaii the Mediterranean fruit fly was extremely abundant and was recorded as attacking approximately the same host fruits which *dorsalis* now infests. For some unexplained reason the Mediterranean fruit fly has become relatively scarce during the past two or three years and is now difficult to find in many parts of the Islands. Many entomologists believe that the competition presented by the oriental fruit fly is actually effecting control of the Mediterranean fruit fly. This supposition is entirely theoretical, however, and it will be necessary that a thorough study of the interactions of these two species be made before the competitive effects can be understood. Possibly the Mediterranean fruit fly has become restricted in low-land areas by the drastic curtailment it has caused in the raising of some of its favorite hosts.

C. capitata apparently entered Hawaii, at Honolulu, about 1907 and until the advent of *dorsalis* it was the most serious pest of fruits in the Islands. It is interesting to note that *Ceratitis capitata* evidently came to Hawaii from Africa by way of Southern Australia and *Dacus dorsalis* came from the Orient by way of Micronesia; apparently this is the only place

⁴1899, Ent. News, 10:129 (*Dacus*).

⁵1824, Analecta Ent. 4:55 (*Tephritis*).

in the world where the range of these two species is definitely known to overlap.

ADULT CHARACTERS

The three species of fruit flies treated here are readily distinguishable in the adult stages, and it will not be necessary to discuss more than just their diagnostic characters in this paper.

Dacus dorsalis Hendel

Dacus dorsalis is an extremely variable species. It has apparently been described in the literature under many different names because of the confusing differences in the coloration of some individuals. The extent and significance of these variations will be discussed in a forthcoming paper and will be treated only briefly here. It is now apparent that many of the characters which have been considered of specific or sub-specific value by various authors are not constant and cannot be depended upon for separating species in this particular complex. Color characters are particularly variable and often misleading. Typical specimens of *dorsalis* can be distinguished by color, but where long series have been available for study, wide extremes of color variation have been seen from numerous localities throughout the range of this species.

D. dorsalis adults are readily distinguished from *cucurbitæ* by the differences in wing characters. There are no cross-bands on the wings, no apical spot, and the cubital streak⁶ is narrow.

Head: Most of the head characters which have been used have been found to be of very little value in distinguishing this species. The front typically has a small dark-colored spot at base of each frontal bristle and a brown median spot is usually present; very often, however, the face may be unspotted. The occiput varies from yellow to brownish or blackish and the vertical bristles vary from yellow to black. The palpi are not shaped as in Shiraki's figure.⁷ They are broad, rounded at apices, and gently concave on the dorsal surface. The palpi are of rather uniform thickness, except for the attenuated bases⁸ (fig. 39). *Thorax*: The thoraces of *dorsalis* and

⁶Anal streak of other authors.

⁷1933, Mem. Soc. Sci. Taihoku Imp. Univ. vii: 62, fig. 18.

⁸In general, the palpi characters have not appeared of much value in distinguishing most species of Dacinae which the writer has studied. A few species appear to have reliable differences in the shape of these structures but one cannot always be sure of the true shape of the palpi in dried specimens.

cucurbitæ are differently marked. *D. dorsalis* has just two yellow vittæ on the mesonotum. These extend from the suture to the hind edge of the mesonotum, near the lateral margins. The mesonotum almost always has black or dark brown markings on the median portion. The anterior portion of each mesopleuron is usually brown to black, sometimes with just an obliquely placed black mark extending through it. The sternopleura are all black except for an oblong yellow spot on the dorsal edge, near the posterior margin. The pteropleura are largely brown to blackish, the hypopleura are usually entirely covered by a large black spot, and the metapleura are black along their posterior margins. The metanotum is black on the sides and yellow through the central portion. *Legs*: Typically yellow with discolored coxæ and tibiæ. The legs are often all yellow but intergrade to those individuals which have the tibiæ almost all black and the femora blackened on apical portions. The coloration of the legs is apparently of little value in separating *dorsalis* from other species of *Dacus*. *Wings*: The costal band occupies all of the subcostal cell and cell R_2 ⁹ but does not extend below vein R_3 except at its apex. (There is sometimes a very faint yellowing along the underside of vein R_3 .) The costal band extends across the apex of cell R_3 and about half-way through the apex of cell R_5 . The section of cell R just above M is densely covered with brownish yellow microtrichia, no distinct clear spot is present in this area as in *cucurbitæ*. The r-m cross-vein is almost straight, although somewhat diagonal in position, without a strong curve on the lower portion. Vein R_{4+5} very gently curved beyond the r-m cross-vein and with a noticeably thickened area just beyond the halfway point from r-m to wing apex; this thickening is opposite or very slightly before the apex of vein R_3 . The microtrichia do not extend to the base of cell 1st M_2 but end, except for a few hairs, slightly before a point opposite the forking of R_3 from the radial sector. The cubital streak fills only the lower half of cell M_4 at its base. The upper basal portion of cell M_4 is bare of microtrichia. The cubital streak is much narrower at its broadest point than the greatest width of the cubital cell (fig. 56). *Abdomen*: Chiefly rufous, usually with black horizontal vittæ at bases of terga two and three and with a longitudinal median vitta extending from base of third segment to apex of abdomen. This pattern varies considerably in some specimens. *Female ovipositor*: Very slender and rather sharply pointed. The sub-

⁹The wing veins are named according to the Comstock-Needham system, as modified by Tillyard and Alexander. The writer has used this nomenclature in several other dipterous families.

apical bristles are very small and inconspicuous and are situated well before the apex of the ovipositor. The bristles extend less than half way to the ovipositor tip (fig. 53). The rasper extends over two-thirds of the membranous portion and is produced into a sharp point in the middle at its anterior margin (fig. 44). *Male genitalia*: The finger-like lobes at the apices of the ninth segment are not so slender or elongated as in *cucurbitæ* or *capitata*, but are shorter and more thickened (fig. 47). The apical portion of the ædeagus is very different in shape and structure from *capitata*. It differs from *cucurbitæ* chiefly by having no spiculated area (fig. 50).

Specimens of *dorsalis* average about 8.0 mm. for the body length and 7.3 mm. for the wing length. The wing is about 2.8 mm. wide at its broadest point.

Dacus cucurbitæ Coquillett

Dacus cucurbitæ adults are easily identified by the wing characters (fig. 57), especially by the large apical spot in each wing and by the presence of a broad crossband along the m cross-vein. The upper portion of the r-m cross-vein is covered by a small brown spot and the cubital streak is very broad compared to that of *dorsalis*.

Head: The characters of the head are not distinctive. The frontal spots are typically faint or lacking. The front usually has three pairs of lower orbital bristles while *D. dorsalis* usually has two pairs of lower orbitals, although specimens are often seen which have three. The palpi are slightly longer than in *dorsalis* and have a tendency to be narrower at apex and more swollen below. The palp is thickest at the basal one-third and narrows slightly toward the apex (fig. 40).

Thorax: More consistently paler in color than *dorsalis*, usually with no black markings. It is distinctive (from *dorsalis*) because of the presence of a median yellow vitta extending on the hind part of the mesonotum from the suture to hind margin. The lateral vittæ are also narrower than in *dorsalis*.

