LIPID STORAGE IN THE PRE-IMAGO AND YOUNG ADULT
PLUSIA GAMMA
BY
E. D. M. MACAULAY
Rothamsted Experimental Station, Harpenden, Hertfordshire, England

Changes in live weight, dry weight and fat content of larvae, pupae and adults of *P. gamma* were assessed. Fat increased during larval life and decreased during the pupal stage. On emergence 11% of the dry weight of adult moths was due to fat. This amount is sufficient to provide energy for a flight of about 20 hours by a large moth. On average a moth flew for 3 hours without feeding.

The Silver-Y moth *Plusia gamma* L. is a migrant, large numbers reaching S. England in summer and spreading northwards (Fisher, 1938). It is probably unable to overwinter in Britain. Fat is the main source of energy for migratory flight (Weis-Fogh, 1952a) and many moths that migrate do so soon after emergence (Johnson, 1960). This paper describes the accumulation of fat in *P. gamma* and estimates how far young adult moths can fly and thus their potential migratory range.

Materials and Methods

Moths were cultured in winter, in a glasshouse at about 22°C, normal daylight being supplemented by the light of a single 400 W mercury vapour lamp for 14 h daily. Larvae were reared on broad bean seedlings and adults fed with a mixture

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Fig. 1. Kymograph used for determination of flight duration of tethered moths.
of honey and water. Larvae used for investigating the effect of temperature on growth were reared in 1-litre plastic boxes, each with ten larvae, at four constant temperatures with a 14 : 10 L : D regime provided by fluorescent strip lights, fresh bean leaves being supplied daily.

Insects of less than 20 mg were weighed on a torsion balance, heavier ones on an analytical balance, and the fat content of their abdomens and thoraces determined by Soxhlet extraction with petroleum ether (boiling point 40°—60°). Duration of free, spontaneous flight was measured in an aktograph (Macaulay, 1972), and tethered flight with a kymograph (Fig. 1) similar to that used by Hwang & How (1966). Moths were mounted for tethered flight by removing scales from part of the thorax and attaching a small piece of cork with contact adhesive. The cork was fixed to a pin attached to a thin glass fibre, one end of which touched the surface of a smoked drum. Vibration of the fibre during flight gave a record of flight duration.

Results

The relationship between the live and dry weights of larvae is shown in Fig. 2, and that between dry weight and fat content in Fig. 3. The heavier larvae had the

![Graph](image.png)

Fig. 2. Relationship between live and dry weights of *P. gamma* larvae.
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Fig. 3. Relationship between dry weight and petroleum ether extractable fat of *P. gamma* larvae.

greatest proportion of solid matter and, as this increased, the proportion of fat also did so, possibly reflecting the accumulation of reserves as distinct from growth (Laughlin, 1957).

The temperature at which the larvae were reared affected their rate of development and the weight of the resulting pupae. Duration of larval life and the weight of the pupae produced at four constant temperatures are shown in Table I.

### TABLE I

**Effect of rearing temperature on Plusia gamma larvae**

<table>
<thead>
<tr>
<th>Rearing temperature</th>
<th>10°</th>
<th>15°</th>
<th>20°</th>
<th>27°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number surviving of 25 newly hatched larvae</td>
<td>11</td>
<td>15</td>
<td>16</td>
<td>11</td>
</tr>
<tr>
<td>Mean weight of pupae after last larval moult (mg)</td>
<td>344 ± 5</td>
<td>334 ± 5</td>
<td>293 ± 7</td>
<td>169 ± 11</td>
</tr>
<tr>
<td>Mean duration of larval life (days)</td>
<td>64</td>
<td>40</td>
<td>16</td>
<td>13</td>
</tr>
</tbody>
</table>

*Loss of weight by pupae.* Fifty pupae from the glasshouse culture were weighed at intervals until the adults emerged; the percentage loss of live weight by the same individuals is shown in Fig. 4. The rate of loss increased throughout the 10
days of pupal life, presumably reflecting accelerating metabolic activity during metamorphosis. (cf. La Due, 1964). Table II shows the dry weight of 20 of another group of 46 newly pupated insects and of their fat (expressed as a percentage of dry matter) as well as similar measurements for the remaining 26 pupae which had been left to develop for 8 days at 20°. The initial live weights of the new pupae of the two groups were 214 ± 9 mg in the case of the 20 pupae killed immediately, and 194 ± 9 mg for the 26 pupae which were left for 8 days. These weights did not differ significantly and, presumably, neither did their initial fat content.

