Some Aspects of the Life History and Bionomics of the Fig Moth, *Ephestia cautella* (Wlk.), and some Comparisons with the Mediterranean Flour Moth, *E. kuhniella* (Zell.), and the Tobacco Moth, *E. elutella* (Hb).

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I) INTRODUCTION.

Order: Lepidoptera
Suborder: Heteroneura
Superfamily: Pyraloidea
Family: Phycitidae

(from Imms, 1934).

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The larvae of the three common species of *Ephestia*, namely, *E. cautella*, Wlk., *E. elutella*, Hb., and *E. kuhniella*, Zell., are serious pests of various stored food products, especially cereals, dried fruit, nuts and cacao, as well as tobacco. In recent years the storage of large quanties of these products in warehouses has made the ravages of these insects both more important and noticeable. At the same time, increased facilities for transport have not only directly enlarged the range of the species, but have opened up new countries as a source of various products and so still further spread the pests, so that they now have a world-wide distribution.

These species often occur together on stored products, e.g. *E. elutella* and *E. cautella* on dried fruit, or *E. kuhniella* and *E. elutella* on grain (Hinton, 1942); *E. elutella* and *E. cautella* on cacao, (Herford, 1933), and nuts, (Curran, 1926). Sometimes all three are found together on the same products. To know what species are present is of considerable importance, since they differ in the amount of damage they are likely to do, in their resistance to fumigants and in the frequency with which they are recorded as pests of other products.

Hitherto, the species have been differentiated almost entirely by their wing pattern, slight differences in the wing venation and in the scale tufts (found in the wings of the males), being used to a lesser extent. Unfortunately, the pattern is often obscure and highly variable, and tends to become rubbed off the wings with increasing age, so that in the past, misidentifications have been very frequent. Recently, Curran, 1926, showed that the males of the principal species infecting stored products could be very easily distinguished by the structure of the external male genitalia. Richards and Herford, (1930), and Richards and Thomson, (1932), have focussed their attention on the characters provided by the male and female genitalia, and have found that they provide stable characters for identification, while the specific differences are of considerable magnitude.

Similarly, it had not hitherto been possible to identify the larvae with certainty except by breeding them out, which is unsatisfactory both because of the time it takes and because it frequently happens that many of the larvae die. But Hinton, (1942 and 1943), has found stable characters both for the 1st instar larvae and final instar larvae on which to differentiate the species.

The eggs of all the three specis are rugose, and Lehmensiek and Liebers, (1938), have discovered specific differences in the patterns of the ridges.

The pupae do not afford a reliable guide for identification, since their characters tend to vary within a species.

In this paper, the morphological differences among the three common species of Ephestia have been confirmed by the present author, so that they may be easily identified. The life history of E. cautella has also been worked out, as well as some aspects of the life history of E. elutella and E. kuhniella. These three species have been found to differ at certain points of their life histories. Finally, the results of other authors have been compared with the findings of the present author.

2) DIAGNOSIS OF THE GENUS EPHESTIA, G.N.

Richards and Thomson, (1932), have given a full description of the diagnostic characters of Ephestia, but the following description is a summary of the more important characters:-

The face is smooth without a projecting cone of scales. Both the maxillary and labial palpi are three-segmented, the former being short and filiform, while the latter are moderately long and clothed with appressed scales.

"Forewings with Sc. meeting the Costa at about its middle, R_1 obsolescent before reaching the costa, R_2 either reaching the costa or obsolescent just before it; R_3, R_4 and R_5 coincident; M_2 and M_3 coincident; one anal vein present; only veins M_1, M_2, Cu_{Ia} and Cu_{Ib} received by the termen, Cu_2 absent, ... The base of the costa in the male sometimes deflected towards the undersurface of the wing, enclosing a tuft of modified scales...

Hindwings with Sc+R+M anastomosed to near the middle of the wing; $Sc+R_1$, arising near the apex of Rs, sometimes co-incident with it..; M_{2+3} and Cu_{Ia} always closely approximated in the neighbourhood of M - Cu;.. Veins Cu_{Ia} and 2A each with a defined pecten of hairs, often more developed in the male than in the female, that on the anal vein also often preceded by a minute tuft of modified scales.

Markings: forewings with three transverse lines: the first usually before the middle of the wing and darker in colour, bordered inwardly with paler scales; the second line beyond the middle, paler, outwardly margined with dark scales, sometimes inwardly also, the third line consisting of a series of dark spots just before the apex; on the disc of the wing a small dark spot, the orbicular. The discal end of this line is frequently darker than the rest of it, forming another dark spot, the claviform;... Hindwings whitish or greyish, rarely darker,... sometimes with a subterminal dark line...

In the male the eighth tergite is usually modified; the sides of the tergite are largely membranous, but an apical area and a narrow central strip are more heavily chitinised; at the sides anteriorly are narrow chitinised strips from which arise tufts of modified scales.

External male genitalia.

Saccus with a median membranous area....; valves with a strongly chitinised dorsal costa which is bifurcated anteriorly, ... the basal margin reflexed forming a small sacculus;... anellus usually exhibiting chitinised areas: 2 of these are ventral and often fused across the median line, the other two are dorsal and appear, after the extraction of the aedeagus, as a pair of thickenings in the ventral wall of the tegumen; each of these dorsal thickenings sends out antero-laterally a process which is in close connection with the inner bifurcation of the costa, posteriorly they are sometimes fusted together across the median line..

The gnathos is a small median structure, sometimes emitting 2 lateral arms, and supported on a pair of struts: these struts run from the gnathos anteriorly, then curve sharply round and join the sides of the uncus: .... the anal tube emerges from the substance of the tegumen at a point immediately posteriorly to the gnathos; the ventral wall of the free part of the anal tube is sometimes thickened to form a subscaphium, which is often transversely striate: the uncus is broadly rounded; the tegumen laterally, at a point just dorsal to the articulation of the valve, is produced into a small lobe (E, cautella, Wlk.),or a finger-shaped process. (see plate 5).

External female genitalia.

The 8th tergite sometimes evenly chitinised, sometimes with antero-lateral membranous areas, leaving a central more chitinised portion, whose shape varies specifically: 8th Sternite chitinised laterally, with a more or less central membranous area; ovipositor of simple structure:.... bursa copulatrix large, the lamina dentata, ... usually replaced by 2-18 chitinised plates; the walls of the bursa sometimes also in part studded with small chitinised spots, bearing minute teeth projecting into the bursa; the ductus bursae either with similar tooth-bearing spots,.. or with a long, chitinised plate; more rarely the whole ductus is evenly chitinised: the ostium bursa lies on the membrane between the 7th and 8th sternites. (see plate 6).

3) TECHNIQUE.

Details of technique will be described under the various sections but the following is a brief description of the more general methods of technique:-

Methods of rearing larvae.

The larvae of all three species were reared in ball fruit jars with wide mouths. They were kept closed by means of corks with a very fine wire mesh plus organdie gauze to keep out parasites. It was found that cashew nuts were the most suitable medium for growth, since they have the advantage of being relatively dry and not liable to mould infestation unless supporting a very large population of larvae. Furthermore, they render the examination of larvae relatively easy, since individual nuts may be removed and the larvae therein easily examined. Therefore, stock cultures were reared on cashew nuts, as well as dried fruit, raisins and chocolate to a certain extent.

Stock cultures were also raised on a cheap artificial medium advocated by Haydak, 1936, thus: 16½ oz. glycerine was thoroughly mixed with 16½ oz. honey, and stirred into a mixture of dry material composed of 12 oz. mealie meal, 6 oz. No. 1 unsifted boermeal, 6 oz. bran, 3 oz. dry yeast and 6 oz. powdered milk. This mixture was used when required.

E. kuhniella was also reared on No. 1 unsifted meal, as advocated by Ullyett and van der Merwe (1947), and E. elutella reared on tobacco as well, with lesser success.

The larvae were reared at room temperatures and in the warm room with a constant temperature of 85°F. and constant relative humidity of 60%. The length of development varies at different temperatures, for the eggs, larvae and pupae and the nature of the food also influences the length of larval life. A thermohydrograph was used to record the temperature and humidity in the warm room and at room temperatures.

Although sometimes two or three generations were bred on the same food without fresh supplies being added, the old cultures were periodically destroyed and the jars sterilised in an autoclave.

The larvae were provided with strips of double-faced corrugated board in which to pupate, the number of strips depending on the number of larvae. The majority of the larvae crawl into these apertures, but some pupate between, and on the surface of, the food medium, or between the food medium and the glass, especially in the case of E. kuhniella.

The adults were collected by suction or by hand and introduced into breeding cages, each species having its own cage. The cages were eighteen inches square and twenty-five inches long with four sides of calico and provided with a glass door. The floor was of wire gauze with a compartment underneath it containing a large sheet of paper. Eggs laid by the moths were dropped through the gauze onto brown paper below, and were collected when required. The moths were fed on a mixture of water and honey soaked up in cotton wool and contained in a wire gauze cylinder, which was suspended from the roof. This increases the fecundity of E. cautella and E. elutella, according to Norris, (1933 & 1934). If eggs were required they were counted on black paper marked into squares. Generally, from 200 - 300 eggs were gently brushed onto the food medium in jars of 2 pint capacity, the food material occupying about half the volume of jar.

In the case of E. elutella, it was found that the females preferred to oviposit directly onto the sides of the cage, and in cracks and crevices, rather than through the gauze. Therefore, the moths of this species were placed in a large dual display jar and allowed to oviposit directly onto pieces of organdie gauze to which the eggs adhered. The gauze was then removed and the eggs counted in the usual way.

4) DISEASES IN THE COLONY.

In the beginning, it was found that large numbers of larvae, especially those of E. elutella, died during growth, sometimes resulting in 90% mortality. The larvae would become dark brown and soft, and after death, turn black and brittle. This occurred especially in the warm room, but also at room temperatures. Samples were sent to parasite laboratories in Natal, and thence to America, but the casual organism was not identified, and was thought to be a virus. However, after sterilisation of all the bottles and food medium in an autoclave the disease was reduced to a minimum.

There were also occasional outbreaks of Microbracon species, a parasitic wasp which lays its eggs in the living larvae of all three species. By using cork tops covered with fine wire mesh and further covered with organdie, the wasps were usually prevented from obtaining entrance to the jars or ovipositing into larvae on the opposite sides of the gauze. However, in spite of all these precautions, some jars occasionally became contaminated, and the contents of these were destroyed.

Cultures were also contaminated by small mites of the species Pediculoides ventricosus which destroyed the eggs by sucking out the contents. The warm room was periodically washed down with gammatox to destroy the mites, and the bottles at room temperature kept on a table with its legs standing in tins of paraffin. These ~~numbers~~ measures served to reduce the numbers of mites, but they were never completely destroyed.

The next section is concerned with the morphological differences among the three species of Ephestia. As has been mentioned before, it is most important that these species are properly identified, since they differ in the amount of damage they are likely to do, and in their resistance to fumigants (Hinton, 1942). They have also been found to differ in the lengths of their life histories (see section 6).

5)SYSTEMATICS.

(a) Possible differences in the eggs.

The eggs of all three species are white to pale yellow, sometimes darker yellow in the case of E. elutella, and are about half a millimetre in size. The eggs all turn darker a few days after they have been laid, those of E. cautella often becoming orange or a dark buff or yellow colour. When first laid, the eggs of all the species are covered with a sticky glue which in most cases fastens them securely to the surface upon which they are laid; however, in the case of E. cautella the eggs are more brittle and do not adhere readily to any surface, in contrast to the other 2 species.

The eggs exhibit specific differences in shape, those of E. cautella being barrel-shaped or nearly spherical, those of E. elutella being oval and those of E. kuhniella being elongate-elliptical.

When examined microscopically, the eggs exhibit a markedly rugose structure, with a pattern of ridges and valleys joining each other, these patterns also exhibiting specific differences. Lehmensick and Liebers, 1938, have noticed how the patterns differ in the three species, and their observations have been confirmed by the present author.

E. cautella. (Plate I, fig.A). This is the only species with a regular surface structure, with longitudinal ridges in more-or-less straight lines, and transverse smaller ridges radiating from the longitudinal ones.

E. elutella. (Plate I, fig.B). There is no regular arrangement of ridges, of which there are more than in the other 2 species. Furthermore, instead of longitudinal ridges, there are a number of points with smaller ridges radiating in all directions from them.

E. kuhniella. (Plate I. fig.C). Again, there is no regular arrangement of ridges, but in this case the longitudinal ridges are larger, and fewer in number than the other 2 species. The transverse ridges also radiate in all directions from the longitudinal ridges, but the former are not as twisted as those of E. elutella .

The lengths and breadths of the eggs were also measured with an oculomicrometer, and the microscope lens used was such that 80 divisions corresponded to 1 millimetre. Therefore, each measurement was divided by 1/80 to convert it to millimetres. One hundred eggs of each species was measured. The results are as follows:-

Table I - Dimensions of the eggs of Ephestia.

Species	length in mm.		Breadth in mm.		Length x Breadth (sq. mm.)
	range	average	range	average	average
E. cautella	.31-.44	.38	.22-.35	.29	.118
E. elutella	.36-.56	.50	.23-.42	.35	.172
E. kuhniella	.46-.66	.55	.28-.48	.33	.180

The results have also been expressed graphically, (plate 7), and from the graphs and table I, it is seen that the 3 species overlap to a certain extent, although the graph of lengths x breadth shows clearly that the eggs of E. cautella are the smallest, and those of E. kuhniella are the largest. The eggs of E. elutella and E. kuhniella have approximately the same length, while the eggs of E. cautella are much shorter. As regards the breadths, there is much more overlap, with a tendency for E. cautella to have the shortest breadth, and E. elutella the longest.

(b) Possible differences in the larvae.

The first stage larvae of all three species are delicate white, rather hairy, and just visible to the naked eye, being about 1 mm. long. The head capsule is the widest part of the body, and is light brown in colour. Hinton (1943 and 1944), has worked out a key for the separation of the first-stage larvae. His observations have been confirmed by examination of the larvae by the present author and the key is as follows:-

1) "Eighth abdominal segment with seta epsilon separated from the spiracle by a distance equal to very slightly more, or to distinctly less, than the diameter of the spiracle.... E. cautella". (see plate 2, fig B).

"Eighth abdominal segment with seta epsilon separated from the spiracle by a distance equal to much more than the diameter of the latter.......(2). (see plate 2, fig. BI and B3).

2) "Mandible, when viewed ventro-mesally, with outer ventral tooth not forming part of the outer margin of the mandible, but displaced mesally so

larva are 4 distinct series of black spots, each spot giving rise to one or two fine bristles. (see plate 2, fig.A).

The three species cannot be differentiated on colour, although the larvae of E. cautella are often more distinctly marked with pink or buff, those of E. elutella are often creamy-yellow, especially when feeding on tobacco, and those of E. kuhniella often have a greenish or purplish ground colour.

The sexes may be distinguished in the last instar by means of the testes of the male, which are often highly coloured and show through the skin of the 5th abdominal segment as "paired lobate bodies on either side of the dorsal vessel." (Noyes, 1930).

The larvae cannot be separated on size alone, although the larvae of E. kuhniella are noticeably larger than the other 3 species. Since the size of a larva is not constant during its growth, and since the larva is elastic, the head capsule of 100 males and 100 females of each species have been measured, using an oculomicrometer scale as before. The larvae had all been bred in the warm room on cashew nuts, at a temperature of 85°F., and were obtained from rolls of corrugated paper placed in the rearing jars, since they creep into the paper to pupate. The results were as follows:-

Table 3 - Head capsule sizes of last instar larvae.

Species	length in mm.		breadth in mm.		length x breadth. (sq. mm.)	Ave. length x breadth for male and female.
	Range	Ave.	Range	Ave.	Ave.	
E. cautella						
male	.75-.99	.88	.75-.89	.82	.721	.774
female	.81-1.08	.95	.80-.95	.87	.826	
E. elutella						
male	.74-1.06	.88	.75-.95	.85	.748	.726
female	.65-1.04	.85	.66-.94	.83	.705	
E. kuhniella						
male	.92-1.25	1.09	.98-1.31	1.09	1.18	1.19
female	.95-1.21	1.09	.92-1.21	1.10	1.20	

Table 3 again shows that the three species overlap, E. kuhniella being noticeable larger than the other 2 species, and E. cautella being slightly larger than E. elutella. The female is slightly larger than the male in the case of E. cautella and E. kuhniella, although in the latter case the difference in size is very slight, while in the case of E. elutella, the male is larger than the female.

are the diffs. significant?

However, the only reliable guide to the differentiation of the larvae has been given by Hinton, 1942 and 1943: this has been found correct by observations of the present author. His key is as follows:-

1) "Eighth abdominal segment with spiracle not more than two-thirds as broad as membranous part enclosed by sclerite of seta rho." (see plate 2, fig. B3.) "Prothorax with diameter of spiracle much less than distance between kappa setae." (see plate 2, fig C1)........................ *E. elutella.*

"Eighth abdominal segment with spiracle as broad as or broader than membranous part enclosed by sclerite of seta rho. Prothorax with diameter of spiracle as great as or greater than distance between kappa setae..............(2).

2) Eighth abdominal segment with seta epsilon separated from spiracle by considerably more than the diameter of the latter (see plate 2, fig B1)... .... *E. kuhniella.*

Eighth abdominal segment with seta epsilon separated from spiracle by less than the diameter of the latter........................... *E. cautella.* (see plate 2, fig B2).

In addition, in *E. elutella*, the "subprimary seta theta (plate 2, fig. B3,D) is sometimes present on the eighth abdominal segment."

(C) Possible differences in the pupae.

Richards and Thomson, 1932, have drawn up a key to the differentiation of the pupae of the 3 species, but upon examination it has been found that their key does not always hold. Observations of the present author have shown that in all the species, the pupae are of the complex obtecta type, since the developing wings, legs, mandibles, maxillae and antennae are glued to the surface, and are therefore fixed. The whole pupa is covered by a hard, shiny, external skin, which is white when the pupa is first formed, but which becomes an amber-brown colour a few hours afterwards; sometimes the wing cases become hard and black after about 4 days.

In *E. cautella*, (plate 3, A), the antennae do not end distinctly before the second pair of legs and the third pair of legs are not exposed; in *E. elutella*, (plate 3, B), the antennae also do not end before the second pair of legs, but the third pair of legs are exposed (plate 3, fig B, L_3). In *E. kuhniella*, (plate 3 fig C), the third pair of legs are also exposed, and the antennae usually end before the wings, although this is a variable character. Also, the maxillae become hidden by the second pair of legs just before their termination.

The sex of a pupa may be determined according to the description of Richards and Thomson, 1932, which is as follows: "The rudiments of the genital and anal apertures appear as short, longitudinal thickenings on the mid-ventral line, the anus (ao, plate 3) being on the 10th segment, the male genital aperture being on the 9th segment (plate 3, fig. C, go), and the female on the 8th (plate 3, fig A and B, go)."

Measurements of 100 males and 100 females of all three species were obtained by allowing last instar larvae bred on cashew nuts in the warm room at 85°F. to creep into double-faced corrugated board and pupate there. The pupae were then removed and measured from the tip of the head to the tip of the abdomen using vernier callipers. The measurements obtained were as follows:-

Table 4 - Measurements of the pupae of Ephestia species. (in cms.)

	E. cautella		E. elutella		E. kuhniella	
	male	female	male	female	male	female
Range	.51-.78	.60.-.82	.50-.82	.50-.80	.64-1.06	.70-1.09
Average	.69	.72	.69	.67	.87	.88
Ave. male and female length	.70		.68		.88	

Therefore, as in the case of the last instar larvae, the species overlap, although the pupae of E. kuhniella are noticeably larger than the other 2 species, and E. cautella is larger than E. elutella. Again, the females of E. cautella and E. kuhniella attain a larger size than the males, this difference being very slight in the latter case, and again, the males of E. elutella are slightly larger than the females.

(D) Possible differences in the adults.

The adults of the three species (plate 4, fig. A, B and C), differ from one another in the wing patterns and genitalia, but the wing venation and the size of the body offer no reliable guide to differentiation.

One hundred males and 100 female adults of the three species have been measured from species fed on cashew nuts in the warm room at 85°F. The males and females may be easily differentiated by the fact that in the male the abdomen is elongated and has a pair of claspers while in the female the abdomen is about twice as long as broad, with a large aperture at the anal end and no claspers. The adults were measured from the tip of the head to the tip of the abdomen with vernier callipers as soon as they were dead. The results were as follows:-

Table 8 - Body Lengths of Adult *Ephestia* Species. (In cms.)

	E. cautella		*E. elutella*		*E. kuhniella*	
	male	female	male	female	male	female
Range	.60-.83	.65-.91	.55-.84	.53-.79	.61-1.05	.76-1.00
Average	.72	.76	.71	.67	.87	.88
Ave. male and female length	.74		.69		.88	

The results have also been expressed graphically, (plate 8). Again, it is seen that the species overlap is size, although *E. kuhniella* is noticeably larger than the other 2 species, and *E. cautella* is slightly larger than *E. elutella*. Again, as in the case of the larvae and pupae, the females of *E. cautella* and *E. kuhniella* are slightly larger than the males, while the males of *E. elutella* are larger than the females on the average. Thus it is seen that size offers no reliable guide to the differentiation of the adults.

Differences in colouration and wing patterns. (Observations of the present author).