Legs: Chiefly yellow, hind tibiæ brownish-yellow. Apparently the leg characters are of no taxonomic value. *Wings*: In addition to the above, the lower one-fourth of the r-m cross-vein is strongly curved and the portion of vein R_{4+5} beyond the swelling on that vein is very distinctly curved upward, making the apical part of this vein sinuate. The swollen portion of vein R_{4+5} is located well before the apex of vein R_3 and is about opposite the m cross-vein in position. The section of cell R directly above cell M is densely covered with microtrichia, except for an oblong bare spot near the apical portion below. The costal band is broad and fills all of cells Sc, R_2 and R_3 . At the wing apex the band expands into a large dark

brown spot which occupies all the apical portion of cell R_3 , extends two-fifths the distance through cell R_5 , and back along vein R_{4+5} over one-third the distance from its apex to the r-m cross-vein. The microtrichia of cell 1st M_2 extend to the base of the cell and fill it entirely except for a narrow clear area extending half the length of the cell along the top side of vein M_{3+4} . The cubital streak is well developed, it fills all of the basal portion of cell M_4 and is distinctly broader than any portion of the cubital cell. The excision at the apex of $Cu_1 + 1st A$ is very acute and more deeply V-shaped than in *dorsalis*. *Abdomen*: Almost all reddish-yellow, with dark basal bands on terga two and three. The band on segment two is usually brown while that on three is black. The median, brown to black vitta is usually present from tergum three to apex of abdomen; however, it is sometimes very faint. *Female ovipositor*: Broader and much longer than that of *dorsalis* or *capitata*. Characterized by the presence of a pair of strong bristles on each side near the apex; these bristles extend as far as the tip of the ovipositor (fig. 54). The rasper is rather short and extends just over half the length of the membranous portion of the ovipositor. The anterior margin of the rasper is only slightly extended in the middle (fig. 45) and is not produced into an acute point. *Male genitalia*: The subapical lobes of the ninth segment are well developed and elongated and from a dorsal view the apical lobes are rather well developed (fig. 48). The ædeagus is somewhat similar to *dorsalis* in shape but the apical portion is densely covered with spiculi (fig. 51).

***Ceratitis capitata* (Weidemann)**

The Mediterranean fruit fly adult can not be confused with any other Tephritidæ found in Hawaii. It is very characteristic and can be recognized by its small size (4.5-5.5 mm. in length) and by the distinctive patterns of marks on the wings and mesonotum.

Head: The males possess a pair of modified bristles on the front that are very distinctive; these bristles are long and spatulate, the enlarged apex is diamond-shaped, and is marked with fine longitudinal striæ (fig. 42). These peculiar appendages are modifications of the second pair (from the vertex) of frontal bristles and are borne on distinct tubercles. The first pair of frontals is very tiny and poorly developed in the males. In the females the second pair of frontal bristles is more strongly developed than are the others but they are not modified as in the male and the front is not tuberculate at their bases. The first pair of bristles is much stronger than in the males and about equal in size to the third and fourth pairs.

The face is entirely yellow or whitish; the front is chiefly pale in color with dark discolorations on sides of lower portion. The palpi are straight on upper edge, convex below (fig. 41). The palpi of *capitata* are much smaller than those of the other species and are somewhat narrowed at the apex and swollen on the ventral portion so that they are widest at their apical two-thirds. *Thorax*: Mesonotum shining black or brown in ground color except for the yellow hind margin and a yellow mark extending along the suture at each side. Humeri yellow to whitish, each with a shining black spot on the upper portion, surrounding base of humeral bristle. Scutellum shining black except for a narrow, undulated, yellow line across its base. Mesonotum with a large densely gray pollinose and white to yellowish pilose area over the median portion. The post-humeral area and sides of mesonotum, except for the yellow notopleura and marks on the suture, are polished black, devoid of pollen or pile. A median, black vitta extends from anterior margin to about even with the suture. In line with the notopleura is a pair of moderately large, shining black spots. Posterior to these, from the dorsocentral to the pre-scutellar bristles, is a pair of large wedge-shaped black spots marked off from the posterior calli and interalar areas by a thin line of pollen on each side. The pleura are yellowish to white, with a row of black bristles along the hind margin of the mesopleura and numerous black hairs over the lower three-fourths of these sclerites. The sternopleura and pteropleura each have a strong black bristle near their upper margins. Metapleura and hypopleura bare, upper third of mesopleura and other sclerites of pleura rather densely covered with yellowish to white pile. Metanotum polished black on upper portion, opaque gray below except for a narrow brownish apex. *Legs*: Entirely yellowish, under surfaces of front femora each with an outer row of long yellowish bristles and an inner row of long yellowish hairs; these form a receptacle for the tibiae in their resting position. *Wings*: Very short and broad compared to species of *Dacus*; they average 5.0 mm. long by 2.5 mm. wide. The maculations are very characteristic, the basal portion is filled with numerous round and elongated dark brown to blackish spots. In the middle portion of the wing is a broad vertical band extending from costal margin to $Cu_1 + 1$ st anal veins, although fading gradually in the lower portion of cell M_4 . This median band is chiefly yellow in color, the upper portion is dark brown in the subcostal cell, the remainder is indistinctly bordered with brown. Cell R_2 almost all filled with a large brownish-yellow spot; this is continuous to the apex of the wing, through the middle of cell R_3 to apex of vein R_{4+5} . This longitudinal spot is yellowish in the middle

portion (through all R_3) and is brown at the apex (end of vein R_{4+5}). Vein R_{4+5} has a small round, dark-colored spot at about half way between the apex and the r-m cross-vein. The submedian portion of cell R_3 also has a tiny brown spot on the inner edge of the yellow band. An elongate brown spot extends along the m cross-vein. The second anal vein is distinct and extends more than three-fourths the distance through the anal lobe (fig. 55). *Abdomen*: Yellowish in ground color, covered with short, chiefly black bristles and with a ring of long black bristles at apex. First tergum grayish in the middle, apical half of second tergum gray pollinose, all of fourth tergum gray pollinose except for a very narrow, yellow base. *Female ovipositor*: The ovipositor differs from that of the other two species by having no setæ on the apical portion (fig. 52). It is much smaller, is sharp pointed, but is not as slender as in *dorsalis*. The rasper is produced into a pointed area in middle, extending toward base of abdomen (fig. 43). *Male genitalia*: From end view the genital portion is broader, not as elongated as in the other two species. The subapical lobes of the ninth segment are slender and finger-like (fig. 46). The ædeagus is very characteristic of the species (fig. 49). The enlarged apex has a sack-like enlargement at the dorsal portion of the apex; this is densely covered with minute spiculi. The genital pore is at the apex, on the ventral surface.

EGG CHARACTERS

The eggs are typical of those laid by most Tephritidæ but they possess characteristics which will separate the three species with which we are dealing. They are pure white in color, elongate elliptical in shape with the ventral edge straight or nearly so and the dorsal surface gently convex. The chorion of the eggs is smooth and without sculpturing.

D. dorsalis eggs vary in size from about 1.03 mm. to 1.30 mm. in length and average approximately 1.17 mm. The eggs are about 0.21 mm. wide. They are slightly smaller than those of *cucurbitæ* and more gradually tapered just before the micropyle. This portion is not distinctly nipple-like as in the other species (fig. 1).

Dacus cucurbitæ eggs are distinguished from the other species by their larger size and by the development of the area around the micropyle. The eggs vary from about 1.14 mm. to 1.35 mm. in length and average approximately 1.30 mm. They average about 0.25 mm. in width. In shape they are most similar to the eggs of *Ceratitis capitata*. The area directly behind the micropyle is somewhat constricted and mammilate in appearance, as in *capitata*. *D. cucurbitæ* eggs are at least one-third larger than those of *capitata* and are

easily separated by size alone. *D. cucurbitæ* and *dorsalis* eggs are more nearly the same size but when the two are placed side by side a significant difference in the average extremes of size is easily seen. A high percentage of the eggs can be recognized by this difference. There is a slight overlap, however and all specimens cannot be differentiated by size. Small eggs of *cucurbitæ* will approximate in size the larger eggs of *dorsalis*. The more distinctly mammilate micropyle will separate *cucurbitæ* (fig. 2).

Ceratitis capitata eggs are very small compared to those of other species. They average about 0.93 mm. in length by 0.17 mm. in width and are about one-fourth smaller than eggs of *cucurbitæ* and one-fifth smaller than those of *dorsalis*. The distinctly mammilate anterior portion readily separates this from *dorsalis* (fig. 3).

GENERAL LARVAL CHARACTERS

The larvæ of the three species are similar in most characteristics. They are creamy-white in color and conform in general shape as do most Tephritidæ that develop in soft juicy media. The papillules and tubercles on the posterior portion of the body are not as useful in distinguishing these species as they are in most fruit fly larvæ. The characters of the respiratory organs, the anal lobes, head, and cephalopharyngeal skeletons appear to be more valuable in separating the species discussed in this paper. The length of the mouth hooks is very important in distinguishing the different instars and is apparently of specific value. The characters used in differentiating the instars are, in general, the same as for many other Diptera.