**Fat content.** The mean fat content of fully grown larvae was 18% of their dry weight and that of new pupae 21% (Table II). Presumably much energy, and,
therefore, dry matter, is used when spinning the cocoon before pupating, but after 8 days of pupal life the fat content had decreased to 11% of the dry weight. Thus, from a quarter to half of the fat accumulated by the larvae is used as fuel during metamorphosis. The actual quantities involved were 14.8 ± 0.5 mg and 10.5 ± 0.9 mg for late larvae and new pupae, respectively, and 4.2 ± 0.5 mg for 8-day old pupae just before emergence.

Absolute amounts of fat, and amounts of fat expressed as a percentage of dry matter, did not differ between a group of 8-day old pupae and another of newly emerged adults (Table II). A small amount of dry matter is lost in the meconium and pupal case.

Thirty adults, confined with water only from the time they emerged until they died of starvation, had a mean fat content at death of 0.7 ± 0.12 mg.

DISCUSSION

Fat accumulated steadily during larval life, reaching a maximum of 20 mg which represented about 20% of the dry weight of the insect at this time. During the transition from larva to pupa, this proportion did not change, but the pupae contained on average only 10.5 ± 0.9 mg of fat, which decrease may be associated with cocoon spinning and reorganisation of tissues. The metabolic activity of the pupa, as reflected by the weight loss, was at first slow and then accelerated until the insect lost about 3% of its live weight per day towards the end of pupal life. This process was accompanied by a decrease in total fat from 10.5 ± 0.9 mg at the start of pupal life, to 4.2 ± 0.5 mg after 8 days at 20°C, which, expressed as a percentage of dry matter, is a decrease from 20% to 10%. Newly emerged adults contained similar amounts of fat as late pupae (Table II).

Laughlin (1956) found that, in the garden chafer (Phylloperta horticola), half the fat reserves that were accumulated during larval life had been used by the time the adult emerged; and, using data from Wigglesworth (1950), he calculated that the remaining fuel in the adult chafer would not sustain flight for more than about 20 minutes.

P. gamma that had died of starvation contained an average of 0.7 mg of fat. Assuming that this was “structural” lipid and not available as fuel, an average of 3.5 mg was available for flight in the newly emerged moth. Laughlin argued that because a bee weighing about 100 mg uses about 10 mg of sugar per hour when flying, and, as fat has 2.2 times the calorific value of carbohydrate, an insect weighing 100 mg and using fat as fuel will use 4.5 mg/h when flying. Those moths whose fat at emergence was measured had a mean weight of 114 mg (Table II) and would according to Laughlin have only had sufficient fuel for 40 minutes flying (i.e. \( \frac{3.5 \times 100}{4.5 \times 114} = 0.68 \) h). Koerwitz & Pruess (1964) also concluded that, in the army cutworm, Chorizagrotis auxiliaris, little flight is possible on the reserves remaining from the pupal stage, but Johnson (1969) disputed this conclusion.
Duration of flight depends upon initial weight (Fig. 5), and regressions for free flying and tethered moths did not differ significantly (P > 0.10). The common regression is log $y = 3.00 \log x - 3.898$. From this regression it was calculated that the average newly emerged moth, whose flight potential was estimated by Laughlin's method as about 30 min, is capable of flying for 3 hours on its reserves.

The relationship between fat content and flight duration is shown in Fig. 6 for *P. gamma*, an aphid, *Aphis fabae* (Cockbain, 1961), a locust, *Schistocerca gregaria* (Weis-Fogh, 1952b), and the moth *Spodoptera frugiperda* (Nayar & van Handel, 1971). Fat is the principal fuel of these insects when flying and, despite considerable morphological differences, they all appear to use it equally efficiently.

Flight speeds of about 16 km/h have been measured in the laboratory with noctuid moths (Callahan, 1965). Such a speed would enable a *P. gamma* of average size to fly the 50 km from Europe to Southern England without feeding and unaided by wind, while the largest individuals would, under the same conditions, be capable of flying well over 100 km.
Fig. 6. Relationship between fat content and flight duration in four insect species.

RéSUMÉ

STOCKAGE DE LIPIDES DANS LE PRÉ-IMAGO ET DANS LE JEUNE ADULTE DE PLUSIA GAMMA

On a estimé les variations du poids frais, du poids sec et la teneur en lipides des larves, pupes et adultes de *P. gamma*. Les lipides s'accumulent durant la vie larvaire et diminuent durant le stade nymphal. Au moment de l'émergence, 11% du poids sec des imagos est due aux graisses. Cette quantité est suffisante pour assurer l'énergie nécessaire à une durée de vol d'environ 20 heures pour un papillon de grande taille. En moyenne un papillon vole pendant 3 heures sans s'alimenter.

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