The moths of *E. cautella* are more lightly coloured than the other 2 species, being dull yellow-brown or dull yellow-grey on upper and undersurfaces. The wings are a dull buff-brown or buff-grey, often distinctly tinged with reddish brown scales in the region of the first line. (Chittenden, 1911, has observed that some moths were even darker than *E. elutella* or *E. kuhniella* but this has never been personally observed). Also, the region of the wing before the first line is usually lighter in colour than the rest of the wing. The markings conform to the general pattern as described on page 3, paragraph 5, although the first line is rather diffused with dark scales extending towards the middle of the wing, and the second line is both inwardly and outwardly margined with dark scales. The hind wings are of the same general colour as the body, being a pale straw colour tinged with grey. (see plate 4, A).

chitinised, not striate; apex of uncus rounded; tegumen laterally produced into a short finger-like process." In addition, the gnathos is U shaped, and the aedeagus (not shown in diagram) is a simple, sub-cylindrical tube.

For E. elutella, the description is thus: "the membranous area of saccus covering about three-quarters of its width; costa of the valve simple, with no tooth; ventral thickenings of the anellus about as long as broad; dorsal thickenings elongate, posteriorly curved outwards into a broad hook; gnathos triangular, with short lateral arms; subscaphium weakly chitinised, anteriorly fairly striate; apex of uncus rounded; tegumen laterally produced into short broad lobes; aedeagus a simple, sub-cylindrical tube". (Plate 5,B).

E. kuhniella: "Membranous area of saccus covering one-third its width ; costa of valve produced into a curved, acuminate, apical tooth; ventral thickenings of the anellus somewhat emarginated posteriorly; dorsal thickenings reduced, consisting of elongate, not very conspicuous chitinous bars; gnathos pentagonal, longer than broad, with no lateral arms; subscaphium rather strongly chitinised, transversely striate anteriorly, about 4 times as long as broad; uncus longer than usual, rounded posteriorly; tegumen laterally hardly produced, lobes rounded, very short; aedeagus a sub-cylindrical tube, dilated at its apex." (Plate 5, C).

The female genitalia follow the same general description given on page 4 paragraph three, also with specific differences. In E. cautella, (plate 6, IA and IB), the ovipositor is bluntly rounded, and the eighth tergite quadrate, with a "large, membranous apical area, leaving only a narrow posterior chitinised strip on the disc; .... ductus bursa (plate 6, IB), with parallel-sided, striate plate," (Richards and Thomson, 1932). Bursa with numerous small chitinised spots, the lamina dentata being replaced by 1 to 5 (usually 2 to 3) chitinised plates.

E. elutella, (plate 6, 2A and B). "Ovipositor elongate, rounded at apex, 8th tergite quadrate, with 2 large, antero-lateral membranous areas, leaving rather a narrow posterior chitinised strip, which is produced on the median line into a long, acuminate tooth-like process; ductus bursae with numerous... chitinised spots in the region of the bursa; ...... the lamina dentata replaced by 7 - 10 chitinised plates." (see plate 6, 2B).

E. kuhniella, (Plate 6, 3A and 3B). The ovipositor is elongated, its struts about four times as long as the width of the 8th tergite; the latter is more than twice as long as broad and evenly chitinised; the ductus bursa and bursa copulatrix have chitinised spots; the lamina dentata are replaced by 1-4, (usually 2,) chitinised plates. (see plate 6, 3B).

In addition, the 8th tergite in the males of each species has characteristic chitinised strips and modified scales which will be described briefly according to the description given by Richards and Thomson, 1932.

E. Cautella. (Plate 5, D). "Largely membranous with a fairly broad apical area, which is produced anteriorly into a narrow central strip, more chitinised; the central strip ending in a small, rounded expansion", on each side of the tergite arises five tufts of modified scales, one tuft directed anteriorly, and the other four projecting posteriorly. "There is further, a median, anteriorly directed tuft of hair scales arising from the membrane between the 7th and 8th tergites."

E. elutella. (Plate 5,E). "Almost entirely membranous, with narrow central chitinised strip, which is produced anteriorly into a small, triangular expansion; on each side of the tergite arise four tufts of modified scales"..

E. kuhniella. (Plate 5, F). "Largely membranous with a fairly broad apical area, which is produced backwards as a narrow central strip, more chitinised; the central strip produced into 2 long arms anteriorly; at each side of the anterior end of the tergite , 2 broad fans of modified scales arise from small chitinised areas."

Finally, there are behaviour differences among the three species. The moths of E. cautella and E. elutella are extremely active and may be observed actively flying in their cages in the early mornings and late afternoons, while those of E. kuhniella have not been observed actively flying unless unduly disturbed. Also, individuals of E. kuhniella, when at rest, have the front part of the body elevated, and there is a distinct slope to the wings which are wrapped round the body, making the shape long and thin. In the other 2 species, the front part of the body is slightly elevated, and the wings are laid flat across the back, rarely wrapped round the body.

The next section is concerned with the life history and bionomics of E. cautella, with some comparisons with the other 2 species. Quite a large amount of experimental work has already been carried out on E. elutella and E. kuhniella, but research on E. cautella has been lacking, therefore, it was decided to concentrate mainly upon this species.

6)BIONOMICS.

A) The Egg.

The eggs of all three species have already been described, and the average measurements tabulated in section 5A. They are deposited from the first night after mating on or near the food. In the case of E. cautella, when mated females were confined in glass specimen tubes with pieces of muslin gauze, they preferred to oviposit directly onto the glass, but in the other 2 species, a decided preference was shown for the muslin gauze rather than the glass of the tubes. In section D (the Adult), food-selection experiments on ovipositing females will be described.

a) Duration of development. This was tested for the three species at room temperatures and also in the warm room at a constant temperature of 85°F (29.7°C.) and constant relative humidity of 60%, also in an incubator at a constant temperature of 65°F. (18.3°C.), and constant relative humidity of 65%. In both cases the humidity was kept constant by confining the moths in specimen tubes in dessicators over a H_2SO_4 solution made up to the required strength.

Fertilised females of the 3 species were kept in specimen tubes provided with strips of muslin gauze in the case of E. elutella and E. kuhniella, while females of E. cautella were confined in tubes without gauze. These tubes were kept at room temperatures and were examined during the day each hour for signs of eggs, so that the hour of oviposition was known. The eggs obtained were counted on black paper marked into squares, and placed in numbered specimen tubes, 20 eggs to a tube. The tubes were then placed at a definite condition of temperature and humidity, or left at room temperatures and humidities.

At constant temperatures and humidities, there was no need to test the eggs of all three species at the same time, but at room temperatures this was necessary to compare development. However, it was found impossible to obtain the eggs of all three species simultaneously; stocks of E. kuhniella were not obtainable until March, 1951, and either there were not sufficient fertilised females of all the species, or the females did not all oviposit at the same time, Consequently, the eggs of E. cautella and E. elutella were compared from 30th September - 17th October 1950 at an average temperature and humidity of 62.1°F. and 66% R.H. (Table 6,A). The eggs of E. cautella and E. kuhniella were compared from 2nd - 12th April 1951 at an average temperature and humidity of 69.7°F. and 63.9% R.H. (Table 6, C). Finally, E. cautella was tested alone from the 9 - 19th May, 1951, at an average temperature and humidity of 67.8°F. and 57.8% R.H. (Table 6,B). The results may be summarised as follows:-

Table 6 - Length of development of the eggs of Ephestia species

Average temp.	Range of Temp.	Ave. Humidity	Range of Humidity	No. of eggs used	Incubation period in days.					
					E. cautella		E. elutella		E. kuhniella	
					range	average	range	average	range	average
A) 62.1°F. (16.7°C.)	53 - 74°F. (11.4 - 23.3°C.)	60.7%	43 - 83%	160	12.8 - 14.1	13.5	15.2 -16.6	15.9		
65°F. (18.3°C.)	(constant)	65%	(constant)	200	6.7 - 8.1	7.1	6.9 - 8.2	7.4	6.6-8.2	7.4
B) 67.8°F. (19.9°C.)	59 - 77°F. (15 - 25°C.)	57.8%	44 - 77%	180	8.6 - 9.4	9.0				
C) 69.7°F. (20.9°C.)	63 - 76°F. (17.2 - 24.4°C)	63.9%	45 - 83%	320	5 - 7	6.0			6.6-6.9	6.7
85°F (29.5°C.)	(constant)	60%	(constant)	200	2.75-4.6	3.0	3.5-6.5	4.2	3.3-5.1	4.5

Thus it is seen the development of the eggs of all the species varies with temperature, a high temperature accelerating development. It seems that the eggs of E. cautella take the shortest time to develop at all temperatures, while those of E. kuhniella have the longest development, although the differences between the species is slight, especially at the constant temperatures of 65°F and 85°F. E. cautella takes a longer time to develop at 67.8°F. (9 days) than at 65°F. (7.4 days) since the former temperature is not constant, but ranges from 59 - 77°F.

Therefore, at a range of temperatures between 85°F. and 53°F., the development of the eggs of E. cautella and E. elutella occupies from 3 days to ±2 weeks, and the same is probably true of E. kuhniella.

b) Changes in the eggs during development.

As mentioned before, the eggs of all three species become darker in brown colour. Sometimes the eggs of E. cautella become an orange-brown colour.

In order to determine whether there was any change in size ?, in the eggs of E. cautella during development, 2 batches of 100 eggs each were measured a few hours after they had been laid in the warm room. One batch was left at room temperatues, the average temperature being 66.1°F. (18.9°C.) and the average humidity being 58.2%; the other batch was left in the warm room at a constant temperature and humidity of 85°F. (29.5°C.) and 60% R.H. The eggs at room temperatures were measured again 4 days after being laid, and again 4 days after the second measurement, just prior to hatching. The eggs in the warm room were measured every day. The results were as follows:-

Table 7 - Egg measurements of Ephestia cautella.

	average sizes for 100 eggs (in millimetres).					
	at room temperatures			in the warm room		
	length	breadth	average l. x b.	length	breadth	average l. x b.
1st measurement	.40	.30	.120	.39	.30	.117
2nd measurement	.39	.30	.117	.39	.30	.117
3rd measurement	.39	.30	.117	.39	.30	.117

Therfore, there appears to be no change in the size of the eggs of E. cautella during development.

c) Process of hatching. When the egg is ready to hatch the larva makes a circular opening in the end of the egg-shell by chewing actively through the shell. It then crawls out onto the surface to which the egg is attached during the incubation period, leaving the empty egg-shell remaining attached, and attaining its original shape.

B) The Larva.

The larva of all 3 species has already been described in section 5B, and measurements have also been given for head capsules of first and last instar larvae.

a) Behaviour and activities. The Ephestia larvae are active as soon as they emerge, and crawl away without delay in search of food. The egg-shells are not usually eaten, but in the absence of other food, both the shells and even any unhatched eggs may be eaten.

On cashew nuts, the larvae begin feeding by burrowing into grooves of the nuts, or in the absence of these, tunnel a groove directly on the surface. As they feed, the larvae leave trails of silk, white pellets of excretement and frass behind, these trails becoming more obvious as the larvae increase in size. Often, the larvae feed on one place for a time, scooping out hollows in the nuts. A short time before each moult, feeding stops and the larva becomes restless, often leaving its food. Moulting takes place beneath a slight silken shelter on or off the food, the whole process taking a few hours. After a moult, the larva is quiescent for a time, often for a day, before it resumes feeding again.

When the larvae are fully grown, they leave their food and wander up the sides of the jars to pupate. This upward movement of the last instar larvae is a very marked characteristic of <u>Ephestia</u>. Bovingdon, 1933, Reed & Livingstone, 1937, and many other authors have remarked that in warehouses the larvae crawl up the walls and pupate against the ceiling boards. When the larvae are very numerous the trails of silk which they leave behind them eventually become woven into a compact fabric covering the jar.

Strips of corrugated board are usually provided on the surface of the food medium for pupation, but when this is omitted the larval wandering period is prolonged and finally the larvae pupate against the sides of the glass or in between the nuts. <u>E. kuhniella</u> differs from <u>E. cautella</u> and <u>E. elutella</u> in that the larvae prefer to pupate against the sides of the glass and in between the nuts, rather than in the corrugated board, and will only pupate in the latter when the food medium is very crowded.

Before they pupate, the larvae of the 3 <u>Ephestia</u> species enter a prepupal period when they cease wandering, become quiescent and spin a silken shelter. They remain motionless unless provoked, from one day up till a week or more, before they cast off the final larval skin and pupate.

On the other food substances used, the behaviour of the larvae is the same as on cashew nuts. Attempts to rear <u>E. kuhniella</u> on dried fruit were unsuccessful, but the larvae of <u>E. cautella</u> and <u>E. elutella</u> when reared on dried apricots, peaches, pears, prunes, apples and raisins, attack the crevices on the surface of the fruit, tunnelling through the flesh, also leaving trails of silk, frass and dark brown pellets of excretement. *E. elutella* larvae will not develop on chocolate, but the larvae of *E. cautella* and *E. kuhniella* tunnel into the surface and cause a similar amount of damage as on the other food substances mentioned. When reared on Boermeal, the larvae of *E. Kuhniella* similarly tunnel through the flour, causing unsightly damage since particles of flour and exrretement adhere to their trails of silk causing "webbing"; this confirms the observations of Dendy and Elkington, 1919. Finally, the larvae of *E. elutella*, when reared on tobacco, consume the entire leaf between the larger veins and the mid-rib, making irregularly-shaped holes and leaving particles of silk intermingling with the tobacco, to which particles of tobacco, frass and dark brown pellets of excretement adhere. This confirms the observations of Bovingdon, 1933 and Reed and Livingstone, 1937.

B) The number of moults. The number of moults has been worked out for 30 individual larvae of *E. cautella* at a constant temperature of 85°F. (29.5°C.) and a constant relative humidity of 60%.

Females that had been bred on cashew nuts were allowed to lay eggs in glass specimen tubes, and as soon as the larvae hatched, each larva was gently placed on a half-cashew nut by means of a very fine, sterilised, camel-hair brush. Each larva on its food was then placed into a numbered specimen tube and left in the warm room. The larvae were examined each day and the breadth of their head capsules was measured. As a final check, after each moult the dehisced head capsule was also measured.

It was found that the larvae often fed inside a silken shelter covered with frass and debris, and also moulted inside some covering. Therefore, examination was difficult unless the covering was removed, and this constant interference with the larvae tended to prolong their lives, i.e. the average length of larval life was 47.4 days, while the average length of undisturbed cultures in the warm room was 34.7 days.

It was found that 16 of the larvae completed their development with 7 instars, having 6 moults, while 14 of the larvae completed development with 6 instars, having 5 moults. The average widths of the head capsules for the instars follows in Table 8. (next page).

Table 8 - Average width of head capsules in millimetres.

number of larvae		number of instars						
		I	II	III	IV	V	VI	VII
I6 VII instar larvae.	range average	.162-.188 0.173	.212-.238 0.228	.25-.325 0.301	.338-.45 0.400	.425-.612 0.530	.562-.812 0.703	.80-.9 0.91
I4 VI instar larvae.	range average	.162-.188 0.178	.212-.238 0.230	.275-.338 0.311	.375-.462 0.427	.525-.65 0.592	.772-.875 0.823	

These results have also been expressed in the form of a graph (see plate 9,B).

The head capsule sizes of all the instars have been plotted for all the instars, and it is seen that the head capsule sizes increase in steps. It is seen that the head capsule sizes of the VII instar larvae overlap in the 5th,6th and 7th instars, showing that the larvae have great variation in size even in the same instar. However, the VI instar larvae show no such overlap.

Also, from graph 9B and table 8, it is seen that for each instar, the width of the head capsule of the VI instar larvae is larger than that of the VII - instar larvae at the same stage. But because of their extra moult and instar, the VII - instar larvae attain a larger head capsule in the fully developed larvae.

When the ratio of increase of head capsule sizes is calculated, the results are as follows:-

Table 9 - Increase expressed as a ratio between successive instars.

No. of instars	head capsules						
	I - II	II - III	III-IV	IV - V	V - VI	VI-VII	Average
16 - VII instar larvae	1.32	1.32	1.33	1.32	1.33	1.30	1.32
14 - VI instar larvae	1.30	1.35	1.37	1.39	1.39		1.36

It is seen from table 9 that the ratio of increase between the successive head capsules is almost constant in the VII instar larvae, except for the ratio between the 6th and 7th instars. In the VI instar larvae, the average ratio of increase (1.36) ~~was~~ is greater than that of the VII instar larvae

(1.32). Moreover, the ratio is not constant, but increases from 1.30 - 1.39 with the number of instars. These results will be further discussed later (see section 7B).

The number of moults and instars was also found by taking larvae at random from different populations growing in the warm room on cashew nuts. The breadth of 220 head capsules was measured, and the results are shown graphically. (see plate 10). When the larvae (vertical axis) are plotted against their corresponding head-capsule sizes, (horizontal axis), seven definite peaks are found, corresponding to seven definite instars and six moults. But unfortunately it is not possible to detect whether there are any VI - instar larvae by this method.

c) <u>The duration of instars.</u> The duration of the instars was worked out at the same time as observations on the number of moults, and the results are as follows:-

Table 10 - The duration of the instars. (in days).

16 VII - instar larvae			14 VI - instar larvae		
stage	length of stage		stage	length of stage	
	range	average		range	average
1st instar	5 - 8	6.4	1st instar	5 - 13	6.9
2nd "	4 - 9	5.8	2nd "	3 - 9	5.1
3rd "	4 - 11	6.2	3rd "	3 - 7	5.0
4th "	3 - 11	6.2	4th "	2 - 8	5.4
5th "	3 - 10	5.4	5th "	2 - 11	6.2
6th "	5 - 11	6.8	6th "	4 - 23	11.0
7th "	3 - 18	9.8			
Ave. length of larval life	38 - 62	51.1		31 - 57	43.7

It is thus seen that in both cases, the average lengths of the stages vary within narrow limits, except for the last instar, when the larvae enter a wandering stage, and the instar is prolonged. Also, although the average lengths of the stadia of the VII - instar larvae are not always longer than the average lengths of the VI - instar larvae, the average length of the larval life of the former is longer than that of the latter, due to the extra instar.

d) The pre-pupa. As mentioned before, the larvae, after the final moult, leave their food and wander in search of a place to pupate. From table 10, it is seen that this wandering stage may last from 3 - 23 days, for both VI and VIIth - instar larvae. Then the larvae spin up and become quiescent, entering the prepupal stage. This stage lasts from 1 - 5 days, with an average of 2.3 days for both classes of larvae.

In this prepupal stage, the larva becomes less mobile and tends to move backwards when stimulated by touch. The head becomes bent into the prothorax and the body tends to contract, becoming stiff and straight, while the thoracic appendages become immobile and point stiffly anteriorly. Finally, all mobility is lost, before pupation occurs.

e) Length of larval stage.

The length of the larval stage, from the hatching of the egg until the prepupal stage, has been determined for the larvae of E. cautella, E. elutella and E. kuhniella developing on different foodstuffs in the warm room, undisturbed. The temperature and humidity were maintained constant at 85° F. (29.5°C.) and 60% R.H. The results were as follows:-

Table 11 - The length of the larval stage of Ephestia species.(in days).

Foodstuff of the larvae	No. of larvae used	Length of the larval stage (in days).					
		E. cautella		E. elutella		E. kuhniella	
		range	ave.	range	ave.	range	ave.
cashew nuts	500	21 - 50	34.7	22 - 50	35.2	29 - 53	38
dried fruit	400	29 - 72	47.1	29 - 68	47.3	no development	
chocolate	500	30 - 76	49.9	no development		41 - 82	63.4
tobacco	350	no development		36 - 79	58.3	no development	
Boermeal	300	(only one veloped)	36 de-	not determined		25 - 59	39

It is thus seen that the development of E. cautella is most rapid on cashew nuts, while its development on dried fruit and chocolate takes about a fortnight longer than on cashew nuts. It did not develop on tobacco, and showed very little development on flour. (The reasons for this will be discussed later). Similarly, the development of E. elutella is also the most

Table 12 - The length of the pupal stage in days.

	E. cautella	E. elutella	E. kuhniella
range	4 - 8	6 - 11.5	7 - 12
average	6.7	8.6	8.4

It is thus seen that again, E. cautella has a shorter development, but the development of the pupae of E. elutella takes the longest time, contrary to the larvae. However, there is not much appreciable difference between the development of the pupae of E. elutella an E. kuhniella.

b) Activities. For the first few days the pupa of all three species is semi-active, and may be observed moving its abdomen. Only segments V and VI of the abdomen are movable. Later on, the pupal case becomes too hard for any movement at all, thus after about 4 or 5 days the pupa remains motionless until the adult emerges.

D) The adult.

The adult has already been described in section 5D, and the average lengths of the males and females of all 3 species have also been stated in the same section.

a) Emergence. Moths from pupae kept in the laboratory at room temperatures and also in the warm room, with a weak artificial light, were observed to emerge at any time during the day or night. The moth emerges from the pupal case by forcing it open at the anterior end and immediately begins to unfold its wings, holding them upright over the back until dry. The whole process takes about 20 minutes or longer.

b) Habits and copulation. The adults of Ephestia species are known to be nocturnal, and personal observations confirm this. It was noticed that the moths kept in cages in the laboratory were quiescent during the day, but they became very active in the early mornings and late afternoons when the light was diffuse. Moths kept in the warm room in a very weak artificial light were observed actively flying at all times of the day.

Copulation occurs when the moths are most active, i.e. in the early mornings at about 7 - 8 am. and in the afternoons from 3 pm. onwards. However, if the moths are unduly disturbed during the day they will copulate at any hour. This confirms the observations of Reed and Livingstone, 1937.

Both sexes are ready for pairing a very short time after emergence, almost as soon as the wings are dry. Virgin females begin "calling" when ready for pairing. Richards and Thomson have best described the action thus: "In this action the female sits with its wings folded up and the apical half of its abdomen bent over its back between them. Meanwhile the apical abdominal segments are alternately exserted and retracted, so that the intersegmental membranes are widely exposed. There is little doubt that during this process, a scent attractive to the males is emitted... the male becomes very excited in the presence of the calling female... and begins fluttering around the female, who at first begins to take little notice or even runs away. Eventually she comes to a standstill and the male stands facing her, head to head, and bends his abdomen over his back to grip the tip of the female abdomen. Almost immediately, the pair twist round so as to be tail to tail."