TECHNICS FOR STUDYING LARVAE

The most satisfactory method which the writer has found of studying the characters of the larvæ has been to use an adjustable (turntable type) examining block. A piece of molding clay is fitted into the block and the larva placed in the desired position in a small hole in the clay. The larva may then be viewed from any angle by slowly revolving the turn-screw on the examining block. This device is especially useful in studying the papillules on the posterior end of the body as well as other characteristics of the larvæ. The papillules are extremely minute and are often difficult to see except from certain angles and under various light conditions. It is usually necessary to apply a small amount of stain to the tip of the body in order that the papillules may be clearly seen. Often these structures will show up more readily if they are silhouetted against a strong light. The microscope light is directed onto a white surface directly beneath the larva so

that the margins of the apex are seen in profile. The best results have been obtained by using Fast Green or Acid Fuchsin stains but any stain which does not form a residue upon drying should be suitable. It is extremely difficult to study and interpret the nature of the caudal papillules and tubercles in slide preparations or in wet specimens. The structures show up more clearly when the specimens are removed from the preserving fluid and the liquid is evaporated off the surface of the body. Care must be taken, however, that the specimen being studied does not dry out too much. As the tissues lose fluid, the integument begins to shrink and wrinkle and much distortion occurs in a short time. To avoid dessication it is necessary to add fluid to the body from time to time when the larva is under observation. Only the mature third instar larvæ can be studied satisfactorily outside a liquid medium. Shrinking and distortion occur so very rapidly with the younger (softer bodied) larvæ that it is not practical to attempt to study them in this semi-dry condition.

The characteristics of the anterior and posterior respiratory organs, the cephalopharyngeal skeleton, anterior and posterior sense organs, and structures on the integument are best studied in slide preparations. Most of the structures stand out more clearly in stained preparations but no stain is needed for the head sclerites. The posterior respiratory organs must be dissected off the body and mounted flat so that a direct dorsal view can be obtained. This is a very delicate and exacting dissection to make on the first instar larvæ and it is often difficult to flatten out the portion of the body bearing the spiracular plates so that the openings can be seen. The cephalopharyngeal skeleton, the anterior respiratory organs, and the head are best studied in cleared whole mounts. Or the head skeleton can be dissected out and mounted separately; the latter procedure is best if a careful study of the sclerites is to be made.

Proper preservation of the larvæ is essential if their characteristics are to be studied. A large share of the immature forms which are sent in for identification are improperly preserved. They are often discolored, badly shrunken, and so contorted that it is very difficult or impossible to observe their characters. The writer has had best success by killing the larvæ in hot water and preserving them in 75 per cent alcohol. The larvæ are placed in cold water and gradually heated nearly to the boiling point. The water is then allowed to cool before the larvæ are transferred to alcohol.

FIRST INSTAR LARVÆ

The first instar larvæ of all three species lack the anterior

respiratory organs and the posterior spiracles have but two openings. The development of the cephalopharyngeal skeleton is very different from that of the later stages and the first instars apparently have no transverse ridges above the mouth hooks. The first instars can be readily recognized by the light colored, tan or pale brown mouth hooks and hypostomal sclerite. The mouth hooks are tiny compared to those of later instars. Only the anterior portion of the pharyngeal sclerite is brown in color and distinctly visible. This character is very useful in separating living larvæ, in or out of media. From a dorsal view the cephalopharyngeal skeleton can readily be observed through the semi-transparent body, and the anterior portions of the pharyngeal sclerites stand out clearly as a pair of small brown dots. The median portion of the head skeleton—that part between the pharyngeal sclerite and the mouth hooks—is very long and slender and rod-like in the first instars (fig. 8); the hypostomal sclerite is not distinctly developed. The mouth hooks are trilobed, with a conspicuous preapical lobe on the ventral portion as in the second instars. The mouth hooks and cephalopharyngeal skeleton can easily be observed through the skin, especially in living larvæ. The larvæ tend to become more opaque when preserved but the membrane around the mouth is quite transparent so at least the pale mouth hooks can readily be seen.

The openings of the posterior spiracles are usually U-shaped (fig. 7) but sometimes form an almost complete ring. The inter-spiracular processes are present and arranged in four groups around the outside edge of each posterior spiracle (fig. 7). The anterior sense organs are well developed and apparently two segmented. The posterior sense organs are not noticeably developed.

The minimum size of the first instar, as it hatches from the egg, is about equal in length to the egg. Immediately after eclosion the larvæ increase rapidly in length.

D. dorsalis first instar larvæ range from about 1.2 mm. to 2.3 mm. in length and average approximately 2.0 mm. when full grown. They conform to the characteristics given above under the general discussion of the larvæ. The mouth hooks are smaller than those of *cucurbitæ* and differ somewhat in shape (fig. 4). The apical lobe is more slender and is separated from the preapical lobe by a more broadly U-shaped concavity. The posterior lobe of the hooks is more slender and elongated than in *cucurbitæ*. The mouth hooks are approximately 0.05 to 0.06 mm. in length.

D. cucurbitæ first instar larvæ range up to about 2.75 mm. in length and average near 2.5 mm. when ready to molt. The mouth hooks are broader and slightly more blunt at the apex

of the anterior lobe (fig. 6). The posterior lobe is thicker and not so slender as in the other species. The openings of the posterior respiratory organs sometimes form a nearly complete circle. The mouth hooks are approximately 0.07 to 0.08 mm. in length.

C. capitata first instar larvæ vary from about 1.0 mm. to 2.5 mm. and average near 2.0 mm. in length when full grown. The mouth hooks are similar to those of *cucurbitæ* but are much smaller in size and with the preapical lobe more strongly developed in proportion to the apical lobe (fig. 5). The mouth hooks are 0.04 mm. in length. The entire cephalopharyngeal skeleton is about 0.17 mm. in length.

SECOND INSTAR LARVÆ

The second instar larvæ have a much more opaque body and have the anterior respiratory organs developed as in the third stage. These organs are usually concave to excised in the middle of the front margin so that each organ is divided into two large lobes which bear the small lobes at their apices. The second instars possess the same number of apical lobes on the anterior respiratory organs as do the third. The posterior respiratory organs have three openings and are distinguished from those of the third instars by their more oval shape and by the lack of numerous transverse lines across the openings (fig. 12-14). The posterior spiracular plates are weakly sclerotized compared to those of the later instar.

The head skeleton is well developed in the second instar and differs markedly from that of the preceding stage. The mouth hooks, as well as the head sclerites, are heavily sclerotized and dark brown to black in color. Each mouth hook is often pale at the extreme apex of the apical lobe, otherwise it is brown to black. The hypostomal sclerite is distinctly developed and the anterior portion of the pharyngeal sclerite is moderately elongated (fig. 9) but not slender and drawn out as in the first instar. The mouth hooks have the preapical lobes well developed but differ in shape from those of the first instar. The transverse ridges above the mouth and the posterior sense organs are well developed.

D. dorsalis range in size from about 2.5 mm. to 5.75 mm. with an average length of approximately 4.50 mm. when full grown. The openings of the posterior respiratory organs are oval in shape and only about one and one-half times longer than wide (fig. 14). There were no cross lines or transverse bars discernible in the specimens studied. The anterior respiratory organs have nine to eleven apical lobes which are very similar to those of the third instar although the anterior margin of each organ is often concave in the middle. The mouth

hooks measure 0.14 to 0.16 mm. in length. They are slightly more slender and more curved beyond the preapical lobe than in *cucurbitæ* (fig. 9).

D. cucurbitæ second instar larvæ range in length from about 3.5 mm. to 7.0 mm. and average approximately 5.5 mm. before molting. The openings of the posterior spiracles are broad and short but decidedly more elongate, and less oval than in the other species. There are also distinct cross bars or lines over the openings (fig. 13). The anterior respiratory organs are similar to those of the third instar, except that they are often concave in the middle of the anterior margin. The anterior respiratory organs are characterized by having eighteen to twenty lobes on the anterior margin. The mouth hooks average 0.16 mm. to 0.18 mm. in length, are slightly thicker at the apices, and are shaped differently from those in the other species (fig. 11).