Females have been observed to mate more than once in all three species, and they may assume the calling position even after they have mated. Males mate repeatedly until with old age they become too weak to grip the females effectively.

In the case of E. cautella, the length of copulation was observed for 100 couples. The moths were introduced into a cage at room temperature which was observed every 15 minutes for copulating couples. The couples were gently coaxed into specimen tubes, one couple to each tube, and the time noted. The tubes were then examined every 15 minutes to see if the moths had separated, so that the beginning and end of copulation was known within 15 minute intervals. The minimum and maximum times recorded were 8 minutes and 30 hours respectively, but the latter case was exceptional and in the former case it was assumed that fertilisation was not successful. The average time was 2 hours 18 minutes:-

15% lasted from 8 minutes to 1 hour
32% lasted from one hour to 2 hours
33% lasted from 2 hours to 3 hours
14% lasted from 3 hours to 4 hours
4% lasted from 4 hours to 5 hours
and 2% lasted for longer periods.

50 couples of E. elutella exhibited about the same average length of copulation as E. cautella, i.e. 2 hours 23 mins., but the average time for 50 couples of E. kuhniella was 4 hours 30 minutes, with a range of 3 - 7 hours

or more, in agreement with results obtained by Brindley, 1930. Therefore, this species has a longer copulation period than the other 2 species.

c) Feeding. The adults of all 3 species do not feed at all, but they consume small quantities of water if present.

d) Longevity. The longevity of males and females of the three species has been determined at room temperatures at a constant temperature of 65°F. (18.3°C.) in an incubator and constant relative humidity of 65%, and at a constant temperature of 85°F. (29.5°C.) in the warm room, with a constant relative humidity of 60%. The stock jars were observed every morning at 8.30, every mid-day and every evening at about 5 pm. so that the times of emergence were known to the nearest half-day. In every case, the adults of the three species were obtained from larvae that had been feeding on cashew nuts.

Adults were placed in separate, numbered specimen tubes kept at room temperature, in the warm room and in an incubator. In the latter 2 cases the humidity was maintained at a constant level by placing the tubes in a desiccator containing sulphuric acid made up to the proper strength. Usually the females were allowed to mate first in a dual display jar with males of known longevity, so that the oviposition periods and fecundity of the females was worked out at the same time as the longevity. The specimen tubes were observed every morning, mid-day and evening, so that the time of death was known to the nearest half-day as well, and the longevity could be calculated.

Unfortunately, it was not possible to compare the longevity at room temperatures for all the 3 species at the same time. Stocks of E. kuhniella were not obtainable until March, 1951, and even when cultures of the 3 species were breeding the adults did not all emerge at the same time or on the same days. Consequently, the longevity of E. cautella was determined from the 3rd June - 9th September, 1950; the longevity of E. elutella was determined from 22nd June - 28th July, 1950 and again from 12th August - 29th September, 1950; and the longevity of E. kuhniella was determined from 7th April - 17th May, 1951, at temperatures and humidities indicated in table 13. The results may be summarised as follows:-

Table 13 - Length of life of *Ephestia* adults in days.

	Range of temperature	Ave. temp.	Range of Humidity	Ave. Humidity	no. used	E. cautella		E. elutella		E. kuhniel	
						range	ave.	range	ave.	range	ave
Room temperature male	52 - 78°F.	59.5°F. (15.3°C.)	30 - 86%	68.5%	50			17 - 37	26.4		
female	"	"	"	"	50			20 - 34	27.7		
male	54 - 74° F.	60.1°F. (15.6°C.)	28 - 90%	69.5%	50	2 - 27	12.0				
female	"	"	"	"	50	2 - 24	13.0				
male	54 - 78°F.	61.2°F. (16.2°C)	35 - 87%	62.4%	30			6 - 31	21.3		
female	"	"	"	"	30			5 - 50	23.7		
Constant temperature male	65°F.	65°F. (18.3°C.)		65%	50	3 - 19.5	11.5	6.5 -27	17.9	2.5 -29	16.
female	"	"		"	50	5 - 18	11.5	10 - 33	17.8	6 - 32	13.
Room temperature male	58 - 76°F	65.8°F. (18.8°C.)	42 - 90%	66.6%	50					4 - 21	13.
female	58 - 76°F.	"	"	"	50					5 - 27	10.
Constant temperature male		85°F. (29.5°C.)			50	1 - 7	4.0	1 - 9	5.6	1 - 8.5	6.
female		"			50	2 - 7	4.6	2 - 10	5.8	2.5-.8	5.
Average longevity for all temperatures						2 - 34	9.1	2 - 50	18.3	1 - 32	11.

It is thus seen from the above table that the longevity becomes shorter s the temperature rises, for all the 3 species. Although the results obained for *E. kuhniella* at room temperatures cannot strictly be compared with he results for the other species, since it was tested at a higher temperature, rom the results at the 2 constant temperatures, it is seen that *E. cautella* as the shortest longevity, and *E. elutella* the longest, with *E. kuhniella* ntermediate. At low temperatures, this difference is more apparent, but at he high temperature of 85°F. the difference between *E. elutella* and *E. kuhiella* is negligible, since the average lengths of life for both sexes at his temperature is 5.7 and 5.6 days, respectively. But in spite of the ifferences in longevity among the species, their ranges of longevity overlap a certain extent at all temperatures tested.

As regards differences between males and females, in *E. cautella* and *E. elutella* there is no difference at 65°F., but at the other temperatures the female lives slightly longer than the male. In the case of *E. kuhniella*, however, the male lives longer than the female at all temperatures tested.

e) Oviposition.

i) *The number of eggs per female.* This was determined concurrently with longevity experiments as described in section (d), and at the same conditions in the warm room, in an incubator and at room temperatures. At room temperatures the same difficulty was encountered as before, i.e. females of all 3 species were not obtainable at the same time, and when they were avaialble, they would not all lay eggs at the same time. Therefore, the number of eggs oviposited was recorded for *E. cautella* from 3rd June - 9th September, 1950 ...... (a), and again from 22nd September, - 28th October, 1950.......... (b).

The number of eggs oviposited by E. elutella was recorded from 22nd June - 28th July, 1950......(c) and again from 12th August - 29th September, 1950 ......(d).

The number of eggs oviposited by *E. kuhniella* was recorded from 7th April - 17th May, 1951....(e) and again from 29th March - 14th April, 1951....(f).

The corresponding temperatures are stated in table 14 (next page).

Females were allowed to mate first with males in a dual display jar at the different conditions, and the mating couples removed into specimen tubes. As soon as copulation was ended, the male was removed, and the female, in a numbered specimen tube, was provided with a piece of muslin gauze as a stimulus to oviposition, and placed at the condition required. The tubes were then examined in the mornings at 8.30, at noon and at 5 pm., and the number of eggs laid were counted on black paper marked into squares. The results were as follows:- (see Table 14 next page).

It is seen from the following table that at a range of temperatures from about 60°F. - 85°F., *E. kuhniella* lays the greatest average number of eggs (182.6), *E. elutella* lays the least, (76.6) and *E. cautella* is intermediate (167.6). But this is not always the case. Although *E. cautella* and *E. elutella* do not seem to be effected by temperature, it seems that *E. kuhniella* is adversely affected, and at a temperature of 85°F. it lays a lesser number of eggs (122.4). Thus at 85°F. *E. cautella* lays the greatest number of eggs (158.2) followed by *E. kuhniella* (122) and the *E. elutella* (78.1). At all temperatures *E. elutella* lays an appreciably smaller number of eggs than the other 2 species.

Table 14 - The number of eggs per female.

Condition	Range of temperature	Average temperature	Range of humidity	Ave. humidity	No. of females used.	*E. cautella*		*E. elutella*		*E. kuhniella.*	
						range	ave.	range	ave.	range	ave.
room temperature a)	51 - 74°F.	60.6°F. (15.9°C.)	28 - 90%	69.5%	50	72 - 342	149.1				
b)	53 - 75°F.	63.7°F. (17.6°C)	31 - 86%	62.5%	100	51 - 445	195.1				
c)	52 - 78°F.	59.2°F. (15.1°C)	30 - 86%	68.5%	30			47 - 143	83		
d)	54 - 78 F.	61.6 F. (16.4 C)	35 - 87%	62.4%	30			21 - 134	56.9		
Incubator (constant)		65°F. (18.3°C.)		65%	30	68 - 279	168	40 - 158	98.4	57 - 400	263.5
room temperature e)	58 - 76°F.	65.8 F. (18.8°C)	42 - 90%	66.6%	30					32 - 370	186
f)	63 - 76°F.	69.4 F. (20.8°C)	45 - 83%	64.2%	30					47 - 289	159.4
warm room (constant)		85°F. (29.5°C.)		60%	50	73 - 243	158.2	41 - 122	78.1	38 - 330	122.4
Average number of eggs for all conditions:						51 - 445	167.6	21 - 158	76.6	32 - 400	182.6

ii) Where deposited.

It was decided to test whether *E. cautella* has any food preferences, and whether the eggs are deposited by a mechanical stimulus or by an olfactory sense. Accordingly, 2 sets of experiments were carried out. In the first, mated females were introduced into a dessicator of diameter 9 inches, containing 10 different substances. A little of each substance was placed in a square staining dish that had been hollowed out, the diameter of each hollow being 1.2 inches. The dishes were supported so that their surfaces just appeared above the lower portion of the dessicator; they were arranged so that their bases just touched each other in three rows, with 4 dishes in the middle row and 3 each in the rows on either side. A cork mat was placed above the dishes, fitting firmly against the sides of the dessicator, and with circles cut out to correspond exactly with the hollows of the dishes. The food material was arranged so that it filled the dishes completely and projected slightly above the level of the mat.

Since it was known that the moths prefer to oviposit in semi-darkness, or dark (see next section), the desiccator was placed in an incubator, at 65°F. (18.3°C.) and left undisturbed for 5 days each time the experiment was carried out. By placing the desiccator in an incubator in complete darkness, this avoided the possibility that the moths might be influenced by the direction and strength of light in any part of the dessicator. Furthermore, Ullyett, 1945, has shown that the effect of moth density must be taken into account as a factor influencing the data obtained, therefore, five fertilised moths were used every time the experiment was repeated. By means of this there was no over-crowding, and all the moths could oviposit on one food without interference, if they so desired.

In preliminary experiments, the food materials used were these:- dried peaches, pears, prunes and apricots, raisins, cashew nuts, tobacco, boermeal, chocolate and organdie gauze. No eggs were laid in the flour, and very few in the gauze, therefore, in later experiments these 2 substances were left out, and dried apples and figs substituted. The experiment was repeated 10 times, changing the position of each food every time. Thus a total of 50 fertilised moths was used, and each foodstuff was placed in 10 different positions.

The results may be summarised in table 15 (next page). The numbers in the horizontal columns represent the percentage of eggs found on the corresponding food substance, while the numbers in brackets refer to the order of preference of the corresponding food substance-(the order of preference of a substance was indicated by the percentage of eggs laid on it).

It is seen from table 15 that although the moths of <u>E. cautella</u> prefer dried apricots, dried pears, dried figs, dried apples, raisins, dried peaches chocolate, prunes, cashew nuts and tobacco in decreasing preference, they did not exhibit this order of preference every time the experiment was carried out, e.g. the order of preference for dried apricots was 6th and 8th, the 2nd and 10th time the experiments were carried out, respectively. Tobacco seems to be the only substance that was consistently the lowest or second-lowest preference. Therefore, although in general the moths of <u>E. cautella</u> may be said to prefer dried fruit, chocolate, prunes, nuts and tobacco in order of decreasing preference, this is not always the case. Most probably the condition of the food substance influences the oviposition response, although it was endeavoured to keep each food substance at a uniform condition every time the experiment was repeated.

Table 15 - Oviposition preference of E. cautella.

Food substance	Percentage and position preference.									
	1st time	2nd time	3rd time	4th time	5th time	6th time	7th time	8th time	9th time	10th time	To
dried apricots	19.8 (1)	8.8 (6)	7.7 (5)	13.2 (2)	20.8 (1)	28.0 (1)	9.8 (6)	9.7 (4)	17.9 (2)	5.6 (8)	140.
" pears	15.6 (2)	10.4(4)	21.6(1)	12.6(3)	17.5 (2)	17.3 (3)	6.4 (8)	9.1 (5)	8.4 (6)	19.4(2)	138.
" figs	6.5 (8)	9.8(5)	10.8(4)	6.9 (7)	12.4 (5)	18.9 (2)	15.7(1)	8.4 (6)	20.1 (1)	19.5(1)	129.
" apples	7.7 (6)	14.1(2)	7.7 (5)	27.1 (1)	6.2 (7)	6.2 (5)	11.3(5)	15.6(2)	10.4 (4)	12.5(4)	119.
raisins	7.7 (6)	11.1 (3)	7.7 (5)	4.7 (9)	14.9 (3)	5.3 (6)	15.2(2)	20.9(1)	15.7 (3)	7.6 (5)	110.8
dried peaches	12.1 (4)	8.5 (7)	16.2 (2)	9.5 (4)	8.4 (6)	9.5 (4)	9.5 (7)	11.9(3)	5.5 (8)	15.6(3)	106.7
chocolate	12.1 (4)	23.3 (1)	12.3 (3)	8.8 (6)	3.6 (8)	4.1 (8)	11.6(8)	8.2 (7)	5.7 (7)	6.9 (6)	96.6
prunes	12.9 (3)	6.8 (8)	7.1 (8)	5.1 (8)	13.3 (4)	5.3 (7)	3.3 (9)	3.9(10)	9.5 (5)	6.6 (7)	73.8
cashew nuts	1.5 (10)	4.2 (9)	7.2 (8)	9.2 (5)	0.6 (10)	2.1 (10)	15.2(2)	7.4 (8)	3.5 (9)	3.0(10)	53.9
tobacco	4.1 (9)	3.0 (10)	1.7 (10)	2.9 (10)	2.3 (9)	2.9 (9)	2.0 (10)	4.9 (9)	3.3 (10)	3.9 (9)	31.0

However, this experiment did not show whether the moths chose the oviposition ~~response~~ site through an olfactory or tactile sense. Therefore, in a second series of experiments, another series of moths was introduced into a breeding cage with a wire bottom, as mentioned in section 3. Beneath the bottom was placed a board of cardboard demarcated into 9 equal squares, with a breadth and length of 9.4 cm. In the centre of each square was placed a dish containing a food substance. Each dish had a diameter of 5.1 cm. and length of 3.3. cm. The board was so arranged that the top of each dish was about 2 cm. from the bottom of the wire.

The 9 food substances used were dried peaches, pears, figs and apples, raisins, prunes, tobacco, cashew nuts and chocolate, and every time the experiment was repeated, the position of eadh food-stuff was changed, so that each food occupied 9 differant positions in all. Fifteen to twenty fertilised females were introduced into the cage every time the experiment was repeated, and the whole cage was covered with black paper, so that the oviposition would not be influenced by light, and left in a corner of the laboratory free from draughts for 5 days. The board then removed and the number of eggs laid on the foodstuff counted, as well as the number of eggs in each square. The experiment was repeated 9 times. The results were as follows in table 16.

Again, the numbers in the horizontal columns represent the percentage of eggs found on and around the corresponding food-substance, while the numbers in brackets refer to the order of preference of each food substance.

Table 16 - To test whether oviposition in <u>E. cautella</u> is due to an olfactory sense.

Food substance.	Percentage and position of preference.									
	1st time	2nd time	3rd time	4th time	5th time	6th time	7th time	8th time	9th time	Total
cashew nuts	6.1 (7)	6.9 (6)	15.4 (2)	4.7 (9)	15.3 (2)	17.4 (2)	18.7 (2)	6.5 (7)	14.6 (2)	105.6
Dried peaches	5.7 (9)	35.9 (1)	8.9 (6)	15.2 (2)	11.2 (5)	8.4 (6)	3.1 (9)	9.5 (5)	7.0 (7)	104.9
prunes	9.4 (5)	9.1 (5)	10.7 (4)	13.7 (4)	5.4 (9)	16.2 (3)	18.8 (1)	6.8 (6)	13.3 (3)	103.4
raisins	13.1 (3)	2.5 (8)	14.6 (3)	9.1 (6)	17.5 (1)	7.1 (7)	8.7 (6)	23.3 (1)	5.9 (9)	101.8
chocolate	14.8 (2)	1.9 (9)	7.1 (7)	13.8 (3)	10.7 (6)	19.2 (1)	5.9 (7)	19.7 (2)	7.4 (6)	100.5
Dried apples	5.6 (8)	19.4 (2)	20.9 (1)	5.8 (8)	9.1 (7)	3.9 (8)	12.4 (5)	12.0 (4)	9.0 (5)	98.1
tobacco	11.7 (4)	10.6 (3)	5.6 (9)	11.1 (5)	13.0 (3)	13.9 (4)	13.8 (4)	6.0 (8)	12.1 (4)	97.8
Dried figs	9.0 (6)	3.2 (7)	6.3 (8)	19.0 (1)	12.1 (4)	10.3 (5)	14.0 (3)	14.5 (3)	7.0 (7)	95.4
" pears	24.6 (1)	10.5 (4)	10.5 (5)	7.6 (7)	5.7 (8)	3.6 (9)	4.6 (8)	1.7 (9)	23.7 (1)	92.5

The results found in Table 16 do not correspond with those of table 15, i.e

Table 15 order of preference	Table 16 order of preference.
1) dried apricots	1) cashew nuts
2) " pears	2) dried peaches
3) " figs	3) prunes
4) " apples	4) raisins
5) raisins	5) chocolate
6) dried peaches	6) dried apples
7) chocolate	7) tobacco
8) prunes	8) dried figs
9) cashew nuts	9) " pears.
10) tobacco	

Moreover, from table 16 it is seen that not only did the order of food preference change every time the experiment was repeated, e.g. the order of preference for cashew nuts was 7,6,2,9,2,2,2,7,2, but also the difference between the least preferred food (92.5) and the most preferred food (105.6) is only 13.1.

Therefore, it is concluded that although the moths of E. cautella may find their oviposition sites due to an olfactory response, oviposition is due to a tactile stimulus. This conclusion is supported by the fact that these moths oviposit directly onto glass as well, in the absence of any food, and also oviposit through wire gauze. However, it seems that when present, substances with a soft, slightly sticky surface, such as dried fruits and raisins, are preferred to harder substances which are often brittle, such as chocolate, nuts and tobacco. The low preference for prunes is probably due to the fact that the prunes used in the experiment were of 2nd grade quality, and rather hard and dry.

iii) The time of oviposition.

To find the optimum time of oviposition, mated females were placed in separate, numbered specimen tubes and observed at regular intervals. The day was divided into three periods of hours, i.e. the first period from 8 am. until 12 pm., the second period from 12 pm. until 4 pm., and the third period from 4 pm. until 8 am. The females were also observed during the night, from 8 pm. until 12 am., and then at 8 am the following morning. The eggs which had been laid were removed and counted. For the purposes of observing the moths during the night, they were taken home each evening and brought back to the laboratory during the day. In all, recordings of 100 females were made. The results were as follows:-

Table 17 - The time of oviposition.

The number of ovipositions	Frequencies of oviposition				
	DAY			NIGHT	
	8am.-12pm.	12-4pm.	4-8pm.	8pm-12am.	12am-8am.
1st oviposition	1	15	72	66	22
2nd "	1	16	58	51	6
3rd "	0	8	51	51	6
4th "	0	6	43	53	7
5th "	0	4	26	22	6
6th "	0	4	13	7	0
7th "	0	1	8	4	3
8th "	0	1	6	6	1
9th "	0	0	2	3	1
10th "	0	0	1	1	2
11th "	0	0	1	1	2
12th "	0	0	1	1	0
13th "	0	0	1	0	0
14th "	0	0	1	0	0
Total	2	55	284	267	56
Percentage	.3%	8.3%	42.8%	40.3%	8.3%

Therefore, most of the eggs are laid between 4 pm. and 12 am., with lesser amounts between 12 pm. and 4 pm. and from 12am. until 8 am. Only 2 cases have been recorded of eggs being laid in the mornings from 8am. until 12 pm. Therefore, the optimum time for egg-laying begins when the light begins to fail, and goes on through the night.

In the warm room, however, with a weak artificial light, or no light, eggs are apparently laid at any time of the day or night.

iv) The duration of the pre-oviposition period.

The duration of the pre-oviposition period was determined for 100 females of *E. cautella* by allowing females to mate in a cage, then gently removing each couple into a separate specimen tube and noting the time of separation and 1st oviposition. The specimen tubes were left at room temperatures, with a range of temperature of 53-75°F. (11.7 - 24°C.) and an average temperature of 63.7°F. (17.6°C.), and examined every hour of the day after 12 pm., but during the night this was impossible and the tubes were usually examined at 8pm., 12am. and 8 am. the following morning.

The results were as follows:- (Where the pre-oviposition periods overlapped between two 12 - hour periods, they were counted in both periods).

Table 18: Pre-oviposition periods from the end of copulation.

	0 - 12 hrs.	12 -24 hrs.	24 - 36 hrs.	36 - 48 hrs.	48 - 60 hrs.	60 - 72 hrs.	72 -84 hrs.	84-96 hrs.	more hrs.
frequency	36	8	34	11	18	2	5	0	2
percentage	31.3%	7.0%	29.3%	9.4%	15.4%	1.7%	4.2%		1.7%
frequency for 24-hr. cycle	44		45		20		5		2
percentage	38.3%		38.7%		17.1%		4.2%		1.7%

Therefore, there appear to be definite 24 -hour cycles for egg-laying after copulation, and most of the eggs are laid in the first half of each cycle. The first oviposition usually takes place within the first 24 hours, or first 36 hours after the end of copulation, but sometimes no eggs are laid until the 3rd and even fourth 24 - hour period, or even later. The average pre-oviposition period for 100 females was 36 hours.

It is not known why there is such a lapse between the end of copulation and the first oviposition in some moths , but it is very probable that low temperatures, below 60°F., cause oviposition to be suspended. Heat definitely accelerates oviposition, since 30 females kept in the warm room at 85°F.

(29.5°C.), had an average pre-oviposition period of 12 hours.

v) Interovulation periods.

These were measured by continuing observations on the fertilised females used for previous experiments on the pre-oviposition period. Again, the specimen tubes were left at room temperatures, with a range of 53-75°F. (11.7-24°C.), and an average temperature of 63.7°F. (17.6°C.), and examined every hour of the day after 12 pm., and during the night at 8pm. and 12am., and again the following morning at 8 am. The results were as follows:-

Table 19 - The frequencies of interovulation periods.

Oviposition periods.	frequencies					
	0 -12 hrs.	12 - 24 hrs.	24 - 36 hrs.	36 - 48 hrs.	48 - 60 hrs.	more hours.
1st oviposition	2	48	30	6	4	4
2nd "	9	45	34	1	2	1
3rd "	1	35	38	0	1	4
4th "	2	17	19	0	1	4
5th "	0	8	8	2	2	0
6th "	2	4	5	1	1	0
7th "	2	4	5	0	0	0
8th "	0	1	2	0	0	0
9th "	0	1	2	0	0	0
10th "	0	2	1	0	0	0
11th "	0	1	1	0	0	0
12th "	0	1	0	0	0	0
13th "	0	0	1	0	0	0
Total	18	167	146	10	11	13
Percentage	4.9%	45.8%	40%	2.7%	3%	3.6%
Percentage for 24-hour period	50.7%		42.7%		6.6%	

As regards interovulation periods, there are no definite 24-hour cycles found, like those of the 1st oviposition periods. In most cases, eggs are laid from 12 to 36 hours after the previous oviposition. 93% of the cases laid eggs from 0 - 48 hours after the previous oviposition, while, among these, slightly more laid eggs within 24 hours than within 48 hours.

Again, as in the case of the pre-oviposition period, oviposition must be influenced by temperature; it is seen from the table above that some moths had an interovulation period of more than 60 hours, the maximum which was recorded being 112 hours. In the warm room, however, in most cases eggs were laid regularly within 24 hours of the previous oviposition.

Sometimes egg-laying continues until death, in other cases death occurs a few days after the last oviposition. The average period between the last oviposition and death, measured for 50 females at room temperature (ave. 63.7°F.) was 2.1 days, with a range of 0 - 7 days. In the warm room, the average time elapsing was 0.9 days, for 50 females.

At room temperatures ranging from 53-75°F. (11.7-24°C), the average temperature being 63.7°F. (17.6°C.), the oviposition containing the greatest number of eggs was also observed. The results of 100 females of E. cautella were as follows:-

51% laid the maximum number of eggs in the 1st oviposition
30% " " " " " " " " 2nd oviposition
6% " " " " " " " " 3rd "
1% " " " " " " " " 4th "
2% " " " " " " " " 5th "
0% " " " " " " " " 6th "
1% " " " " " " " " 7th "
2% " " " " " " " " 8th "
1% " " " " " " " " 9th "
1% " " " " " " " " 10th "
5% " " " " " " " " last "

Therefore, while in 51% of the cases, the maximum number of eggs were laid in the 1st oviposition, it does not follow that the number of eggs laid by a female decreases steadily with each oviposition, and in 5% of the cases, the maximum number of eggs was laid in the last oviposition. The cause of this is not known. In the warm room, the greatest number of eggs was laid by a female in the first two days of ~~the~~ its life. 80.8% of the females laid the maximum number of eggs with the first oviposition, and 19.2% ;aid the maximum number within the second oviposition. Therefore, perhaps the irregularity found at room temperatures is somehow connected with temperature.

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E) The total length of life.

Unfortunately, there are no records at hand of the seasonal history of E. cautella in this country. However, the length of life, from the egg to the adult, has been determined for this species in the warm room at 85°F. (29.5°C.) for 2000 adults, the larvae of which had fed on cashew nuts, while at room temperatures the total length of life was determined for 500 individuals breeding on cashew nuts from the 20th May - December, 1950. The range of temperature recorded for this time was 51 - 79°F. (10.6 - 27.2°C.), with an average temperature of 61.9°F. (16.6°C.) The results were as follows:

Table 20 - The total length of life of E. cautella in days.
(breeding on cashew nuts).

	room temperature (ave. temp. = 61.9°F.)	warm room (ave. temp.= 85°F.)
Range of development	118 - 183 days. (±17 - 26 weeks)	31 - 60 days (4 - 9 weeks).
Average length of development	145.5 days. (±21 weeks)	44.8 days (6 weeks)

Thus it is seen that while the life cycle of E. cautella lasts about 6 weeks at a temperature of 85°F., which corresponds to a summer temperature, at the lower temperature of approximately 62°F., corresponding to temperatures during winter and spring, the development may be prolonged to five or six months. Therefore, it is possible that in summer, four generations develop, while another generation develops over the winter. Therefore, at conditions in the Western Province with a mediterranean climate similar to Cape Town, it is possible that 5 generations of E. cautella develop on cashew nuts throughout the year.

The development of E. cautella, E. elutella and E. kuhniella has also been determined breeding on different substances as well as cashew nuts in the warm room at a temperature of 85°F. The results were as follows:-

Table 21 - The total life history of Ephestia species at 85°F.

Foodstuff	Total length of life in days.								
	E. cautella			E. elutella			E. kuhniella		
	no. used	range	ave.	no. used	range	ave.	no. used	range	ave.
cashew nuts	2000	31-60 (±6 weeks).	44.8	300	32-65 (±6½ weeks).	45.9	500	39-73 (±7 weeks).	51.2
dried fruit	300	39-79 (±8 weeks).	55.1	200	39-71 (±8½ weeks).	59.2	no development		
chocolate	200	40-85 (±8½ weeks).	59.3	no development			100	51-100 (±10½ weeks).	72.1
tobacco	no development			150	42-80 (±9 weeks).	62.1	no development		
boermeal	negligible development			not	tested		300	35-65 (±7 weeks).	49.6

Therefore, as was seen in the larval development, when bred on cashew nuts at 85°F., E. cautella has the shortest development, (45 days), followed E. elutella with a slightly longer development (46 days), and E. kuhniella, which has the longest development (51 days.) Moreover, E. cautella and

E. elutella develop the most rapidly on cashew nuts, while development on dried fruit and chocolate is prolonged for *E. cautella* (55 and 59 days, respectively): and the development of *E. elutella* on dried fruit and tobacco is also prolonged (59 and 62 days, respectively). However, *E. kuhniella* shows a slightly shorter development on boermeal (49.6 days) than on cashew nuts (51.2 days), therefore boermeal must be its optimum food. But it resembles *E. cautella* in that its development is prolonged on chocolate (72 days), and also, this devebpment was not very successful, with only a small percentage of the larvae developing.

From these results, the possible number of annual broods of these three species on different foodstuffs is indicated as follows (assuming one generation developing in winter in climates similar to that of the Cape Province).

Table 22 - The possible number of Generations of *Ephestia* species in the Cape.

Foodstuff	The possible number of generations		
	E. cautella	*E. elutella*	*E. kuhniella*
cashew nuts	4 - 5	4 - 5	3 - 4
dried fruit	3 - 4	3 - 4	
chocolate	3 - 4		3
tobacco		3 - 4	
meal			3 - 4

7) DISCUSSION.

A) The eggs.

In section 5 (1), the eggs of *Ephestia* species were described and the ranges and average measurements were tabulated. When observations of the present author on the dimensions of the eggs are compared with the results of other authors, it is seen that, for the most part, they agree very well (see table 23).

Table 23 - The dimensions of the eggs of *Ephestia* species.

Species	Length in mm.		Breadth in mm.		Length x breadth (sq. mm.)
	range	average	range	average	average
E. cautella (Personal 1950)	.31 - .44	.38	.22 - .35	.29	.118
Chittenden, 1911	.33 - .38		.22 - .32		
Richards and Thomson, 1932		.43		.29	
Lehmensick and Liebers, 1938		.40		.36	
(General average)		(.40)		(.31)	
E. elutella (Personal 1950)	.36 - .56	.50	.23 - .42	.35	.172
Richards and Thomson, 1932		.6		.32	
Lehmensick and Liebers, 1938		.5		.3	
(General average)		(.53)		(.32)	
E. kuhniella (Personal 1950)	.46 - .66	.55	.28 - .48	.33	.180
Durrant and Beveridge, 1913		.58		.31	
Burkhardt, 1919		.56		.29	
Brindley, 1930		.58		.33	
Richards and Thomson, 1932		.57		.30	
Lehmensick and Liebers, 1938		.6		.3	
(General average)		(.57)		(.31)	

From these results, it is concluded, as before, that althouth the dimensions of the eggs overlap in all three species, in general the eggs of

E. cautella are the smallest and those of E. kuhniella are the largest. But although this is true of the lengths as well, as regards the breadths, the eggs of E. elutella are slightly larger than those of E. kuhniella, while the breadths of the eggs of E. cautella are the smallest.

When results of the present author for the development of the eggs are compared with the results of other authors, it is again seen that the developmental period shortens as the temperature rises. (see table 24.)

Table 24 - The development of the eggs of Ephestia species (in days).

Average temp.	Average humidity	Observer	no. eggs used	Incubation periods of the eggs (in day				
				E. cautella		E. elutella		E. k
				range	ave.	range	ave.	range
59°F. (15°C.)		Mokrzecki, 1931				8 - 10	9	
		Reed and Livingstone, 1937	31			9 - 12	11	
		Herford, 1933		± 14				
62.1°F. (16.7°C.)	60.7%	Personal, 1950	160	12.8 - 141	13.5	15.2-16.6	15.9	
		Waloff, 1948 (constant temp.)				13 - 15	14	
65°F. (18.3°C.)	65%	Personal (constant temp.)	200	6.7 - 8.1	7.1	6.9 - 8.2	7.4	6.6 - 8,
		Potter, 1936					7.0	
67.8°F. (19.9°C.)	57.8%	Personal, 1950	180	8.6 - 9.4	9.0			
		Reed and Livingstone, 1937	77			10 - 12	11.5	
		" " " "	220			8 - 10	8.6	
69.7°F. (20.9°C.)	63.9%	Personal, 1950	320	5 - 7	6.0			6.6. - 6
		Candura, 1928						9 - 11
		Simmons, etc., 1931		7 - 9	7.8			
		Reed and Livingstone, 1937	16			12 - 13	12.5	
		" " " "	764			8 - 10	8.8	
		Waloff, 1948 (constant temp.)				9 - 10	9.5	
71.6 - 75.2°F. (22 - 24°C.)		Richards and Thomson, 1932				6 - 10	6.8	
		Reed and Livingstone, 1937	3,624			5 - 14	7.3	
77 - 78.8°F. (25 - 26°C.)		Hase, 1927						4.75 - 5
		Candura, 1928						
		Mokrzecki, 1931					4.0	
		Richards and Thomson, 1932					5.0	
		Reed and Livingstone, 1937	4,020			5 - 8	5.9	
		Waloff, 1948 (constant temp.)				4 - 5	4.5	
		Bovingdon, 1933, " "					6.2	
80°F. (27.4°C.)		Noyes, 1930						5 - 9
82.4°F. (28.6°C.)		Mokrzecki, 1931					3.0	
		Reed and Livingstone, 1937	1,623			3 - 7	4.7	
85°F. (29.5°C.)	60%	Personal, (constant temp.)	200	2.75-4.6	3.0	3.5-6.5	4.2	3.3-5.1
		Chittenden, 1911		up to 3.5				
		Brindley, 1930 (const. temp.)						
		Boselli, 1933			4.5			
		Reed and Livingstone, 1937	1,149			3 - 10	4.6	

It is seen from table 24 that the results of other authors do not always correspond with personal results, e.g. at 85° F. personal results for the development of the eggs of *E. cautella* were 3 days, while Boselli, 1933, has an average of 4.5 days. Moreover, results of the present author for the development of the eggs of *E. cautella* at 65° F. is lower (7.1 days) than results for the development at the higher temperature of 67.8° F. (9.0 days). However, these discrepancies are explained in both cases by the fact that personal results at 85°F. and 65°F. were carried out at constant temperatures, while the observations of Boselli, and personal observations at 67.8° F. were carried out at room temperatures.

Nevertheless, it is concluded that the development of the eggs of *E. cautella*, *E. elutella* and *E. kuhniella* within a range of temperatures from 59 F. - 85°F. (15 C - 29.5°C.) occupies 2 weeks to 3 - 4 days in the case of *E. cautella* and *E. elutella*, and this is probably true of *E. kuhniella* also. When the eggs of these 3 species are compared at the constant temperatures of 65° F. and 85° F., *E. cautella* has a slightly shorter development than *E. elutella* and *E. kuhniella*. These latter 2 species have about the same rate of development.

Voute, 1935, has found that for *E. kuhniella*, development ensuring hatching began at 50° F. (10°C.), and that the optimum range of development was between 60.8° F. and 78.8° F. (16 - 26° C.). The temperature prevailing at the time of oviposition influenced the subsequent development of the egg. A higher temperature had an accelerating effect while a lower temperature had a retarding effect when development continued at temperatures differing from the initial one. When the eggs were subjected to only one change, or several regular changes, an initial temperature of 73.4° F. (23° C.) was most favourable.

B. The larvae.

The differences among the larvae of the 3 species have already been discussed, according to the key worked out by Hinton, 1942 and 1943, in section 5 B. Dimensions of the head capsules of the first and last instar larvae have also been tabulated in the same section. When the results of the present author for *E. kuhniella* are compared with results obtained by Brindley, 1930, they correspond very well, i.e. see table 25 next page.

Table 25 - Dimensions of the head capsules of 1st and last instar larvae of *E. kuhniella*.

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	length in millimetres.		Breadth in mm.		length x breadth sq mm.
	range	average	range	average	average
1st instar larva					
Personal	.15 - .20	.16	.15 - .21	.20	.032
Brindley, 1930		.17		.20	.03
last instar					
Personal	.92 - 1.25	1.09	.92 - 1.31	1.10	1.20
Brindley, 1930				1.11	

As regards the bionomics of *Ephestia cautella*, *E. elutella* and *E. kuhniella*, they have been recorded as pests of many foods besides nuts, chocolate, dried fruit, tobacco and flour. The following is a table, from Richards and Thomson, 1932, of the foods on which these 3 species have been recorded.

Table 26 - The food substances of *Ephestia* species.

E. cautella	*E. elutella*	*E. kuhniella.*
Cashew nuts (personal)	Cashew nuts (personal)	Cashew nuts (personal)
ground nuts	ground nuts	ground nuts
almonds, walnuts	almonds, walnuts	almonds, walnuts
pecans, gall nuts	pecans	pecans
rice	rice	rice and rice flour
wheatflour,	wheatflour	wheatflour, chestnut flour
bran, maize	bran, maize	bran, maize
maize meal	maize meal	maize meal, rye meal
hominy and oatmeal		rye, oatmeal
		buckwheat flour
biscuits	biscuits	biscuits
cacao, locust beans	cacao	cacao, soy beans
chocolate	nougat	chocolate
dried figs, currants,	dried figs, currants	dried mushrooms
dried apples, pears,	dried apples, pears,	
sultanas, raisins,	sultanas, raisins,	
prunes, dates.	prunes, dates.	
	dried mushrooms, cherries	
	hips and haws, rose	
	petals, dried pomegranate	
	roots (all dried).	
tobacco (Bovingdom)	tobacco	
cotton seed		cotton seed, hemp seed,
cotton seed cake		sesame seed cakes.
linseed meal		linseed meal
dried insects	dried insects	dried insects
pomegranates, pears,	Turkey rhubarb,	potatoes, peas, beans,
damaged citrus fruits	dried vegetables	
seeds of *Zizyphus*	seeds of sugar beet	
" " *Cecropia*		
tonka beans	coffee, chicory	
chick pea	cayenne pepper	chillies
asparagus berries	drugs	
	leather	jelly cubes
	honeycomb	baby food
	acorns (annual	acorns
	report 1946)	
		macaroni

It is thus seen that these three species attack a wide variety of food substances. All three attack nuts, rice and rice products, bran, maize, maize meal, wheat flour, biscuits and cacao.

The behaviour of *E. cautella*, *E. elutella* and *E. kuhniella* larvae on nuts, dried fruit, chocolate, tobacco and boermeal has already been described from observations of the present author in section 6B. However, other authors have described the behaviour of these species on other foodstuffs.

In dried figs, Boselli, 1931, has recorded that the larvae of *E. cautella* usually enter through the apical aperture and begin feeding among the surrounding bracts. They then penetrate within, spinning a web across the aperture after 8 - 10 days. Occasionally they enter directly through the skin. They do not infest figs on the trees or during the first 3 - 4 days of drying. On the other hand, Smyth, 1911, from reliable reports, shows that 5 or 10% of the larvae in dried figs may be traced to the fig trees in Smyrna. In dried fruit, Quinn, 1927, reports that *Ephestia* feed on the dried fruit kernels as well, and therefore maintain the infestation.

On cacao, Silva, 1947, and Herford, 1934, have described the habits of *E. cautella* and *E. elutella*. Silva, 1947 reports that newly hatched larvae survived up to 24 - 28 hours without food, and the larvae could not enter cacao beans that were not injured.

The behaviour of *E. elutella* on tobacco has already been described from observations of the present author in confirmation with the observations of Bovingdon, 1933 and Reed and Livingstone, 1937. The latter authors further concluded that "the young larvae eat the upper or lower cuticle of the tobacco leaf until about the first moult, after which the entire leaf between the larger veins and mib-rib is consumed." Mokrzecki, 1931, has further recorded that on tobacco, *E. elutella* starts feeding at 59°F. (15°C.), and is especially active in summer. Feeding ceases at temperatures below 44.8°F. (7.1°C.) and above 98.6°F. (37°C.), the larvae being killed at 113°F. (45°C.).

Reed and Livingstone, 1937, also record that only various grades of flue-cured, domestic and Turkish tobaccos are infested and Bovingdon, 1933, further shows from experiments that "if bright .. kiln-cured tobacco in good condition is available to *Ephestia* larvae they will consume it in preference to dark tobacco". Mockrzecki, 1931 explains this food preference by the fact that better qualities of leaf contain greater quantities of sugars than the lower grades, and are therefore more liable to be attacked.

Finally, Reed and Livingstone, 1937, state that moisture in the tobacco leaves plays a very great part in the survival and growth of the larvae. "The ideal moisture content for the best growth on flue-cured tobacco is approximately 13%". This is obtained by an atmospheric relative humidity of 65 - 75% R.H.

Richards and Waloff, 1946, have studied the behaviour of E. elutella on bulk grain, and find that the young larvae show a preference for softer grains, and those with a higher water content. Only the embryo is eaten, "and as one larva required 48 embryos to complete development, its food habits alone necessitate wandering and spreading of larval populations.... In unpolished rice... the larval population probably spreads even more extensively.... and in peanuts, cacao beans and beans, the whole of the larval stage is passed inside one bean and the wandering of the feeding larvae cannot be so extensive". They further state that the larvae appear to be negatively geotropic, negatively phototatic and thigmokinetic, and that the larval wandering may be due to thigmokinesis, but these statements must be accepted with reservation as they have no experiments to support them.

The number of moults.

It has been seen that the number of moults found by personal observation for E. cautella are five or six, so that there are both six and seven instar larvae when they feed on cashew nuts at 85°F. and 60% relative humidity. It was decided to check the results obtained for the head capsule sizes and number of moults by using Dyar's law. Dyar, 1890, by examination of a series of figures of head capsule sizes of lepidopterous larvae, stated that "the widths of the head of a larva in its successive stages follow a regular geometric progression." Both Imms, 1934, and Richards, 1949 show that Dyar's original purpose was to determine, "by means of accurate measurements,, .. whether an ecdysis has been overlooked or not during its life-history studies"....since "the head is not subject to growth during a stadium." (Imms, 1934).

Therefore the following method is employed:

Table 27 - VII - instar larvae of E. cautella

	Number of stages							
	I	II	III	IV	V	VI	VII	Ave.
Mean width of head capsules (in mm.)	.173	.228	.301	.400	.530	.703	.914	
Ratio between head capsules		1.32	1.32	1.33	1.32	1.33	1.30	1.32
Duration of the stage in days.	6.4	5.8	6.2	6.2	5.4	6.8	9.8	
Accumulated days	0	6.4	12.2	18.4	24.6	30.0	36.8	
" " omitting I	0	0	5.8	12.0	18.2	23.6	30.4	

From table 27 the following facts emerge:-

1. The ratio between successive instars is constant, except for the ratio between the 6th and 7th instars. It is therefore concluded that the amount of growth between instars was constant, except for the amount between the 6th and 7th instars, which, for some unknown reason, was slightly less than the average. It is known that not all insects follow Dyar's Law (e.g. Heliothis (Lepidoptera) and Popilla (Coleoptera), (Wigglesworth, 1939), but in the case of E. cautella, there is a regular geometric progression, the width of each head capsule increasing by a constant ratio (1.32), therefore Dyar's Law is obeyed in this case.