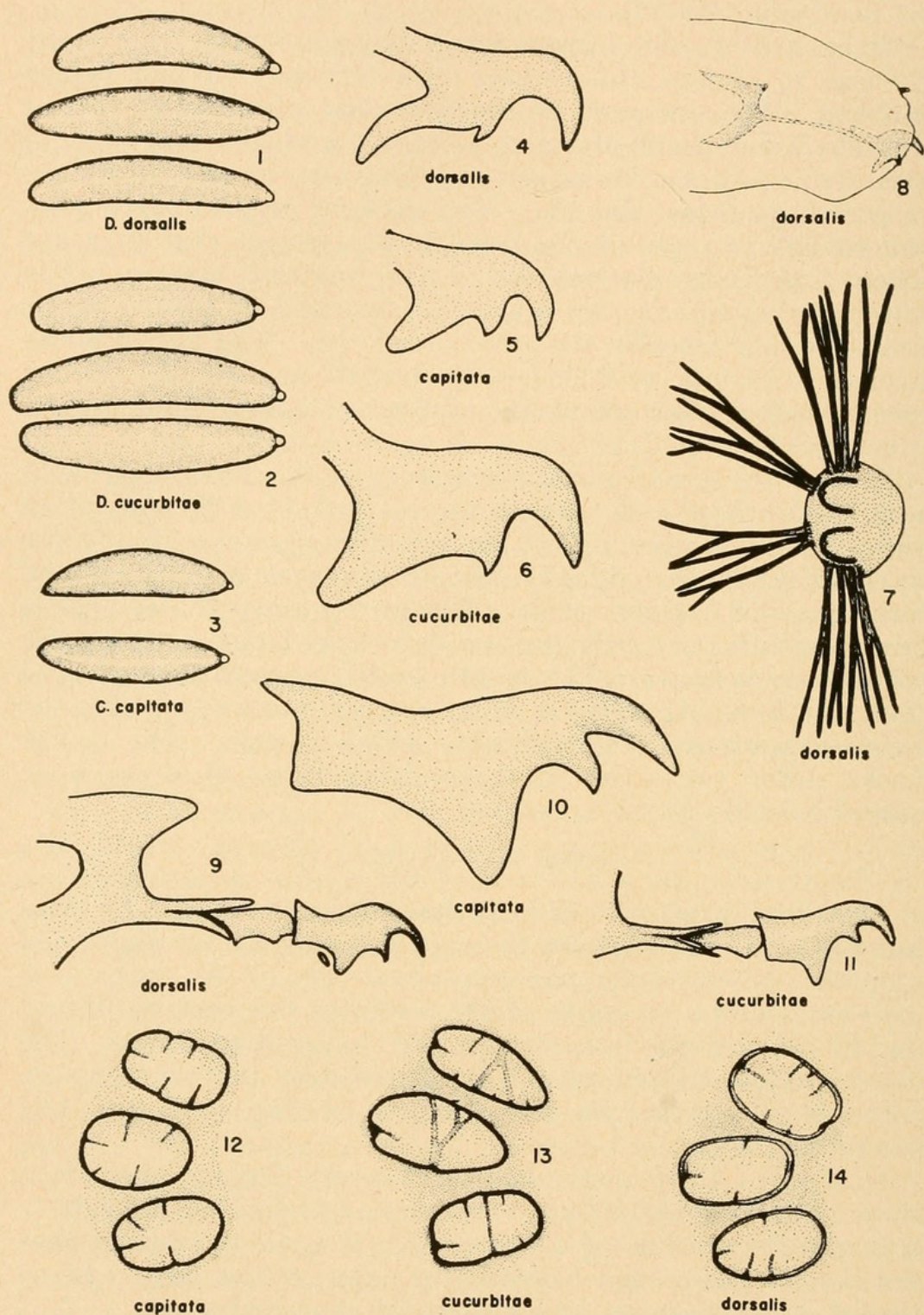
C. capitata second instar larvæ vary in size from about 2.25 mm. to 5.0 mm. and average approximately 4.25 mm. when full grown. The openings of the posterior spiracles are similar to those of *dorsalis* (fig. 12). The openings are about 0.03 mm. long by about 0.02 mm. wide. The anterior respiratory organs are approximately 0.06 mm. wide; their front margins are moderately concave. The mouth hooks measure 0.10 mm. to 0.11 mm. in length and are dark brown to black except for the extreme apex of the apical lobe, which is pale. The mouth hooks differ somewhat in shape from those of *dorsalis* or *cucurbitæ* (fig. 10).

THIRD INSTAR LARVÆ

The third instars are differentiated from the second by lacking the preapical lobes on the mouth hooks, by the shortened anterior portion of the pharyngeal sclerite, by the more elongate and slender openings of the posterior respiratory organs, and by the straight front margins of the anterior organs. The third instars can generally be recognized by their larger size. Some small specimens, however, do overlap with the late second instars.

D. dorsalis third instar larvæ are easily distinguished from those of *cucurbitæ* but are very similar and often difficult to separate from larvæ of *C. capitata*. It is most unusual that the larvæ of two such unrelated groups of flies should be so similar in appearance and structural characteristics.

The third instars range from about 7.0 to 11.0 mm. in length and average approximately 10.0 mm. when mature. The mouth hooks and cephalopharyngeal sclerites are strongly sclerotized and blackish in color. The mouth hooks measure 0.27 mm. to 0.29 mm. in length. The preapical lobes of the mouth hooks



are lacking, although a tiny rudiment of this lobe is sometimes seen in this instar.

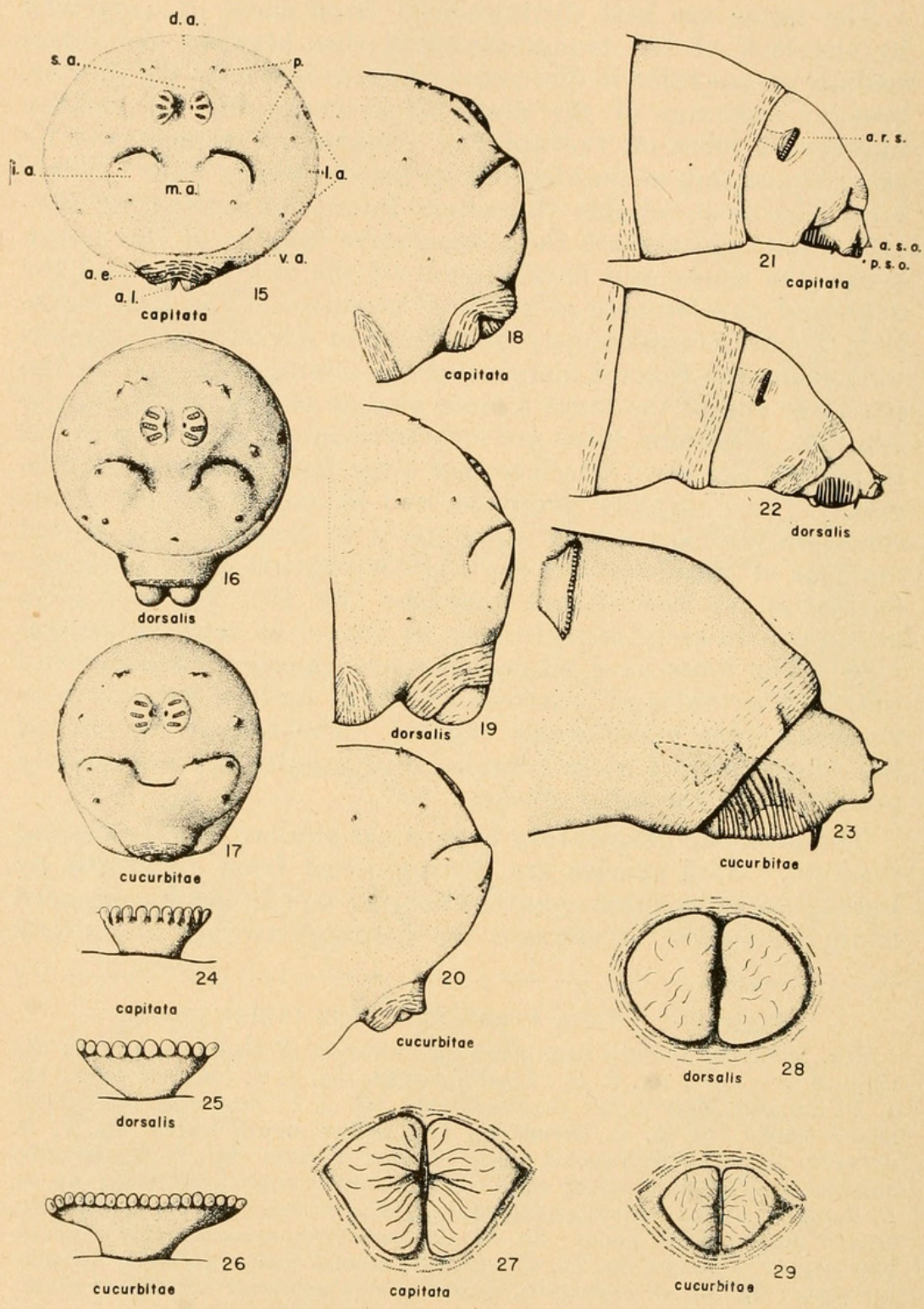
The larvæ are best distinguished from those of *cucurbitæ* by the lack of the transverse dark line between the intermediate areas (refer to discussion of *cucurbitæ*), by the shorter, broader openings of the posterior spiracles, by the smaller number of lobes on the anterior respiratory organs, and by other characters as pointed out in the discussion under *cucurbitæ*. The most reliable characters found for separating *dorsalis* from *capitata* are the comparative lengths of the mouth hooks, the shape and development of the anal lobes, and the degree of development of the anal elevation. The anal elevation is more conspicuously developed in *dorsalis* and extends well below the ventral margins of the lateral areas, giving the posterior end of the larva a more oval or oblong shape than in *capitata*. The anal lobes are very prominent, as seen in direct end view (fig. 16). The lobes are large and rather rounded in shape. They usually protrude well beyond the apex of the elevation and are nearly equal to it in length. The lateral margins of the elevations are slightly concave but not deeply excised at the base of each anal lobe (fig. 19). The anal lobes are approximately semicircular in shape, as seen in ventral view. The lobes have no conspicuous transverse grooves and the tiny wrinkles or furrows on their surface extend more vertically than horizontally (fig. 28). The lateral margins of the anal lobes are more rounded and usually are not acutely pointed as in the other species.

The posterior respiratory organs are similar in *dorsalis* and *capitata*. Both species are distinguished from *cucurbitæ* by having the spiracular openings shorter and broader compared to their lengths. In *dorsalis* the openings average about 0.08

PLATE 14¹⁰. EGGS, FIRST AND SECOND INSTAR LARVÆ

Fig. 1, *Dacus dorsalis* eggs showing extremes of size (the egg on the right is average); fig. 2, *D. cucurbitæ* eggs; fig. 3, *C. capitata* eggs; fig. 4, *D. dorsalis*, first instar mouth hooks; fig. 5, *C. capitata*, first instar mouth hooks; fig. 6, *D. cucurbitæ*, first instar mouth hooks; fig. 7, *D. dorsalis*, posterior spiracular plate of first instar; fig. 8, *D. dorsalis*, anterior end of first instar showing cephalopharyngeal skeleton; fig. 9, *D. dorsalis*, second instar cephalopharyngeal skeleton; fig. 10, *C. capitata*, second instar mouth hooks; fig. 11, *D. cucurbitæ*, second instar cephalopharyngeal skeleton; fig. 12, *C. capitata*, second instar posterior spiracular plate; fig. 13, *D. cucurbitæ*, second instar posterior spiracular plate; fig. 14, *D. dorsalis*, second instar posterior spiracular plate.

¹⁰The drawings of the eggs were made by Dr. G. B. Mainland. The ones of the posterior portions of the larvæ of *D. dorsalis* and *cucurbitæ* were made by Dr. L. D. Tuthill and the drawings of the wings were made by Tokuwo Kono. The writer is very appreciative of this assistance.



mm. in length by 0.027 mm. in width and are approximately three times longer than wide. There is no evidence of the secondary slit extending over the openings in either *dorsalis* or *capitata*.

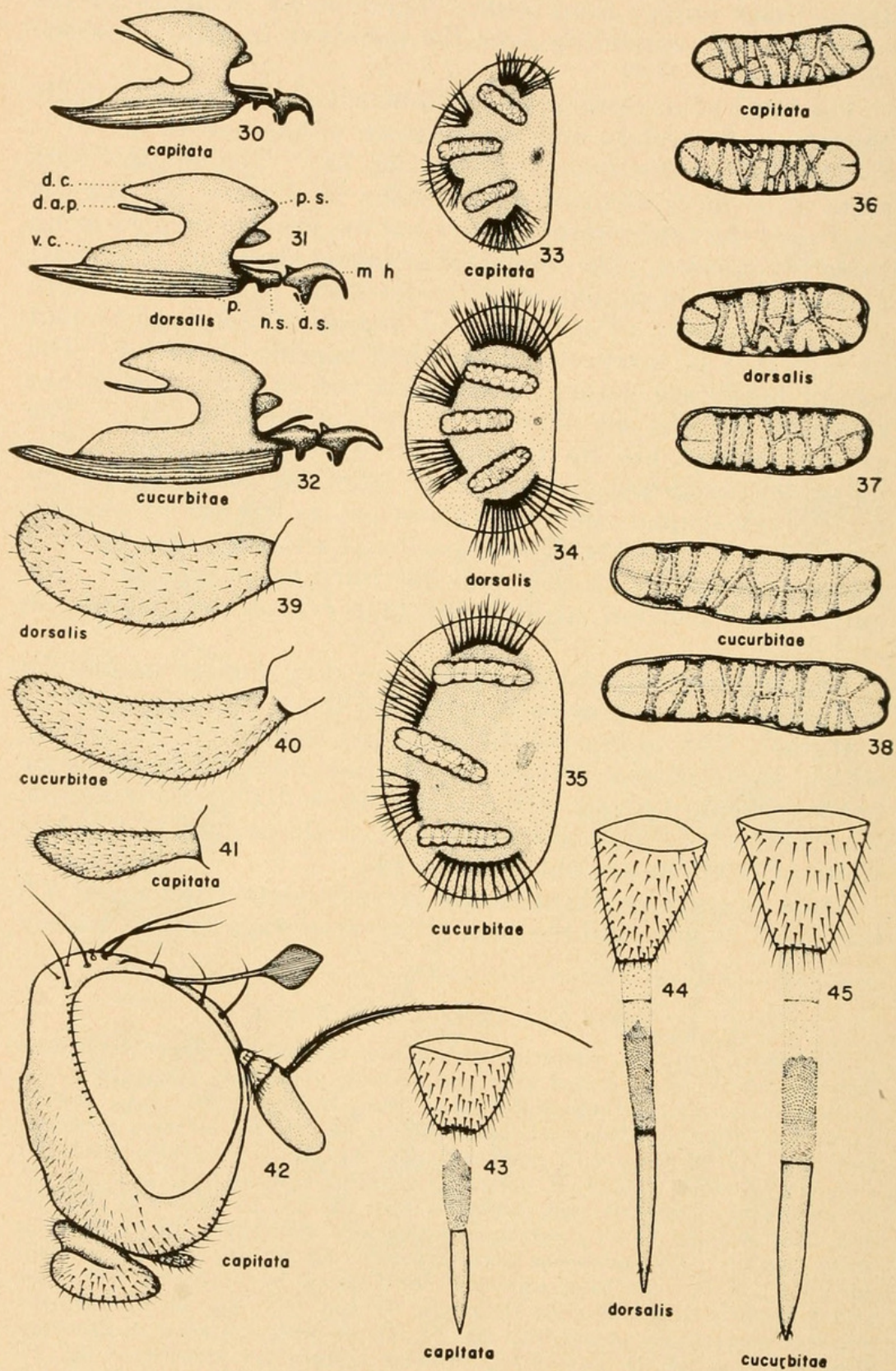
The head of *dorsalis* appears to be somewhat more elongate than that of *capitata* and not so much of the head segment is covered by the first body segment (fig. 22). The mouth ridges seem to be more elongate and slender in *dorsalis* but for the most part the head characters are not too reliable in separating these two species. The cephalopharyngeal skeletons of *dorsalis* and *capitata* are similar in characteristics. The greater length (as given above) of each hook of *dorsalis* (compared to that of *capitata*) is, however, an excellent specific character. The mouth hooks are rather strongly curved in both species but those of *dorsalis* are slightly more slender (fig. 31). The ventral cornua has no tubercle on its dorsal surface. The dorsal accessory piece is separated from the dorsal cornua by a deeply V-shaped cleft but this is not as narrow or sharply pointed as in *capitata*. The hypostomal sclerite is also broader and not as slender on the basal one-third as in *capitata*. The entire head skeleton is distinctly larger in *dorsalis*. (figs. 30 and 31).