As a check, Wigglesworth, 1939, has shown that when the number of the instar is plotted against the logarithm of some measurement of the insect, a straight line is generally obtained. When this method is applied (see plate 11, A.) a straight line is obtained for the VII - instar larvae. It is noticed that the 7th instar falls slightly off the line, agreeing with the results in table 27, therefore, the amount of growth in the 6th instar was less than the average.

Imms, 1934, has advocated another method for applying Dyar's Law thus:-

ave. ratio of increase = 1.32 (see table 27).

	calculated width in mm.	observed width in mm.
1st instar larve		.173
2nd " "	.173 x 1.32 = .228	.228 (.173 x 1.32)
3rd " "	.228 x 1.32 = .301	.301 (.228 x 1.32)
4th " "	.301 x 1.32 = .397	.400 (.301 x 1.33)
5th " "	.397 x 1.32 = .524	.530 (.400 x 1.32)
6th " "	.524 x 1.32 = .692	.703 (.530 x 1.33)
7th " "	.692 x 1.32 = .913	.914 (.703 x 1.30)

The calculated results agree sufficiently with the observed results to show that no instar has been missed, which was Dyar's original purpose. Thus this method again illustrates that the VII - instar larvae obey Dyar's law.

2) The duration in days between the successive instars was not

constant. The second instars had a shorter stadium (5.8 days) than the first (6.4 days), and thereafter the stadia fluctuated, rising to a maximum in the 6th instars (6.8 days). (the 7th instars had an even longer stadium (9.8 days), but since they did not feed, and spent their time in wandering, this stadium was not counted in subsequent calculations.

3) Richards, 1949, has shown for Cherthippus parellelus, Locusta migratoria migratorioides, Calandra granaria and Pieris rapae , that Dyar's law held for these insects provided the instars were all the same length. Growth proceeded at a regular rate; the longer the instar (in time), the greater the amount of growth. To see whether these findings apply to E. cautella, the average head capsule sizes (table 27, 1st row) were plotted against their corresponding accumulated days (table 27, 4th row) It is seen from Plate 11, fig. B.I. that the points do not lie on a straight line. When the length of the 1st instar is omitted, the results are no better. Therefore, although certain insects may very well grow at a regular rate, this is not so in the case of E. cautella. In this case the VII instar larvae follow Dyar's Law irrespective of the time taken between the successive instars. Since the temperature and humidity were constant throughout the growth of the larvae, the uneven rate of growth must be due to some factors connected with the food, and the larvae themselves.

For the VI instar larvae, the results were as follows:-

Table 28 - VI - instar larvae of E. cautella.

	Number of instars						
	I	II	III	IV	V	VI	Ave.
Mean width of head capsules in mm.	.178	.230	.311	.427	.592	.823	
Ratio between head capsules		1.30	1.35	1.37	1.39	1.39	1.36
Duration of stage in days	6.9	5.1	5.0	5.4	6.2	11.0	
Accumulated days	0	6.9	12.0	17.0	22.4	28.6	
" " omitting 1	0	0	5.1	10.1	15.5	21.7	

From table 28 it is seen that:-

1) The ratio between the head capsules is not constant, but increases from 1.30 - 1.39 with the number of instars. Therefore the amount of growth between instars seems to increase as the instars increase in size.

2) When the logarithm of each average head capsule size is plotted

against the corresponding instar, it is seen that the results do not correspond to Dyar's law as closely as the VII instar larvae. Instead of a straight line, the line is slightly curved, showing that the rate of growth is uneven. Since the line diverges to the left, it shows that the rate of growth increased with the age of the larvae.

3) When the method advocated by Imms, I934, is applied, the results are as follows:-

average ratio of increase = I.36 (see table 28).

" " " " omitting ratio I.30 = I.375.

calculated widths in mm.		observed widths in mm.
Ist instar larvae		.I78
2nd " "	.I78 x I.375 = .245	.230 (.I78 x I.30).
3rd " "	.245 x I.375 = .337	.3II (.230 x I.35).
4th " "	.337 x I.375 = .463	.427 (.3II x I.37).
5th " "	.427 x I.375 = .637	.592 (.427 x I.39).
6th " "	.592 x I.375 = .876	.823 (.592 x I.39)

It is seen that the calculated results diverge considerably from the observed results, and Dyar's law is not followed. It seems that the normal number of instars of <u>E. cautella</u> feeding on cashew nuts at 85°F. and 60% relative humidity is seven, but for some unknown reason, I4 larvae completed their development in only six instars. Some unknown factor caused the 2nd instar larvae to have larger amounts of growth, so that the following instars diverged from the expected results and did not follow Dyar's law. Had these I4 increased regularly in size by I.3I5, there would have been 7 instars thus:-

calculated widths in mm.			observed widths for VII instar larvae in mm.
(Ist instar larvae	.I78 for VI instar larvae)		.I73
2nd " "	.I78 x I.3I5	.234	.228 (.I73 x I.32).
3rd " "	.234 x I.3I5	.308	.30I (.228 x I.32).
4th " "	.308 x I.3I5	.405	.400 (.30I x I.33).
5th " "	.405 x I.3I5	.533	.530 (.400 x I.32).
6th " "	.533 x I.3I5	.70I	.703 (.530 x I.33).
7th " "	.70I x I.3I5	.922	.9I4 (.703 x I.30).

4) To find if the time factor was in some way resposible for the different amounts of growth, graph B2, plate II, was plotted. (The average head widths of each instar against the corresponding number of accumulated days.)

Again, it is seen that the points do not lie on a straight line, therefore it cannot be assumed that growth per day is constant, and it is not due to a time factor that the results digress from Dyar's law.

It is thus seen that the normal number of instars for <u>E. cautella</u>

feeding on cashew nuts at 85°F. and 60% relative humidity was seven. These instars increased their head capsule sizes in a regular geometric ratio (1.32), thus obeying Dyar's law. The time taken between the instars had no effect on the amount of growth, contrary to the results of Richards, 1949.

However, for some unknown reason, 14 larvae with slightly larger average 1st instar head capsules had an irregular amount of growth, and completed their development with six instars. Again, the amount of growth between successive instars was not dependent on time, but on some other unknown factor. Had these larvae increased in size by a regular amount (1.31), they would have completed their development in seven instars.

Since the temperature and humidity were constant, the rate and amount of growth of E. cautella depended on the food and the individual larvae themselves.

The following table shows the number of instars obtained by other authors for Ephestia species.

Table 29 - The number of moults of Ephestia species.

species	author	Average temperature	Ave. humidity	Food substance	The number of instars
E. cautella	Richards and Thomson, 1932	78.8°F. (26°C.)			2 males - 5 instars 8 females - 6 ♀
	Personal, 1951	85°F. (29.5°C.) (constant)	60%	cashew nuts	6 and 7 instars
E. elutella	Richards and Thomson, 1932	78.8°F. (26°C.)			6 - 8, usually 6
	Reed and Livingstone, 1937	"warehouse" (U.S.A.)		tobacco	6, sometimes 10
	Waloff and Richards, 1936	"warehouse" (England)		bulk grain	5 or six
	Waloff, 1938	77°F. (25°C.)	70%	Manitoba wheat	6 or 7, usually 7.
	"	"	35%	" "	increased number, up to twelve.
E. kuhniella	Burkhardt, 1919	"warm"		flour	4 - 5, usually 4
	Brindley, 1930	86°F. (29.7°C.) (constant)		"	6
	Von Gierke, 1932	64.4°F. (18°C.)		?	5
	"	77°F. (25°C.)		?	6

Therefore, it is seen from the above table that the number of moults and instars varies for each species, depending upon the food, temperature and humidity. E. cautella seems to have 4 - 6 moults, with 5 - 7 instars;

E. elutella has 4 - 11 or more moults, with five or more instars, but the usual number of moults seems to be five, with 6 instars; E. kuhniella 3 - 5 moults, with 4 - 6 instars.

Richards and Thomson, 1932, consider that the number of moults is linked with sex, since 2 males observed had 5 instars, while 8 females had 6 instars. But the numbers of larvae used are too small. Observations of the present author show that the number of moults is not linked with sex, i.e. In the VII instar larvae, there were 5 males and eleven females, while among the VI - instar larvae, there were seven males and seven females.

Reed and Livingstone, 1937, have shown that the number of moults of E. elutella feeding on tobacco depended to a large extent on the quality of the food and the rate of growth. Waloff, 1948, further showed that humidity also influences the number of moults e.g. at 77°F. and 70% relative humidity there were usually seven moults for E. elutella feeding on Manitoba wheat, but at the same temperature and 35% relative humidity, the number of moults was increased up to 12, and none of the larvae survived until pupation.

Another factor influencing the number of moults is temperature. Von Gierke, 1932, found four moults for E. kuhniella at 64.4°F. and five moults at 77°F. But he further found that there was some factor, connected with season, apart from temperature, which affects the rate of development. The progeny, up to the 4th generation of moths, transferred from a temperature of 18°C to 25°C. developed more quickly than those kept for many generations at 25°C. Similarly, after a change from 25°C. to 18°C., development was slower than when kept for several generations at 18°C.

The length of life of Ephestia larvae.

Kuhn and Henke, 1929, have studied the factors controlling the length of life in E. kuhniella, and have found that the factors mentioned above, i.e. temperature, food supply, the nature of the food, and, to some extent, the heriditary constitution, are important, but that sex has no influence.

Table 30 (next page) contains the results of some authors for the developmental period of Ephestia larvae from the emergence of the first instar larvae until pupation. It is seen that Kuhn and Henk's observations (1929) are illustrated, i.e. the temperature and the nature of the food influence the length of larval life, e.g. for E. elutella, at 85°F. development is faster on dried fruit (47 days) than on tobacco, (58.3 days), while at the lower temperature of 78.8°F., development on tobacco may last from 21 - 200 days (Bovingdon, 1933).

Table 30 - The length of life of *Ephestia* larvae.

Species	Observer,	Range of temperatures	Average Temp.	Food Substance.	Length of develop ment in days.	
					range	ave.
E. cautella	Simmons, etc, 1931	18.2 -33.7°C. (65.7 - 92.7F)	26.8°C. (80.2°F.)	raisins (U.S.A.)	49 - 80	63.6
	Chittenden, 1911	midsummer		dried figs (")	13 - 30	
	Boselli, 1933		86°F. (30°C.)	" " (Italy)	28 - 35	
	Silva, 1949	"room" Dec. - Jan.		cacao (Brazil)	40 - 42	
		May - Aug.			60 - 73	
	Cotterell, 1934	"room"		" (Gold Coast)		49
	Personal, 1950	constant	85°F. (29.9°C.)	cashew nuts	21 - 50	34.7
				dried fruit	29 - 72	47.1
				chocolate	30 - 76	49.9
E. elutella	Stamatinus, 1934	"room"		tobacco (Macedonia)	29 - 70	
	Nakayama, 1935	"summer"		" (Korea)		45
	Bovingdon, 1933	constant	78.8°F. (26°C.)	" (Britain)	21 - 200	51 - 70
	Reed and Livingstone, 1937	70 - 80°F. (21.1 - 26.6°C)		" (U.S.A.)	29 - 77	47.6
		69.1 -75.9°F. (20.6-24.4°C.)		" (")	39 -128	76
	Zacher, 1925	"room"		chocolate (Germany)	78 - 192	
	Personal	constant	85°F. (29.5°C.)	"	no development	
	Waloff and Richards, 1946	"room"	62.4°F. (16.9°C.)	bulk grain (Britain)	60 - 70	
	Waloff, 1948	constant	62.6 F. (17°C.)	Manitoba wheat (")	54 - 80	61.2
	"	"	77°F. (25°C.)	" " "	29 - 50	35.9
	Personal, 1951	"	85°F. (29.5°C.)	dried fruit	29 - 68	47.1
	"	"	"	tobacco	36 - 79	58.3
	"	"	"	cashew nuts	22 - 50	35.2
E. kuhniella	Noyes, 1930	"room"		cacao (Britain)	70 - 154	
	Brindley, 1930	constant	86°F. (30°C.)	flour (U.S.A.)	21 - 42	28
	Ullyett, 1947		75°F. (24°C.)	boermeal (S.Africa)		56
	Kunike, 1939		78.8°F. (26°C.)	flour (Germany)	24 at least	
	Personal, 1951	constant	85°F. (29.5°C.)	cashew nuts	29 - 53	38
				chocolate	41 - 82	63.4
				boermeal	25 - 59	39

It is seen from the above table that most work on the development of *Ephestia* larvae has been done under unstandardised conditions at room temperature, therefore it is difficult to compare the development of all three species on the same and different foodstuffs. From results of the present author (page 25, table 11) it seems that in general, the larvae of *E. cautella* develop the fastest, followed by *E. elutella* and then *E. kuhniella*. It seems that *E. cautella* develops best on cashew nuts, followed by dried fruit, and then possibly cacao and chocolate.

In many cases, larval development is prolonged by a diapause during the winter. This has not been personally observed, but it has been recorded by Chittenden, 1911, for E. cautella feeding on dried figs, and by Reed and Livingstone, 1937, and Bovingdon, 1933, for E. elutella feeding on tobacco, and by Waloff, 1948, for E. elutella feeding on a variety of substances.

Waloff, 1948, has shown that the natural foods of E. elutella may be divided into 3 groups, namely:-

1) Those on which no larvae diapaused at 77°F. (25°C.) and 70% R.H. - Manitoba no. 1 wheat and unpolished rice, in which only the embryos are eaten, English oats, flue-cured bright tobacco, figs and soya flour with 1% fat:

2) Foods on which a low percentage of surviving larvae entered diapause at the same temperature and relative humidity:- soya flour with 7.3% fat, cacao beans, ground nuts and dry peas:

3) Foods on which a high percentage, or all of the surviving larvae entered diapause at the same temperature and relative humidity:- English wheat, white flour, dry beans and an artificial diet with starch as the only carbohydrate. All these foods had a high starch content.

Similarly, according to Voukassovitch and Voukassovitch, 1934, the development of E. kuhniella larvae to the adult stage may require a period of five times as long on the poorest food as on the richest. These authors also record a very marked individual variation in the length of the larval stage, especially when the larvae were fed on poor foods. Kunike 1939, found that for this species, the larvae developed best on flour, groats and flakes of higher nutritive value, provided that these foods contained bran of which the particles were small enough to be easily attacked by the young larvae. Next in order of decreasing importance come entire grains, flour without bran, pulses, hard groats, ground nuts, oats, sweet almonds, dried fruit and cacao beans. Voukassovitch, 1935, says that the development is accelerated by righ foods because of the presence of fat.

The observations on the food requirements of E. elutella and E. kuhniella may be best interpreted according to the findings of Fraenkel and Blewett. (1943, a,b and c, and 1946 a and b). They find that the 3 main factors in the nutrition of Ephestia species are carbohydrates, the qualitative and quantitative requirements of sterols and the qualitative and quantitative requirements of vitamins of the B. group. The carbohydrate requirements of these species are high, and while E. kuhniella,

E. elutella and E. cautella show optimum growth on artificial diets with 80% glucose, only E. kuhniella grows on starch. This agrees with the findings of Waloff, 1948 (page 54). The vitamins of the B. complex indispensible for growth are thiamin, nicotinic acid, pyridoxin and pantothenic acid as well as other undiscovered factors, and E. elutella needs riboflavin as well. Therefore, these authors suggest that since E. kuhniella, E. elutella and E. cautella are all known as pests of grain and cereal products, the latter 2 species feed successfully by picking out such particles of bran or wheat germ low in starch and high in sugar and vitamins of the B. group. Most riboflavin is found in cacao, followed by ground nuts, flour, dried prunes and raisins, therefore, a limiting factor for E. elutella on flour is probably a lack of vitamins of the B group.

Furthermore, Ephestia species need sterols, the requirements of which are met in wheat-germ oil. (Fraenkel and Blewett, 1946b). In its absence growth is slow, mortality is high and the moths fail to emerge from their pupal cases. The saponifiable fraction contains linoleic acid, or linolenic acid, necessary for emergence and good scales, while the unsaponifiable fraction (Vitamin E) is necessary for good growth. These 2 authors (1944) have further found that more food is eaten, and the larval period is prolonged, at decreasing humidities, since part of the food is utilised as water.

C) The pupae.

Differences in the pupae of the 3 Ephestia species have already been described and it has been concluded that E. elutella has the smallest pupae and E. kuhniella the largest. (page 13, table 4). It has also been concluded from observations of the present author at 85°F. that the pupae of E. cautella have the shortest development, and E. elutella the longest. (page 27, table 12). The results of other authors are tabulated in table 31. (next page)

It is seen from the latter table that all the species have a wide range of pupal development, depending upon the species. The length of development of E. cautella varies from 4 - 24 days, that of E. elutella varies from 6 - 42 days, and that of E. kuhniella varies from 7 - 30. It is difficult to compare the development of the different species, since very few of the lengths of development have been determined at constant temperatures. However, from a consideration of all the results, and results of the present author, it seems, that, in general, the pupae of E. cautella have the shortest range of development, while the range of E. kuhniella is somewhat longer; E. elutella has an appreciably longer range. However, at high temperatures (85°F.), these differences are not so noticeable.

Table 30 - The length of pupal development of Ephestia species. (In days).

Species	Observer	Range of temperature	Ave. Temp.	Food of the larvae	length of the stage in days	
					Range	Ave.
E. cautella	Chittenden, 1911		84.2°F. (29°C.)	dried figs (U.S.A)	8.5 - 24	16.2
	Simmons, etc. 1931	65.7-92.7°F. (18.7-33.7°C.)		" "	9 - 17	10.4
	Richards and Thomson, 1932		78.8°F. (26°C.)	? (Britain)	8 - 11	9.7 - 11
	Cotterell, 1934	"room"		cacao (England)		12
	Silva, 1949	"		" (Brazil)	10 - 12	11
	Personal, 1951	constant	85°F. (29.5°C.)	cashew nuts (S. Africa)	4 - 8	6.7
E. elutella	Mossop, 1932	"summer"		tobacco (Rhodesia)	10 - 20	
		"spring"		"	18 - 28	
	Richards and Thomson, 1932		73.4°F. (23°C.)	? (England)	18 - 42	14.2
	Bovingdon, 1933	constant	78.8°F. (26°C.)	tobacco "	6 - 13	
	Reed, etc., 1933	"room"		" (U.S.A.)		
		Aug. - Sept.				11.3
		Oct. - Nov.				16.7
	Stamatinis, 1934		59.9°F. (15.5°C.)	" (Macedonia)		24.0
			80.6°F. (27°C.)			7.0
	Potter, 1935	"low"	53.5°F. (11.9°C.)	dried fruit	21 - 35	
	Waloff, 1948	constant	62.6°F. (17.9°C.)	Manitoba wheat (England)	6 - 39	20.6
	"	"	77°F. (25°C.)	"	6 - 37	13.8
	Personal, 1950	"	85°F. (29.9°C.)	cashew nuts (S. Africa)	6 - 11.5	8.6
E. kuhniella	Burkhardt, 1919	"warm"		flour (Germany)	12 - 30	
	Noyes, 1930	"room"		cacao (England)	11 - 16	
	Brindley, 1931	constant	86°F. (30°C.)	flour (U.S.A.)	7 - 10	8
	Voukassovitch, 1934 and 1936		77°F. (25°C.)	" (Serbia)	12 - 13	
			82.4°F (28°C.)	" "	7 - 10	
	Kunike, 1939		71.6°F. (22°C.)	" (Germany)		12
			78.8°F (26°C)	" "		8
	Personal, 1951	constant	85°F. (29.9C)	cashew nuts (S.Africa)	7 - 12	8.4

D) The Adults.

The adults of the 3 species have been described in section 5D, and the average lengths of the 3 species have also been tabulated in the same section.

Emergence. It has already been mentioned from observations of the present author (page 27) that the moths of *E. cautella*, when kept in the laboratory, emerge at any time of the day or night. This confirms the observations of Brindley, 1930 on *E. kuhniella.* However, under natural conditions, Bremer, 1926, found that light was an important factor in the emergence of *E. kuhniella*, since moths emerged chiefly in the afternoon and evening, and if the pupae were kept in light at night, and during the dark at day, the cycle was reversed. Scott, 1936, further showed that the diurnal cycle of temperature influences emergence, which occurs when the temperatures begin to fall. If the larvae or pupae are exposed to an artificial rhythm of this kind, emergence can be induced at an abnormal time of the day.

Habits. Observations of the present author show that the moths of *E. cautella* and *E. elutella* become very active in the early mornings, before 8 am. and in the afternoons from 3 pm. onwards. Waloff and Richards, 1946, state for *E. elutella*, that "this activity may be partly dependent on temperature, but laboratory data show that light alone is a sufficient stimulus..... it would appear that this periodicity of activity seems to depend on light rather than the time of day". They observed that in warehouses, the moths flew at the changing light intensities of sunrise and sunset, when the light intensity was below 1 foot candle. This is probably true, since when the moths of *E. cautella* were placed in a cage covered with black paper at room temperatures, they were observed by the present author to become active and copulations continued throughout the day. However, it seems that temperature must have some effect, since the moths were especially active in the early mornings and after 3 pm., when the temperature was at its lowest and highest respectively.

Longevity and oviposition.

Norris, 1934, has shown by experiment that the adults of *Ephestia* do not feed since their requirements are met by food stored in the fat body. This author has shown that for *E. cautella* and *E. elutella*, the longevity of both sexes, and the fecundity of the females at 80.6°F. (27°C.) was reduced by about 50% if the adults were deprived of drinking water. At lower temperatures, between 64.4°F. and 68°F. (18 - 20°C.), the reduction in longevity when deprived of drinking water was equally great, and the fecundity was reduced by about 100%. The increase in fecundity and longevity was due to actual drinking of the water, and not atmospheric humidity.