The anterior respiratory organs are very similar in *dorsalis* and *capitata* and possess nine to ten lobes on their anterior margins. This character distinguishes them from *cucurbitæ*, which has eighteen to twenty anterior lobes. The anterior organs measure about 0.16-0.2 mm. in width at their apices. The lobes of *dorsalis* are more oval in shape (fig. 25), while those of *capitata* are oblong (fig. 24).

Dacus cucurbitæ third instar larvæ range from about 7.5 mm. to 11.75 mm. and the mature larvæ average approximately

PLATE 15. THIRD INSTAR LARVÆ.

Fig. 15, *C. capitata*, posterior end, drawn to slightly larger scale than figs. 16 and 17 (d.a., dorsal area; l.a., lateral area; s.a., stigmatic area; p. papillules; i.a., intermediate area; m.a., median area; v.a., ventral area; a.e., anal elevation; a.l., anal lobe); fig. 16, *D. dorsalis*, posterior end; fig. 17, *D. cucurbitæ*, posterior end; fig. 18, *C. capitata*, posterior end, lateral view; fig. 19, *D. dorsalis*, posterior end, lateral view; fig. 20, *D. cucurbitæ*, posterior end, lateral view; fig. 21, *C. capitata*, anterior end, lateral view (a.r.s., anterior respiratory structure; a.s.o., anterior sense organs; p.s.o., posterior sense organs); fig. 22, *D. dorsalis*, anterior end; fig. 23, *D. cucurbitæ*, anterior end (drawn to slightly larger scale and a slightly different view than figs. 21 and 22); fig. 24, *C. capitata*, anterior respiratory structure; fig. 25, *D. dorsalis*, anterior respiratory structure; fig. 26, *D. cucurbitæ*, anterior respiratory structure; fig. 27, *C. capitata*, anal lobes, end view; fig. 28, *D. dorsalis*, anal lobes, end view; fig. 29, *D. cucurbitæ*, anal lobes (drawn to same scale as 27 and 28 but specimen not as fully developed).



11.0 mm. *D. cucurbitæ* is distinguished from the other species by a variety of structural characters. The most useful field character is the presence of a conspicuous dark brown to black sclerotized line extending transversely between the intermediate areas (fig. 17). This is apparently a reliable character in mature larvæ and can easily be seen with a hand lens. The transverse line is not present in first and second instar larvæ or in the early third instar. The dark line is about as long as the stigmatic plates are high.

The length of each opening of the posterior respiratory organs in relation to its width is very characteristic in this species (fig. 38). The openings are long and slender, compared to those of *dorsalis* and *capitata*. The openings measure 0.11 mm. in length by 0.02 mm. in width; they are approximately five times longer than wide. It is interesting to note that the thin transparent membrane covering the opening and the narrow secondary slit, as mentioned by Varley¹¹, is plainly visible under high magnification (fig. 38). The secondary slit has not been observed on the other two species except for slight indications of it near the ends of the stigmatic openings. It may be that the slit is incomplete in *capitata* and *dorsalis* and does not actually cross over the entire surface.

The anterior respiratory organs are useful in distinguishing *cucurbitæ* in the second and third instars. These organs are much broader and have a more attenuated base and more numerous apical lobes than in the other two species. The anterior respiratory organs average about 0.3 mm. in width in this instar and have eighteen to twenty small rounded lobes on their anterior margins. The lobes are much smaller and less distinct than those of the other two species. The anterior organs are nearly twice as broad as those of *C. capitata* and one-third broader than those of *dorsalis*.

¹¹1937, Proc. Roy. Ent. Soc. Lond. Ser. A, 12:116, Fig. 4.

PLATE 16. THIRD INSTAR LARVÆ AND ADULT CHARACTERS.

Fig. 30, *C. capitata*, cephalopharyngeal skeleton; fig. 31, *D. dorsalis*, cephalopharyngeal skeleton (d.c., dorsal cornua; d.a.p., dorsal accessory piece; p.s., pharyngeal sclerite; v. c., ventral cornua; p., pharynx; h.s., hypostomal sclerite; d.s., dental sclerite; m.h., mouth hooks); fig. 32, *D. cucurbitæ*, cephalopharyngeal skeleton; fig. 33, *C. capitata*, posterior stigmal plate; fig. 34, *D. dorsalis*, posterior stigmal plate; fig. 35, *D. cucurbitæ*, posterior stigmal plate; fig. 37, *C. capitata*, openings of posterior spiracle; fig. 37, *D. dorsalis*, openings of posterior spiracle; fig. 38, *D. cucurbitæ*, openings of posterior spiracle; fig. 39, *D. dorsalis*, palpus of adult; fig. 40, *D. cucurbitæ*, palpus of adult; fig. 41, *C. capitata*, palpus of adult; fig. 42, *C. capitata*, head of male, lateral view; fig. 43, *C. capitata*, female ovipositor (not fully extended); fig. 44, *D. dorsalis*, female ovipositor; fig. 45, *D. cucurbitæ*, female ovipositor.