When *E. cautella* was fed on cane sugar fluid, the longevity of both sexes was increased, but the fecundity was not significantly affected. Norris has showed that cane-sugar fluid increases longevity since it provides nutriment which to some extent takes the place of food reserves in the fat body. But "fecundity in *E. cautella* doesn't depend directly on longevity, but is limited by the quantity of "egg-developing substance" in the fat body; when this substance is exhausted, egg-production ceases, although life may continue and although there remain many unripened egg-rudiments in the ovaries which could presumably be ripened were suitable food available".

Norris has further shown that in *E. kuhniella*, the reduction in fecundity and longevity was much less when deprived of drinking water. This is related to the state of the ovaries at emergence, since *E. kuhniella* emerges with a number of ripe eggs in the ovaries, while *E. cautella* has no completely ripe eggs at emergence and therefore needs water.

These results were not personally confirmed, but since there is probably no water available to the moths under natural warehouse conditions, the moths used in longevity and oviposition experiments were not given any water to drink.

Table 31 (next page), tabulates the results obtained by different observers for the fecundity of *Ephestia* species.

It is seen from the latter table that results of the present author correspond with the results of other authors. Although in the case of *E. cautella*, results of the present author for the fecundity are slightly higher than those obtained by Simmons, Reed and M'Gregorr, 1931, these latter authors carried out experiment on 13 moths only, while experiments of the present author were carried out on 30 and 50 moths at 65°F. and 85°F. respectively. For *E. elutella*, results of the present author correspond very well with the results of other authors.

Table 31 - The Number of eggs laid by Ephestia Species.

Species	Observer	Average temp.	the number of eggs laid	
			range	average
E. cautella	Simmons, etc., 1931	"room"		123
		85°F. (29.5°C.)	38 - 207	114.1
	Personal, 1950	" (constant)	73 - 243	158.2
		65°F. (18.3°C.) (constant)	6 8 - 279	168.0
E. elutella	Mokrzecki, 1930	"room"	20 - 130	
	Noyes, 1930	"	100 - 250	
	Mossop, 1932	"		97
	Reed, etc., 1932	"	37 - 397	127.3
	Stamatinis, 1934	"	32 - 267	
	Nakayama, 1935	"		84
	Reed and Livingstone, 1937	"	1 - 260	
	"	85°F. (29.5°C.)		80
	Personal, 1950	" (constant)	41 - 122	78.1
	"	65°F. (18.3°C.) (constant)	40 - 158	98.4
E. kuhniella	Decaux, 1893	"room"	200 - 250	
	Johnson, 1895b	"	120 - 271	240
	Frickhlinger, 1919	"	124 - 325	
	Burkhardt, 1919	"	75 - 320	150 - 200
	Zacher, 1919	"	200	
	Candura, 1928	"	119 - 280	200
	Voukassovitch, 1929	dry atmosphere		225
		damp atmosphere		171
	Brindley, 1930	86°F. (30°C.) (constant)		167
	Richards and Thomson, 1932	"room"	200 - 500	300 - 400
	Kunike, 1939	"	? - 500	300
	Personal, 1951	85°F. (29.5°C.) (constant)	38 - 330	122.4
	"	65°F. (18.3°C.) (constant)	57 - 400	263.5

For E. kuhniella, results of the present author for temperatures below 85°F. correspond very well with the results of other authors, but at 85°F. results of the present author (122.4) and the results of Brindley, 1930 (167) are much lower. According to Brindley, 1930, and Wishart, 1942, when E. kuhniella is reared under 80 - 85°F. (27 - 30°C.), the moths show a marked degree of sterility. This is further confirmed by Ahmad, 1936, who states that the reproductive potential and development of this species is adversely affected by temperatures above 73.4°F. (23°C.) and a high saturation deficiency above 14 mm.

Therefore it is concluded that at temperatures below 73.4°F. (23°C.), the moths of E. kuhniella lay the greatest number of eggs, E. cautella is intermediate and E. elutella lays the least. This is to be expected, since

Ullyett and van der Merwe, 1947, have shown that "there is a well-defined relationship between the size of a female moth and the number of eggs which can be developed in its ovaries." Further, Ullyett, 1945, has shown that for E. kuhniella there was a highly significant positive correlation between moth density and oviposition. The optimum density of moths for the maximum oviposition was 19 females per unit area.

Voukassovitch, 1934 and 1935, states that heat accelerates the deposition of the eggs in the case of E. kuhniella, which ceases to lay eggs when the temperature reaches 23°F. (-5°C.). For E. elutella Mokrzecki, 1931, has stated that a temperature of 59 - 68°F. (15 - 20°C.) is essential for oviposition. Although these statements have not been personally confirmed, it has been observed by the present author that females of E. elutella kept at room temperatures in winter at an average temperature of 59.2°F. (15.1°C.) with a range from 52 - 67°F. (11.1 - 16.1°C.), laid eggs very sporadically, sometimes days elapsing between successive ovipositions, and this was probably due to a low temperature, since in the warm room at 85°F. (29.5°C.) oviposition in E. elutella took place regularly within 24 hours each time. The same was observed inthe case of E. cautella (see page 38).

Finally, Kozhanchikov, 1934 and 1937 has confirmed the findings of Norris, 1933 and 1934, that the fecundity is not directly dependent on longevity. The former author found that the number of eggs depended on the maturation of the gonads in the pupal stage, which, in turn, is affected by humidity and temperature. The optimum temperature for pupal development was between 71.5 and 75.2°F. (22 - 24°C.), but females from pupae that had developed at temperatures below the optimum laid a greater number of eggs.

Therefore, the number of eggs laid and the deposition of the eggs themselves is dependent on a number of interrelated factors. It may also be mentioned that there must be a suitable stimulus for egg-laying. Ullyett, 1935, found that wire gauze was a sufficient stimulus in the case of E. kuhniella since the gauze is very similar in texture to the mesh of a bag through which oviposition naturally occurs, therefore, in experiments of the present author muslin gauze was used to stimulate oviposition in the case of E. kuhniella and E. elutella. For E. cautella, glass was a sufficient stimulus.

Ullyett, 1945, further found that in oviposition experiments with flour and french chalk, and there was no difference in the number of eggs deposited by *E. kuhniella* on both substances. "By replacing flour with french chalk, the property of the texture is retained while any chemotactic stimulus is removed. Therefore, Ullyett concluded that "the ultimate stimulus for oviposition appears to reside in the mechanical texture of the medium and not in its olfactory attractiveness... but if given 2 alternatives, the flour would undoubtedly be chosen since the initial stimulus, by which the insect finds the medium it nature, is an olfactory one. Having fout it, however, the act of oviposition is conditioned by the degree of tactile stimulus present".

On the other hand, Waloff and Richards, 1946, in experiments upon *E. elutella* feeding upon bulk grain, found that this species showed a "striking example of chemotaxis towards grain" in warehouses, but in the laboratory, the females were more strongly attracted by the smell of cacao beans, irrespective of whether fed on cacao or grain. In the laboratory, the order of preference was open grain, sacking over grain, sacking, crevices and flat surfaces such as wood and glass. In general, a rough surface was preferred to a smooth one. In dried fruit factories, Arkhangel'skii, 1931 states that *E. elutella* prefers to oviposit on softer fruit, and prefers dried pears, peaches and apricots more readily than raisins.

Thus it is concluded that females of *E. cautella* may find their food material due to an olfactory response, but the actual oviposition depends on the degree of tactile stimulus present. It seems that softer foods are preferred, like dried apricots, pears, figs, apples, raisins, dried peaches and prunes, while harder material such as chocolate, nuts and tobacco have a low order of preference. However, the actual order of preference seems to depend on the condition of the food material. (see pages 34 and 35).

E) The length and life and the number of annual broods.

The table on the next page summarises the results obtained by different authors for the total length of life of *Ephestia* species from the egg to the adult emergence.

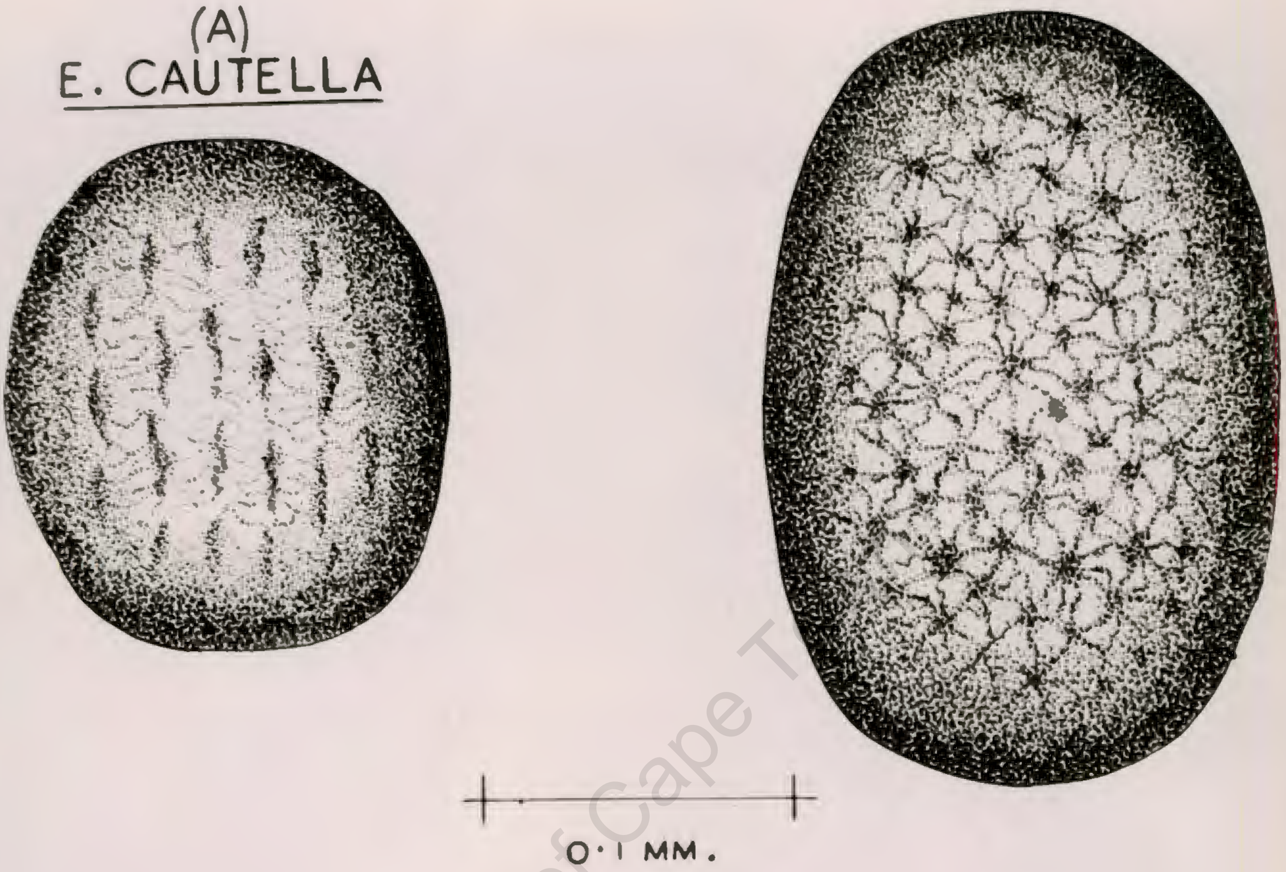
Table 33 - The total length of life and the number of generations of *Ephestia.*

Observer	Country	Food of larvae	Average temperature	Length of Life in days.		The number of annual generations.
				range	ave.	
			E. cautella			
Chittenden, 1911	U.S.A.	dried figs	"summer" autumn and spring		35 49	
Simmons. etc.1931	"	"	67.6-92.7°F. (19.8-33.7°C.)	60 -90	81.9	
Herford, 1933	England	dried fruit	78.8°F.(26°C.)	35 -50		
Essig, 1920	U.S.A.	"		30 -60		5 - 6
Personal, 1951	S. Africa	"	85°F.(29.5°C.)	39 -79	55.1	(3 - 4)?
"	"	cashew nuts	"	31 - 60	44.8	(4 - 5)?
		chocolate		40 - 85	59.3	(3 - 4)?
Cotterell, 1934	Gold Coast	cacao			60	5 - 6
Herford, 1933	England	"				1 - 2
			E. elutella			
Zacher, 1925	Germany	sweets	"room"	78 - 198		1 - 2 time longer with marzipan, chocolate
Archangel'skii, 1931	Russia	dried fruit	"	45 - 90		3 - 4
Potter, 1936	England	"	40.8 - 65.6°F. (4.9 - 18.7°C.)	357 - 367		2. 1st in June-July, 2nd in Aug.-Sept.
Personal, 1950	S. Africa	"	85°F. (29.5°C.)	39 - 71	59.2	(3 - 4)?
"	"	tobacco	"	42 - 80	62.1	(3 - 4)?
Bovingdon, 1933,	England	"	78.8°F.(26°C.)	41 - 210	61 - 100	2, due to a diapause
Stamatiins, 1934	Macedonia	"	"room"	39 - 103		2. 1st May-July, 2nd Sept.-Oct.
Nakayama, 1935	Korea	"				2, sometimes 3.
Reed and Livingstone, 1937	U.S.A.	"	"room"1932 " 1933	58 - 152 46 - 123		2 complete generations. 1st in July, 2nd in September until May.
Mossop, 1937	Rhodesia	"				2 or more.
Reh, 1907	Germany	cacao				more than 1, division not well marked.
Waloff, 1948	England	"	75°F. (29°C.)	63 - 122	86.6	
"	"	dried figs	"	121 - 146	133.5	
"	"	tobacco	"	86 - 175	120	
"	"	unpolished rice	"	47 - 76	57.2	
"	"	wheat	77°F. (25°C.)	42 - 79	49.8	
			69.8°F. (21°C.)	71 - 102	84	
			62.6°F. (17°C.)	62 - 118	79.6	
Van Emden, 1925	Germany	dried vegetables				1 - 2
			E. kuhniella.			
Danysz, 1893	France	flour				2 - 6 according to temperature
Johnson, 1895	U.S.A.	"				5 - 6
Burkhardt, 1919	Germany	"				3
Wadsworth, 1919	England	"				1 - 6 depending on food
Back, 1920	U.S.A.	"			± 63	
Candura, 1928	Italy	"				2 - 5 according to food
Noyes, 1930	England	cacao				1, possibly 2
Brindley, 1931	U.S.A.	flour	86°F. (30°C.)		41	
Personal, 1951	S. Africa	"	85°F. (29.5°C.)	36 - 65	49.6	(3 - 4)?
		cashew nuts	"	39 - 73	51.2	(3 - 4)?
		chocolate	"	51 - 100	72.1	3 ?

It is seen from table 33 that the number of annual broods of *Ephestia* species varies with temperature and with different foods. In general, *E. cautella* has from 1 - 6 generations. Chittenden, 1911, says

PLATE I

THE EGGS OF EPHESTIA SPECIES.



(A)
E. CAUTELLA

(B)
E. ELUTELLA

(C)
E. KUHNIELLA

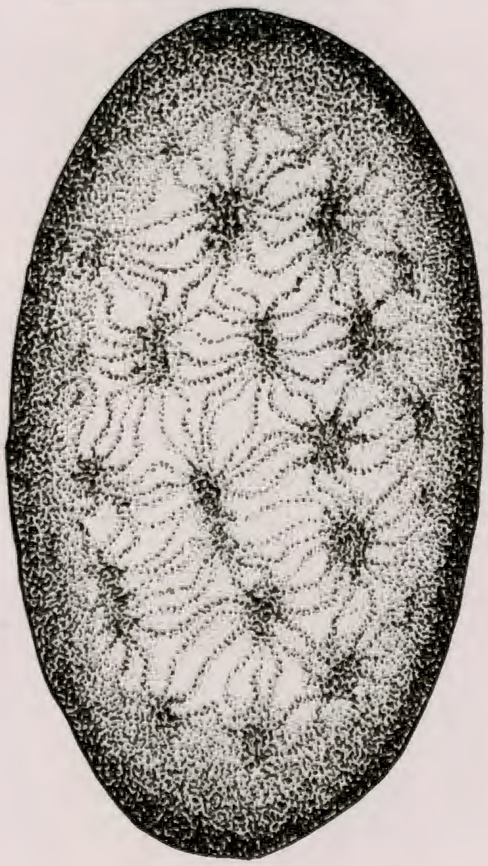
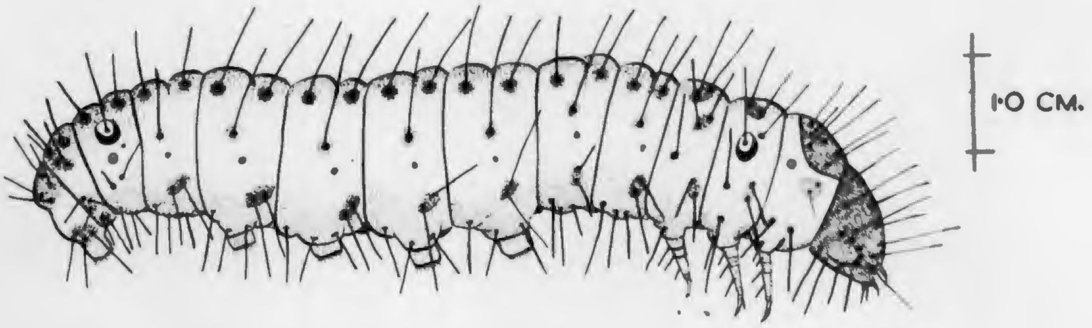


PLATE 2

THE LARVAE OF EPHESTIA SPECIES.

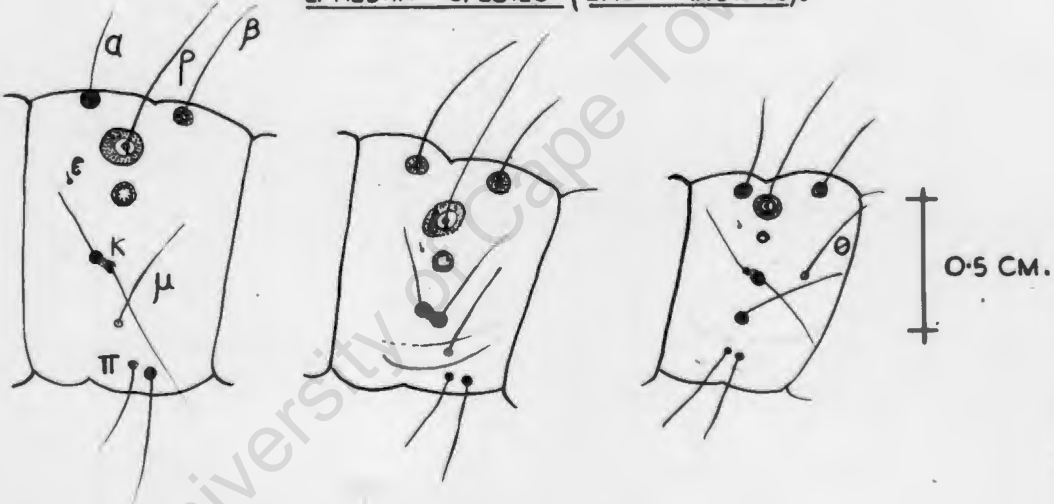
(A)

LAST INSTAR LARVA OF E.CAUTELLA



(B)

LATERAL VIEW OF EIGHTH ABDOMINAL SEGMENTS OF EPHESTIA SPECIES (LAST INSTARS).



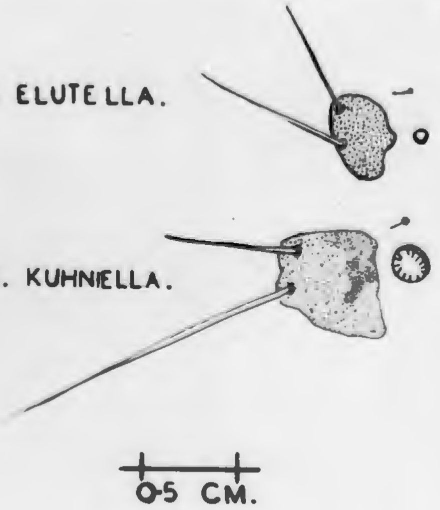
(1) E. KUHNIELLA (2) E. CAUTELLA (3) E. ELUTELLA

(C)

PROTHORACIC SPIRACLE AND KAPPA SETAE OF LAST INSTAR LARVAE.

(1) E. ELUTELLA.

(2)E. KUHNIELLA.



(D)

INNER VENTRAL VIEW OF MANDIBLE OF FIRST INSTAR LARVAE.

(1) E. ELUTELLA. (2) E. KUHNIELLA.

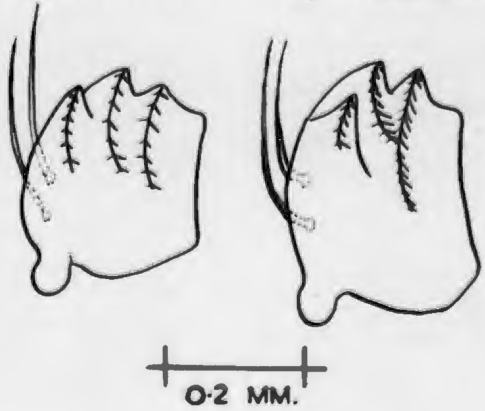
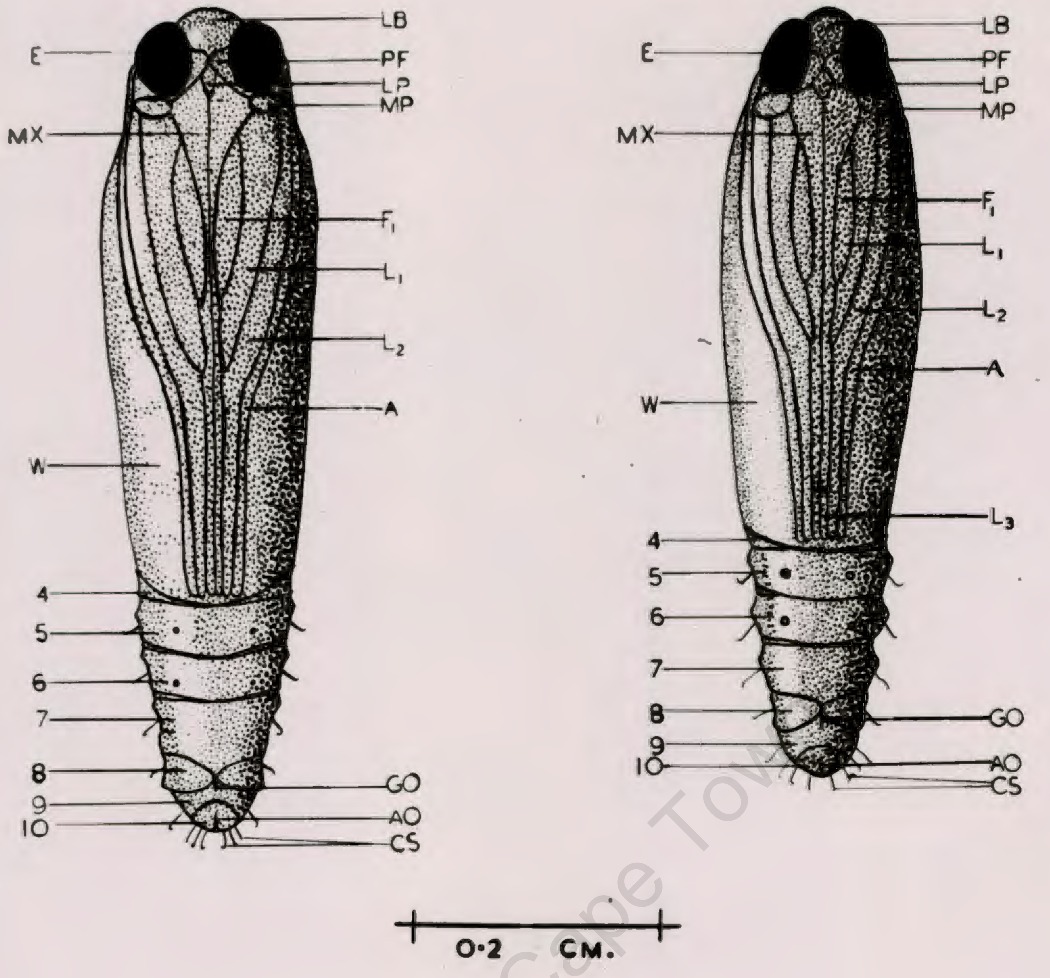


PLATE 3

THE PUPAE OF EPHESTIA SPECIES.



(A)
E. CAUTELLA (FEMALE)

(B)
E. ELUTELLA (FEMALE)

(C)
E. KUHNIELLA (MALE)

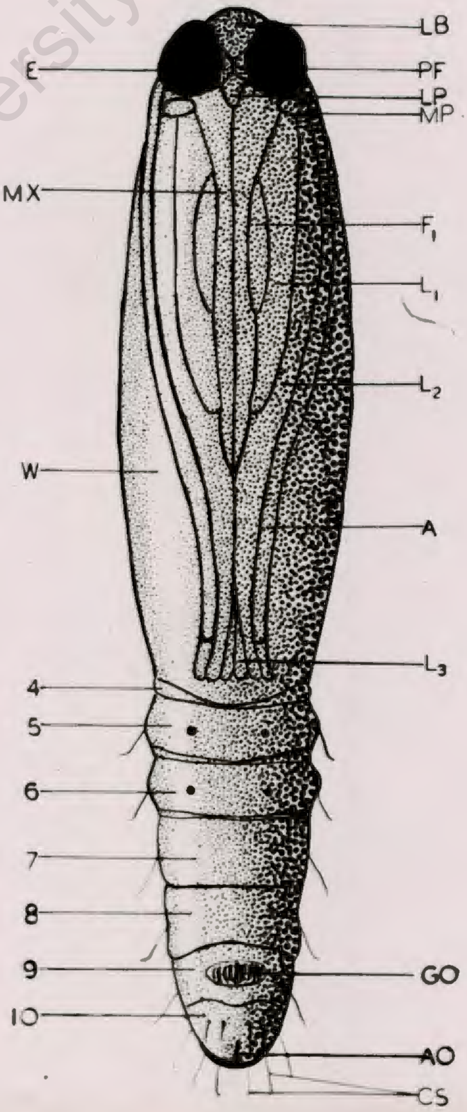
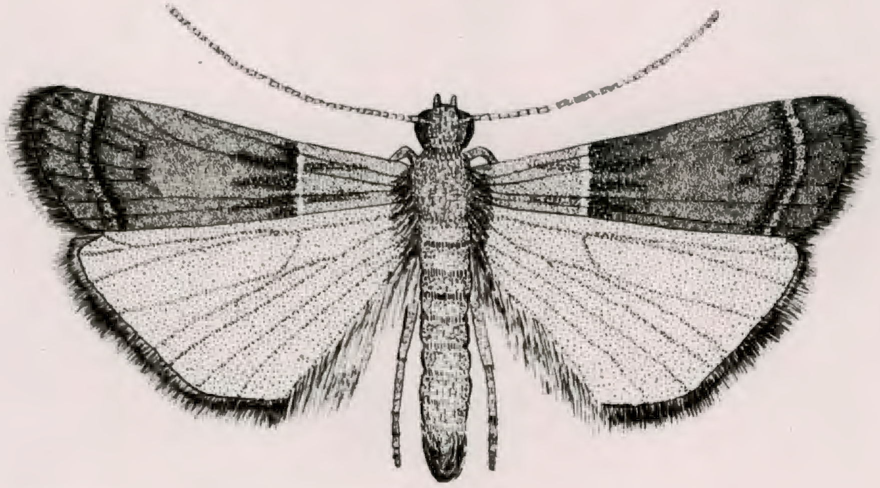


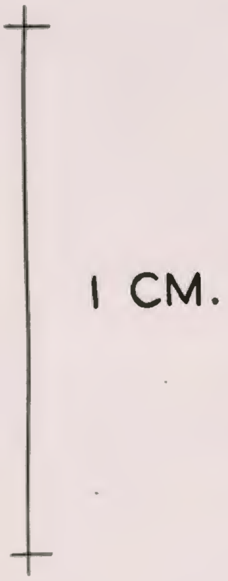
PLATE 4

THE ADULTS OF EPHESTIA SPECIES.

(A)

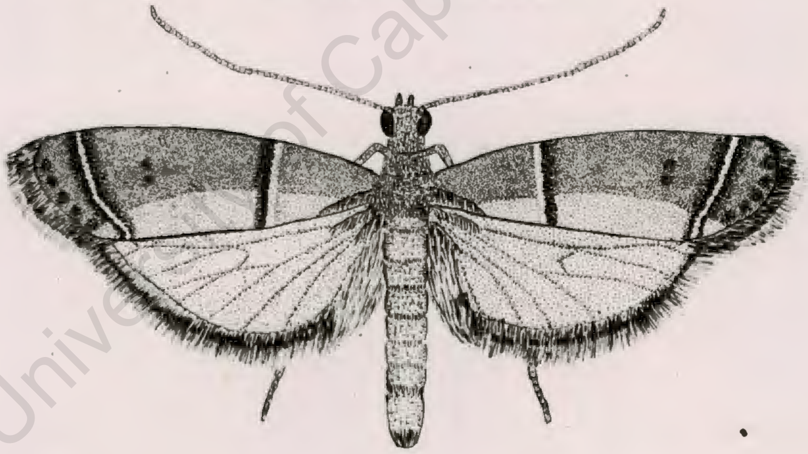
E. CAUTELLA





(B)

E. ELUTELLA



(C)

E. KUHNIELLA

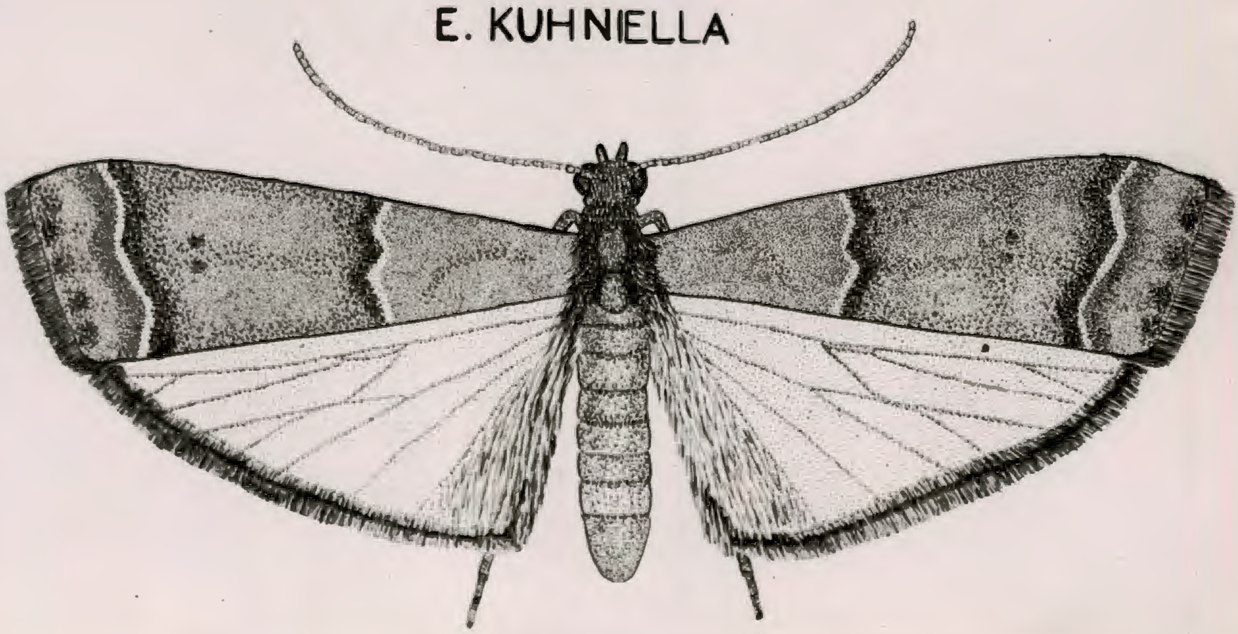
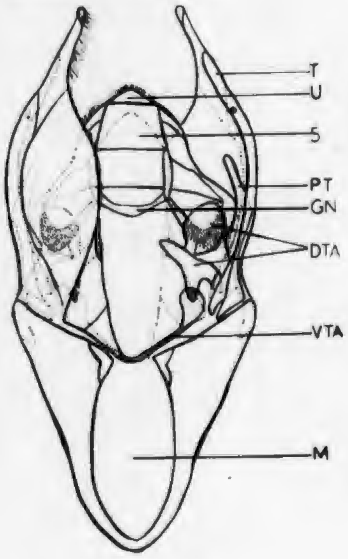


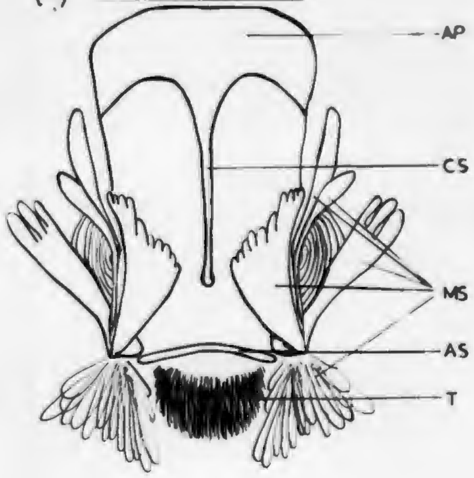
PLATE 5

THE ADULTS OF EPHESTIA SPECIES: MALE GENITALIA AND MODIFIED SCALE TUFTS.

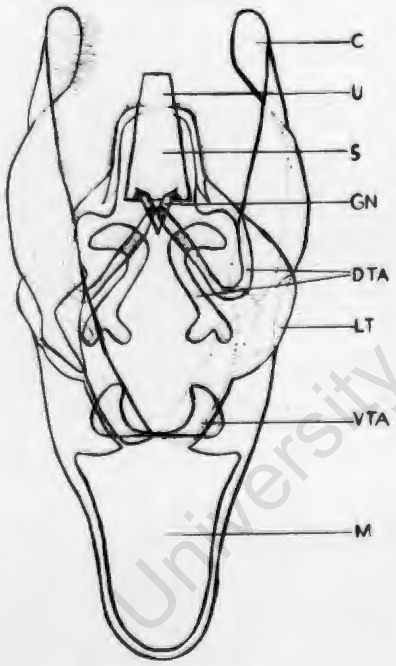
(A) E. CAUTELLA



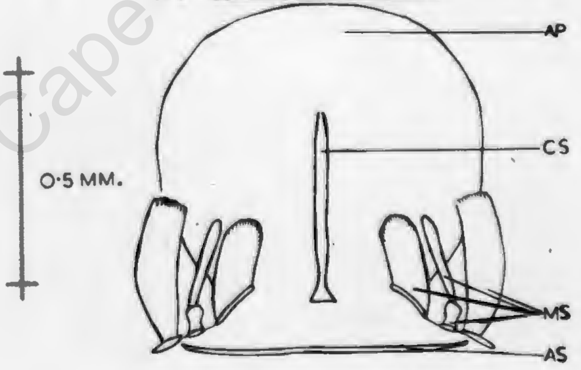
(D) E. CAUTELLA.



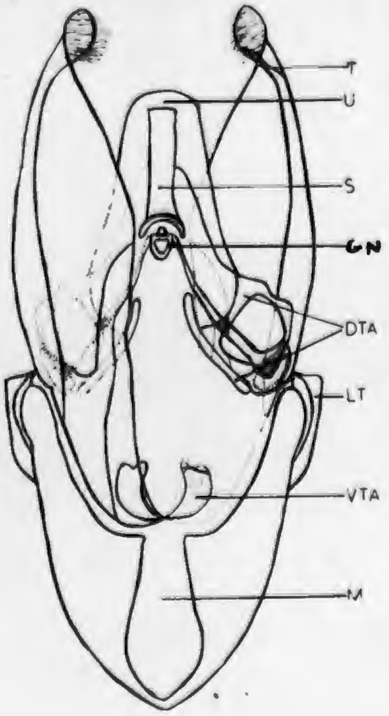
(B) E. ELUTELLA



(E) E. ELUTELLA.



(C) E. KUHNIELLA.



(F) E. KUHNIELLA.

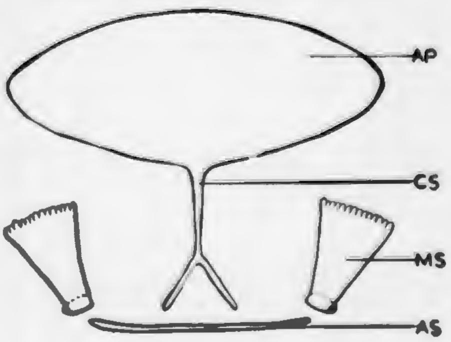
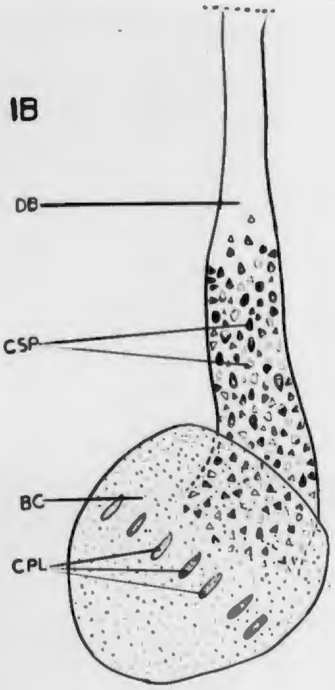


PLATE 6

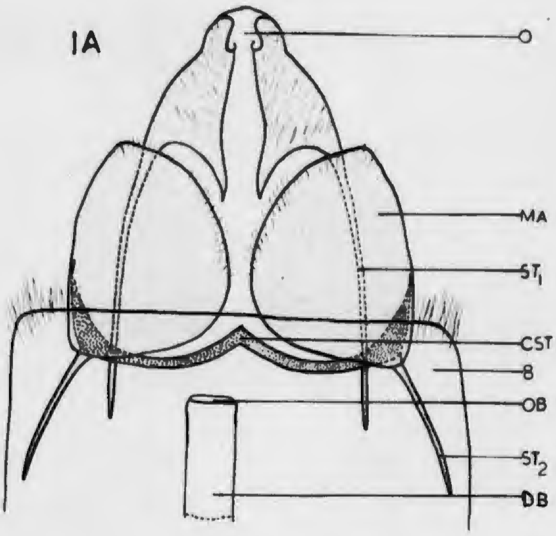
THE ADULTS OF EPHESTIA SPECIES: FEMALE GENITALIA.

E. CAUTELLA.

1B

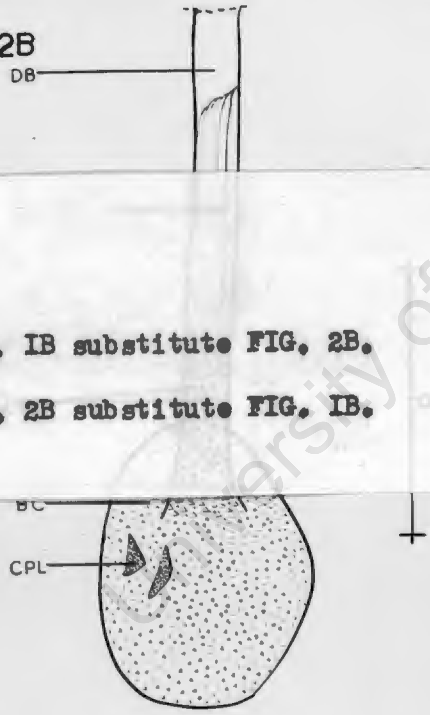


1A

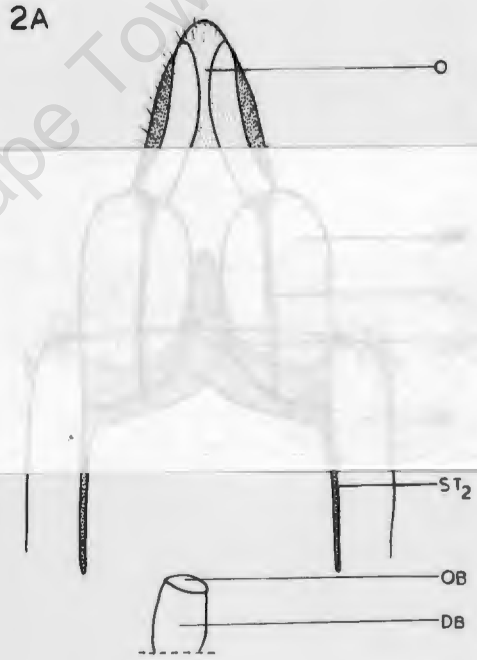


E. ELUTELLA.

2B



2A



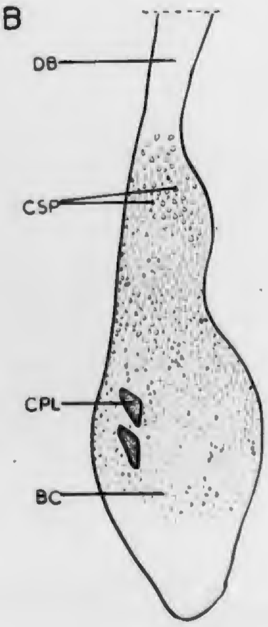
Errata.

For FIG. IB substitute FIG. 2B.

For FIG. 2B substitute FIG. IB.