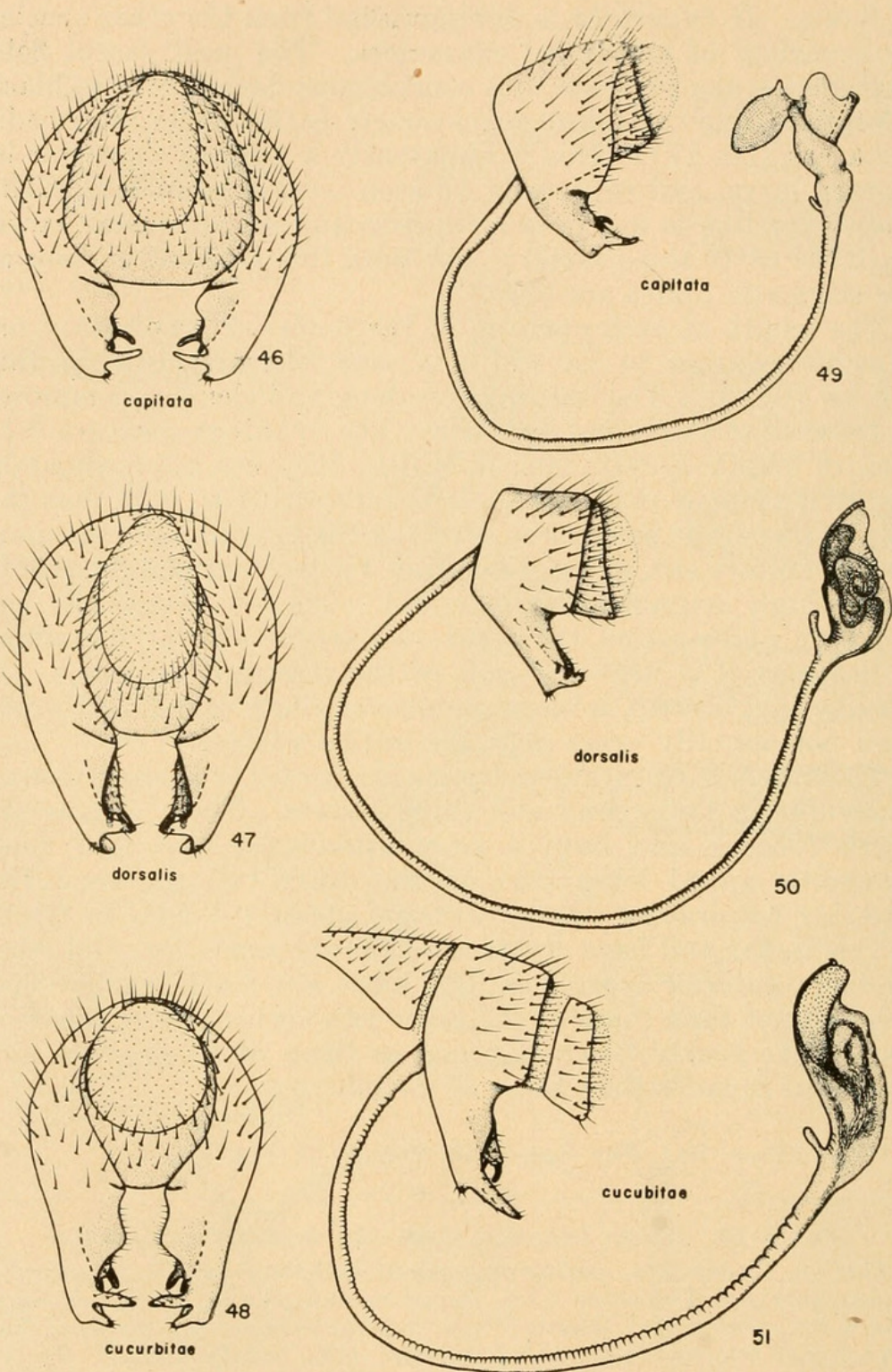


PLATE 17. MALE GENITALIA.

Fig. 46, *C. capitata*, end (dorsal) view; fig. 47, *D. dorsalis*, end (dorsal) view; fig. 48, *D. cucurbitae*, end (dorsal) view; fig. 49, *C. capitata*, lateral; fig. 50, *D. dorsalis*, lateral; fig. 51, *D. cucurbitae*, lateral.

The head is slightly broader in *cucurbita* and not so attenuated as in the other two species. The mouth hooks are broader and not as strongly curved or as pointed (fig. 32). The hypostomal sclerite is broader and not as attenuated at its base. The dorsal accessory piece of the pharyngeal sclerite is separated from the dorsal cornua by a deeply U-shaped cleft (fig. 32), not a narrow V-shaped cleft. The entire cephalopharyngeal skeleton of *cucurbita* is about one-sixth larger than that of *dorsalis* and one-third larger than *capitata*. The transverse ridges behind the mouth hooks are more numerous and closer together than in the other species; there are eighteen to twenty ridges on each side of the head (fig. 23). The second and third body segments have six or more rows of spinules extending all the way around the body.

The anal elevation is rather prominent but extends scarcely, or not at all, beyond the lower margins of the lateral areas, as seen in end view (fig. 20). The anal lobes are small and usually inconspicuous, often completely hidden within the anal elevation, and visible only from a ventral view. The lobes are more similar to those of *C. capitata* than to *dorsalis*. The lobes are pointed at the sides and possess numerous transverse furrows (fig. 29).

Ceratitis capitata (Wiedemann). Much of the discussion under *dorsalis* will also pertain to this species. It is easily distinguished from *cucurbita* but closely resembles *dorsalis*. The differences in the lengths of the mouth hooks and the development of the anal lobes are apparently the most constant characters which can be used in separating these species.

The third instar larvæ range from about 6.5 mm. to 10.0 mm.; the mature larvæ average about 9.0 mm. The mouth hooks are 0.21 mm. in length, they are strongly sclerotized, black in color, and lack the preapical lobe.

C. capitata is best distinguished from *dorsalis* by the shorter mouth hooks and cephalopharyngeal skeleton; by the less conspicuously developed anal elevation; and by the rather small, usually poorly developed anal lobes. In most specimens the lobes project barely beyond the lower margin of the elevation and the anal elevation itself does not project below the ventral margins of the lateral areas (fig. 18). From a direct end view the body is more nearly round in outline (fig. 15); it is about as wide as long and not as oblong as in *dorsalis*. The anal lobes are rather cordate in outline and are inconspicuous compared to those of *dorsalis*. The lobes have numerous transverse furrows or wrinkles extending from their inner margins (fig. 27) and usually have a slight transverse depression through the central portion. The lateral margins are acutely produced and the apical margins of the anal elevations are

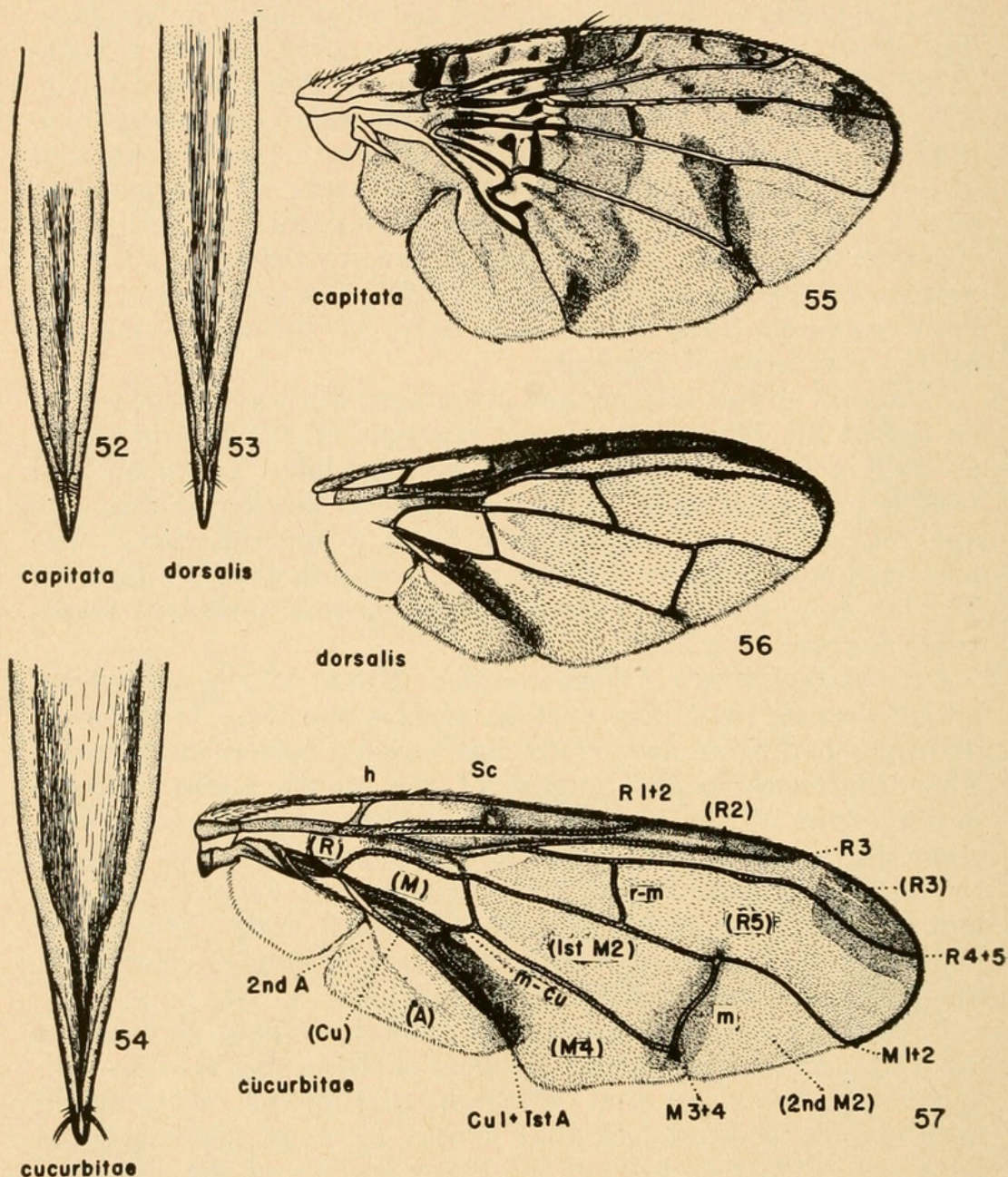


PLATE 18. FEMALE OVIPOSITOR AND MALE WINGS.