E. KUHNIELLA.

3B



3A

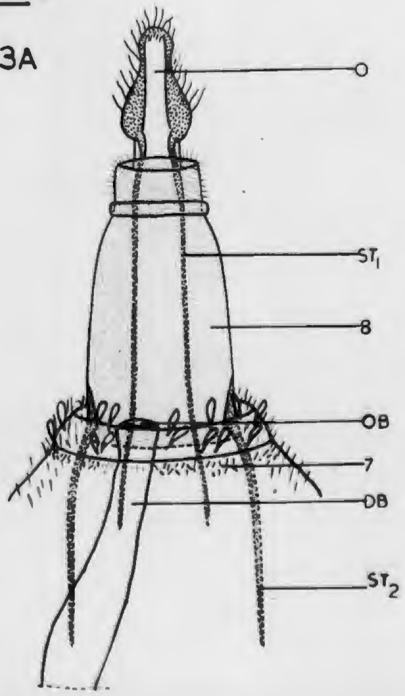
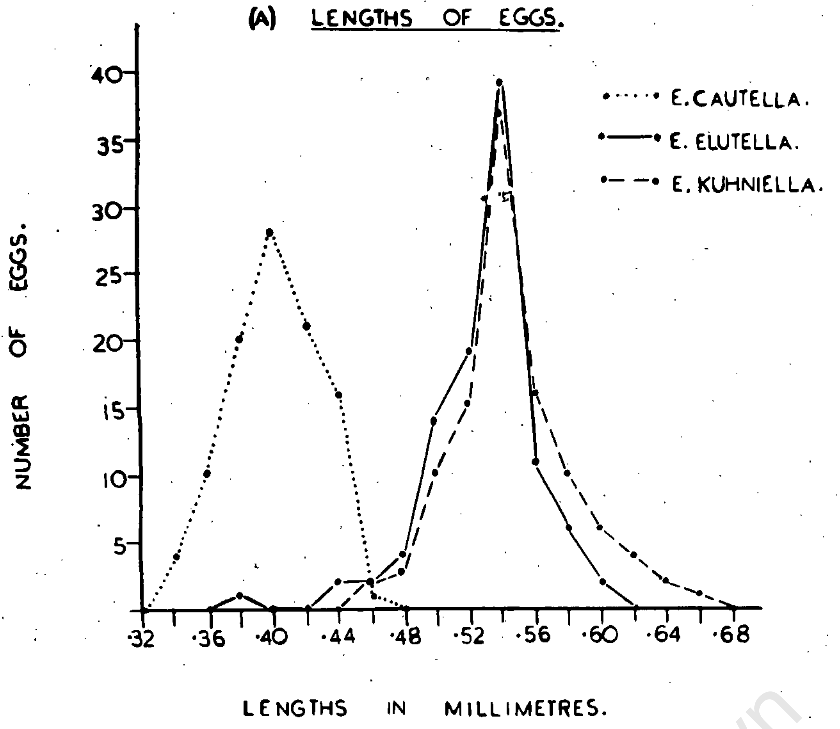


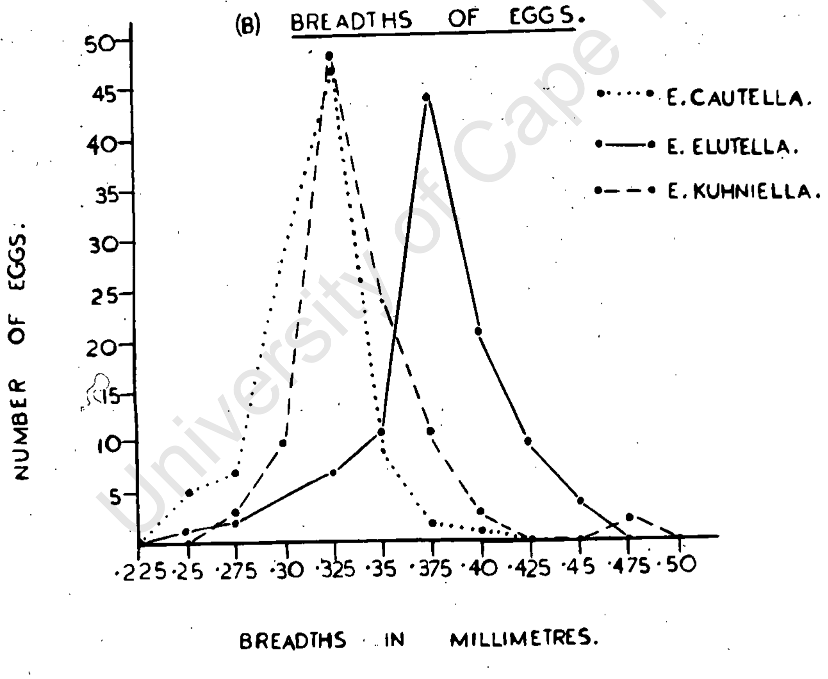
PLATE 7

DIMENSIONS OF THE EGGS OF EPHESTIA SPECIES.

(A) LENGTHS OF EGGS.



(B) BREADTHS OF EGGS.



(C) LENGTH X BREADTH MEASUREMENTS OF EGGS.

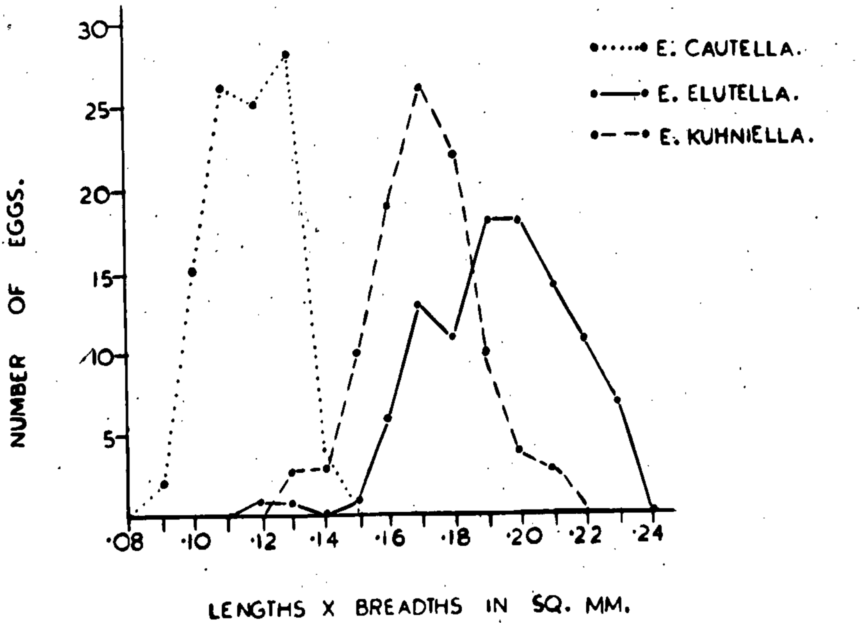


PLATE 8

BODY LENGTHS OF ADULT EPHESTIA SPECIES.

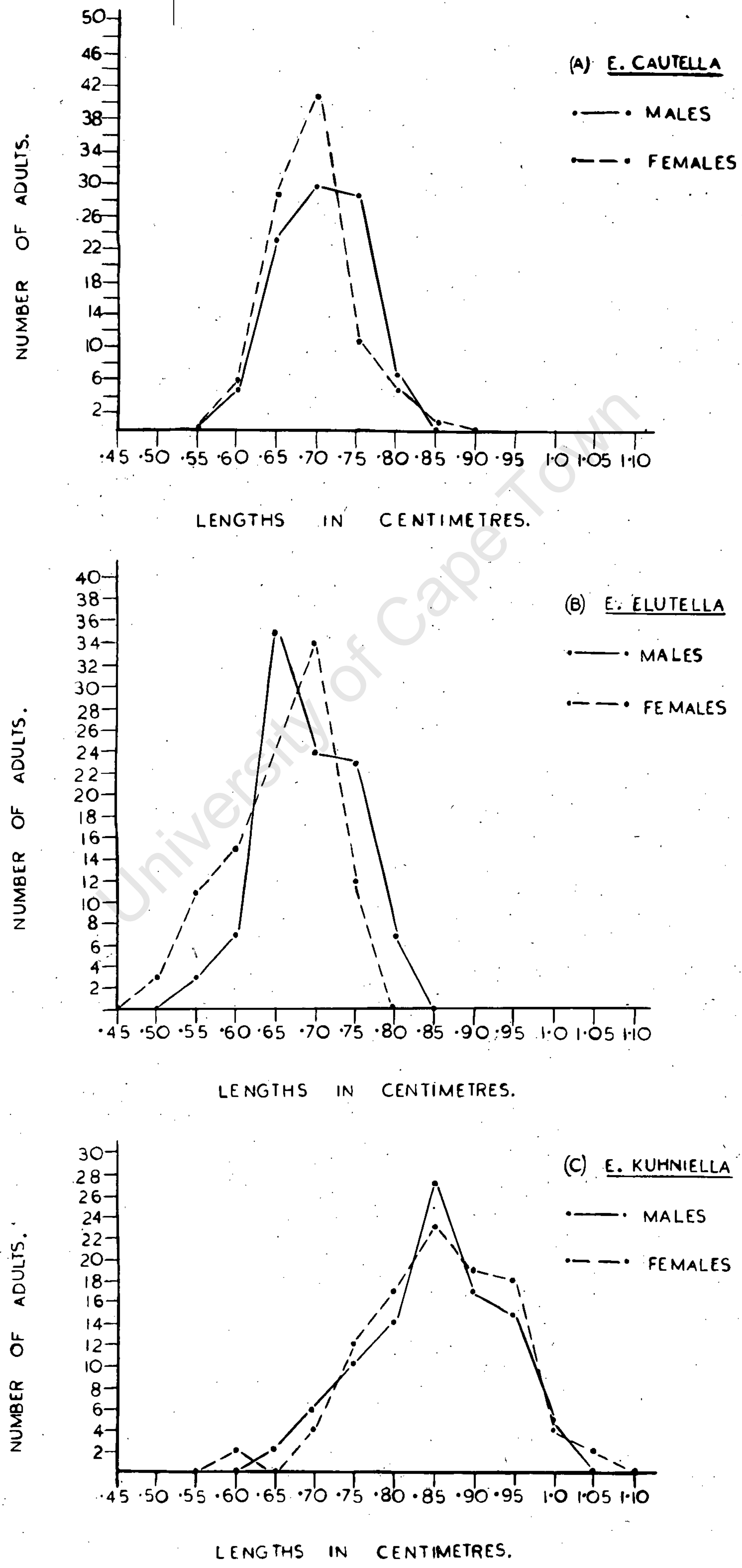
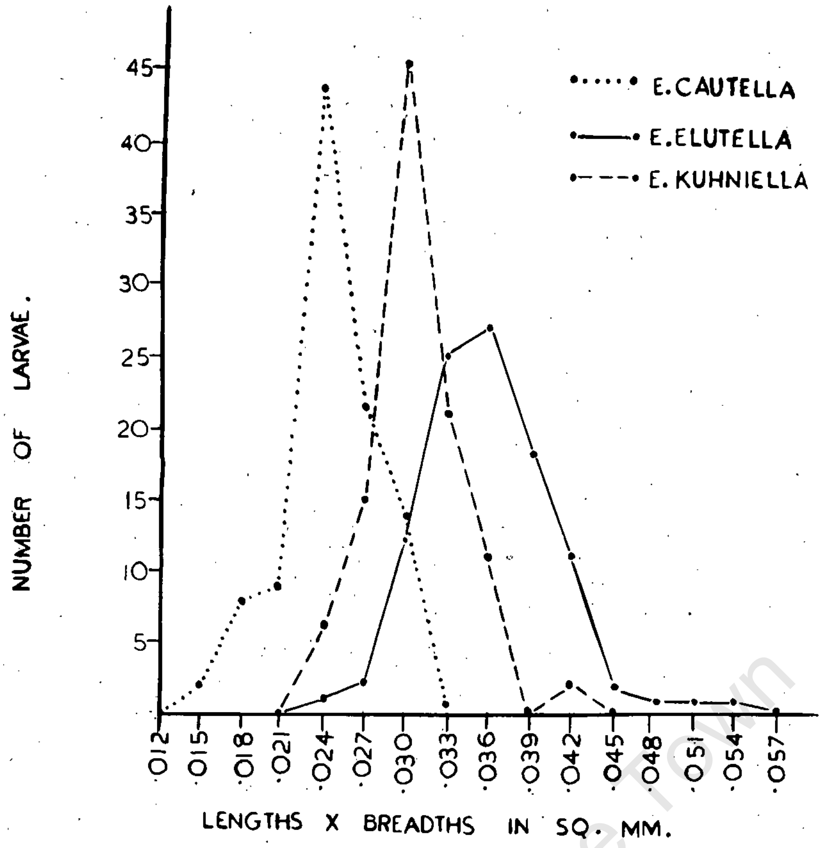


PLATE 9

(A)

1ST INSTAR LARVAE OF EPHESTIA SPECIES: LENGTH X BREADTH MEASUREMENTS OF HEAD CAPSULES.



(B)

E. CAUTELLA: HEAD CAPSULE WIDTHS OF VI AND VII INSTAR LARVAE.

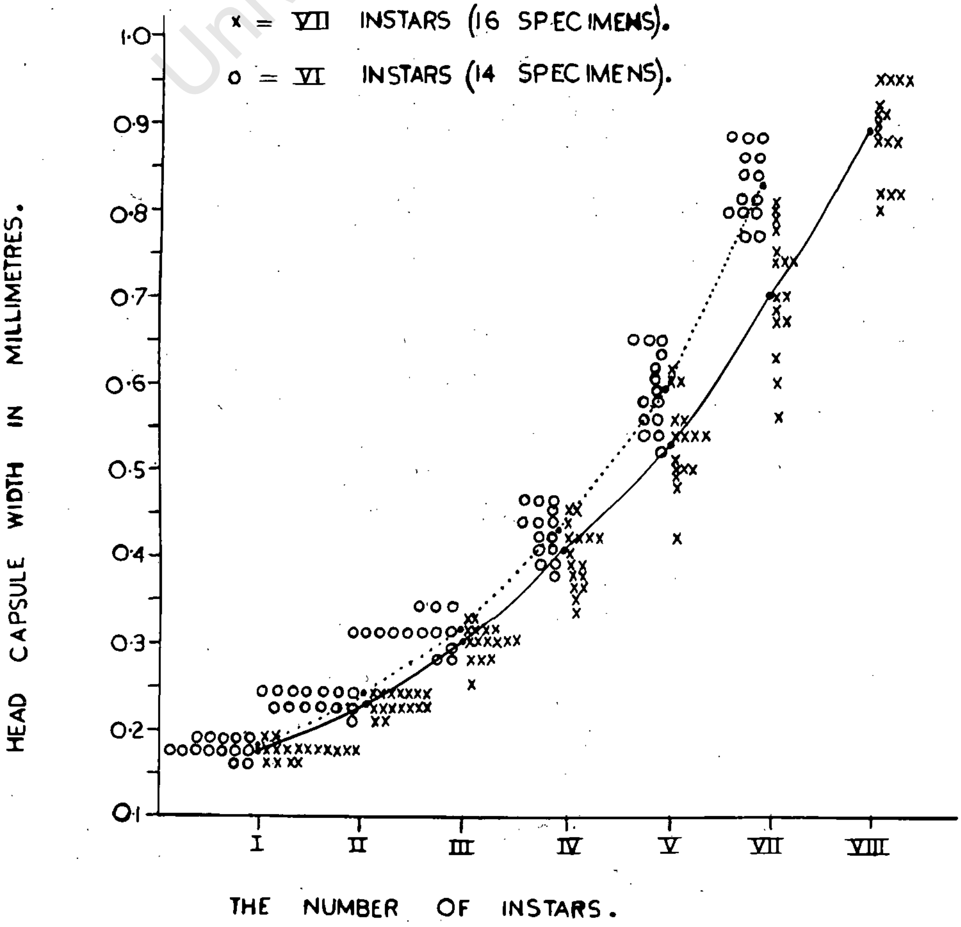
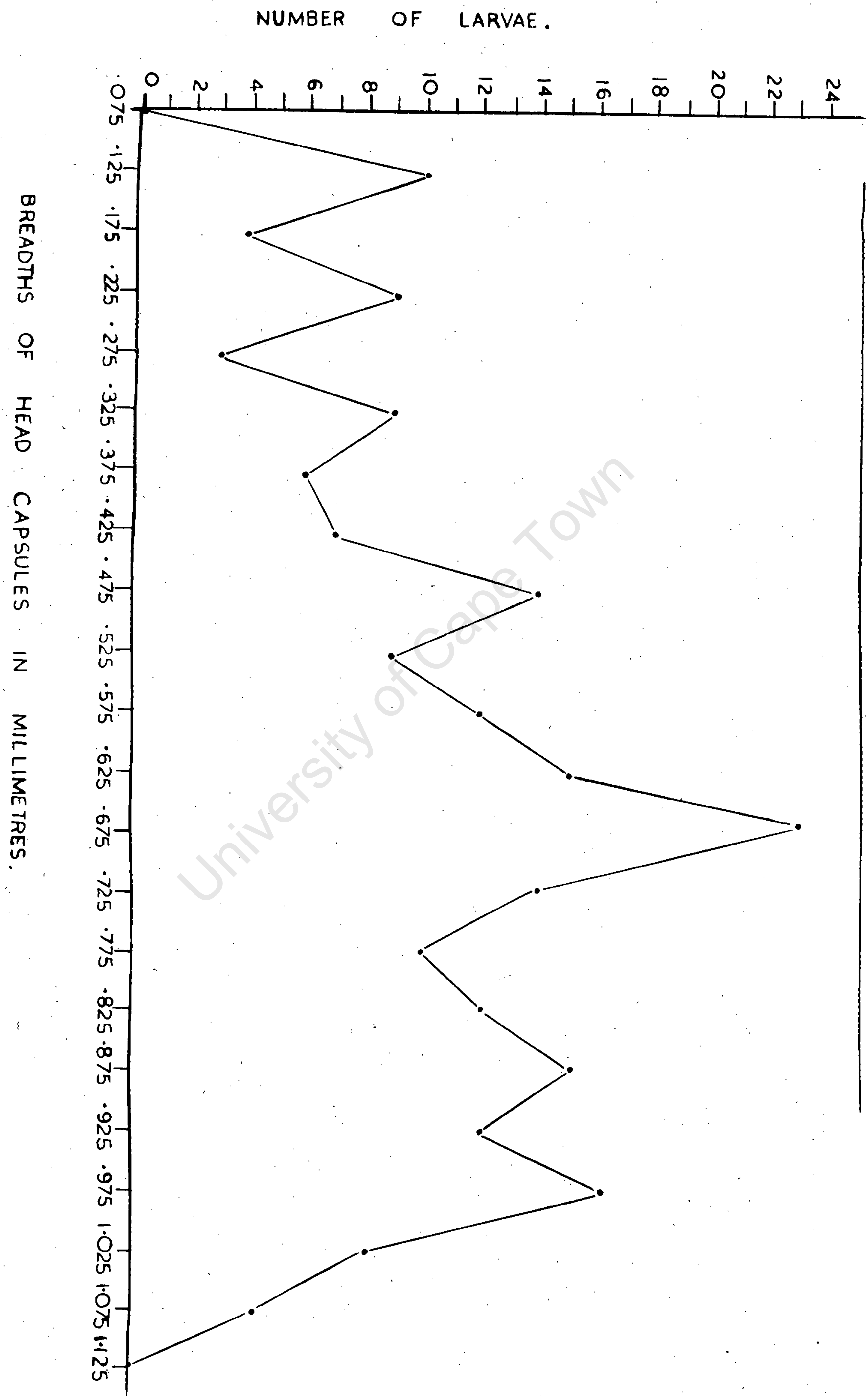


PLATE 10

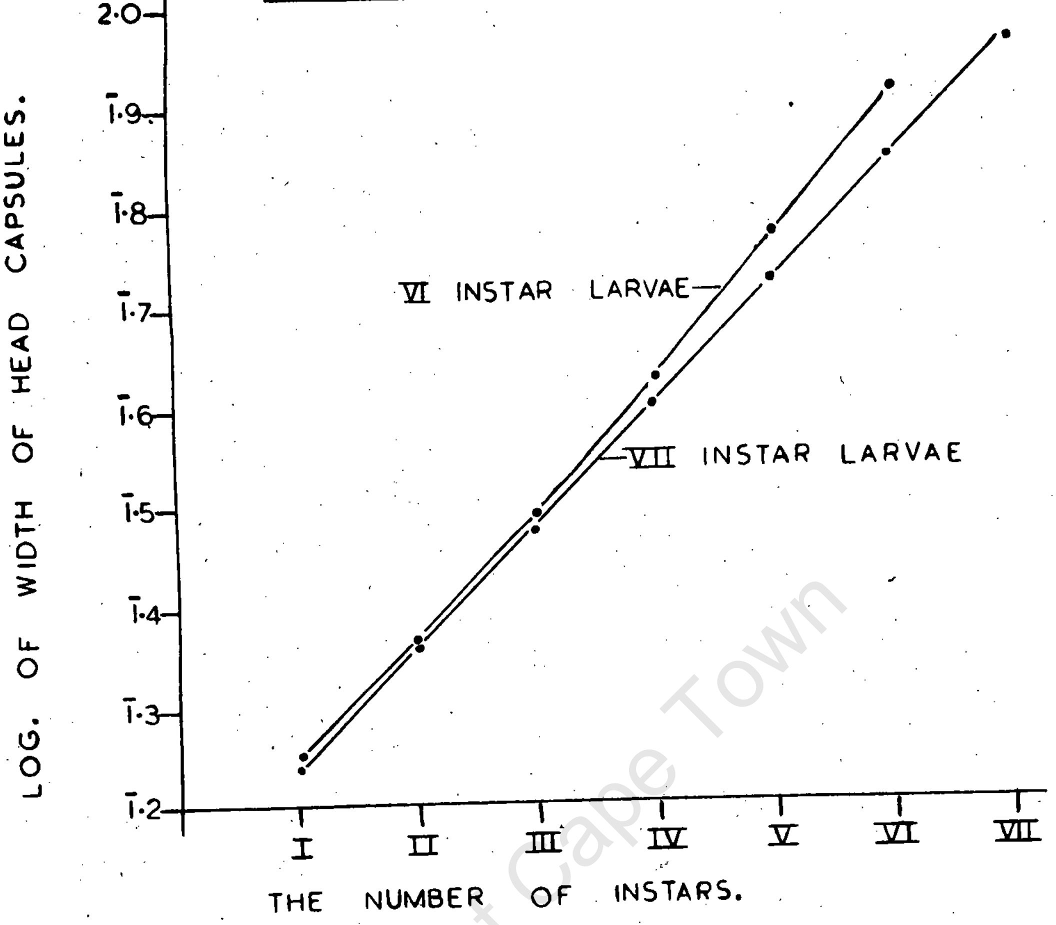


THE MAXIMUM NUMBER OF LARVAL INSTARS OF EPHESTIA CAUTELLA.

PLATE II.

(A)

CHART ILLUSTRATING DYAR'S LAW. (E. CAUTELLA.)



(B)

THE RELATION OF HEAD WIDTHS TO TIME. (E. CAUTELLA.)