Fig. 52, *C. capitata*, apex of female ovipositor; fig. 53, *D. dorsalis*, apex of female ovipositor; fig. 54, *D. cucurbitae*, apex of female ovipositor; fig. 55, *C. capitata*, wing of male; fig. 56, *D. dorsalis*, wing of male; fig. 57, *D. cucurbitae*, wing of male.

rather deeply excised at the base of each lobe (fig. 18).

A conspicuous transverse furrow is present just above the anal elevation in *capitata* (fig. 15). This groove curves upward at the sides toward the intermediate areas. On each side of the posterior stigmatic plates is a slight depression extending longitudinally; this appears to be more distinct than in *dorsalis*. A fairly distinct transverse furrow is usually present in the area between the stigmatic plates and the dorsal papillules.

The head is broader compared to its length and is apparently more retractile than in most *dorsalis*. The first body segment usually extends over the basal series of mouth ridges. The ridges are somewhat shorter and thicker than in *dorsalis*. The anterior respiratory organs are narrower than in *dorsalis* and are scarcely over half as wide as those of *cucurbitæ*. The organs measure about 0.16 mm. in width and the lobes are more oblong in outline than in *dorsalis* (fig. 24). The mouth hooks are smaller but not quite as slender as in *dorsalis*. The ventral cornua has a tubercle developed on its top margin toward its base. The hypostomal sclerite is smaller, more slender than in *dorsalis*, and the dorsal accessory piece is separated from the dorsal cornua by a narrow cleft. This is more sharply pointed at the base of the cleft than in *dorsalis* (fig. 30).

The openings of the posterior respiratory structures are about 0.024 mm. in width by about 0.07 in length (figs. 33, 36).

PUPAL CHARACTERS

The puparia of all three species are similar in shape and general characteristics. They vary considerably in color from pale tan to dark brownish-yellow. The color of the puparia does not appear to be of specific importance and varies greatly in various series of specimens. The age of the puparia and in many cases the host in which the larvæ fed have effects upon the coloration. The puparia of *cucurbitæ* usually have a more distinctly ringed appearance due to narrow bands of yellow extending around each segment. This is not constant, however, and the other species often exhibit this characteristic but usually to a lesser degree.

Since the characters of the anterior and posterior respiratory organs carry over directly from the larvæ, the more numerous lobes and the comparative measurements of the anterior and posterior respiratory organs are the same as in the third instar larvæ. The size of the anal area is useful, as in the larvæ, although in the puparia this area is never lobate.

D. cucurbitæ can be usually recognized by the dark trans-

verse line across the middle of the posterior end (as in the mature larvæ). This line is sometimes absent in pale puparia but can usually be depended upon to distinguish this species. *D. cucurbitæ* can also be separated by the wider anterior respiratory organs and the more elongate openings of the posterior spiracles, as has been discussed under the third instar larvæ. The puparia range from 4.8 mm. to 6.0 mm. and average approximately 5.5 mm. in length.

D. dorsalis and *capitata* pupæ are difficult to separate. The majority of specimens can, however, be distinguished by comparing the widths of the anal areas, the widths of the anterior respiratory organs, the lengths of the mouth hooks, and sizes of the head skeleton when the internal sclerites can be observed through the skin of the puparia. The anal area of *D. dorsalis* measures approximately 0.29 mm. in width. *C. capitata* averages 0.23 mm. across this area and *D. cucurbitæ* 0.18 mm. The other characteristics mentioned above are the same as for the third instar larvæ.

D. dorsalis puparia range from 3.8 mm. to 5.2 mm. in length and average about 4.9 mm. *C. capitata* range from 3.5 mm. to 4.9 mm. and average about 4.5 mm. in length.

KEY TO SPECIES DISCUSSED

ADULTS

1. Mesonotum with polished black areas and patterns of dense gray, no yellow vittæ present. Scutellum black except for a narrow basal portion. Wings broad, with numerous yellow and black maculations as in fig. 55. Face entirely yellow, second pair of frontal bristles modified into a spatulate structure in the males (fig. 42). *Ceratitis capitata* (Wied.)
- No polished black areas on mesonotum; yellow vittæ present; scutellum all yellow; face with black spots; wings more slender and differently marked than in *Ceratitis* (figs. 56-57) 2
2. Mesonotum with three yellow, longitudinal vittæ behind the suture. Wings with a large, brown apical spot and a broad transverse band extending over the m cross-vein (fig. 57) *Dacus cucurbitæ* Coq.
- Mesonotum without a median yellow vitta. Costal band of wing not expanded at apex and cross-vein m not clouded (fig. 56) *Dacus dorsalis* Hendel

EGGS

1. Smaller eggs, about 0.93 mm. in length by 0.17 mm. in width (fig. 3) *Ceratitis capitata* (Wied.)
- Larger eggs, approximately 1.17 mm. or more in length by about 0.21-0.25 mm. in width 2

2. The area bearing the micropyle constricted, mamillate in appearance (fig. 2). Eggs averaging approximately 1.30 mm. in length by 0.25 mm. in width.....*Dacus cucurbitæ* Coq.
Area bearing the micropyle gently tapered, not distinctly mamillated (fig. 1). Eggs averaging approximately 1.17 mm. in length by 0.21 mm. in width.....*Dacus dorsalis* Hendel

LARVÆ—THIRD INSTAR

1. A conspicuous dark brown to black line usually present on the posterior end, extending transversely between the intermediate areas (fig. 17). Anterior respiratory structures with eighteen to twenty lobes (fig. 26). The openings of the posterior respiratory organs are elongate and slender, five times longer than wide (fig. 38), and measure approximately 0.11 mm. by 0.02 mm.....*Dacus cucurbitæ* Coq.
No such transverse line present. Anterior respiratory structures with ten to eleven lobes (figs. 24-25) and the openings of the posterior organs shorter and broader compared to their length. The openings are approximately three times longer than wide and measure about 0.08 mm. in length by 0.02 mm. in width (figs. 36-37)..... 2
2. Anal lobes conspicuously developed, projecting well below the ventral margins of the lateral areas (fig. 16). Anal lobes with no conspicuous transverse grooves or depressions; lateral margins more rounded, not acutely pointed (fig. 28). The mouth hooks measure 0.27-0.29 mm. in length (fig. 31).....*Dacus dorsalis* Hendel
Anal lobes inconspicuous, usually protruding but slightly beyond the anal elevation (fig. 15). The lobes are rather cordate in outline, somewhat pointed on outer margins, and with numerous transverse furrows and usually a slight transverse depression through the central portion (fig. 27). The mouthhooks measure 0.21 mm. in length (fig. 30).....*Ceratitis capitata* (Wied.)

PUPÆ

1. A dark colored transverse line, usually present, across the middle of the posterior end (as in mature larvæ): Anterior and posterior respiratory organs as in first part of couplet 1 under larvæ.....*Dacus cucurbitæ* Coq.
No such transverse line present, fitting second portion of couplet 1 under larvæ..... 2
- 2.¹² Anal area measuring approximately 0.29 mm. in width. The mouthhooks measure 0.27-0.29 mm. in length.....*Dacus dorsalis* Hendel
Anal area measuring approximately 0.23 mm. across. The mouthhooks are about 0.21 mm. in length.....*C. capitata* (Wied.)

¹²These characters are not always satisfactory for separating the puparia.



Hardy, D E. 1949. "Studies in Hawaiian fruit flies (Diptera, Tephritidae)."
Proceedings of the Entomological Society of Washington 51, 181–205.

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