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# WIND-TUNNEL STUDIES ON THE COLLECTION OF AIRBORNE SPRAY DROPLETS BY FLYING LOCUSTS

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Abstract—**In view of the present environmental awareness, the reduction of spray wastage, which in turn lessens environmental contamination, can be achieved by reducing spray volumes and improvement on spray efficiency through the use of correct ranges of spray droplet sizes. Published data on droplets collected by some insects consistently suggest that the optimum droplet sizes lie below 60 μm.**

**An experiment was conducted in a wind-tunnel to assess the locust collection efficiency when subjected to a spectrum of droplet size ranges with a view to determine the optimum droplet size.**

**Locusts were induced to fly in a wind-tunnel and then exposed to spray droplets which were produced by a spinning disc atomiser. Droplets collected on antennae, head, abdomen, legs and wings were sized and counted. The collection efficiency at wind-speeds ranging from 2 m/sec to 6 m/sec was calculated for the different body parts in the droplet size range 10–40, 40–60 and 60–80 μm. The calculated collection efficiency for the 10–40 μm size range was comparatively higher for all locust body parts.**

*Key Words*: Locust, body parts, wind-tunnel, spray droplets, impaction, collection efficiency, optimum droplet sizes

**Résumé—A la lumiére de l'actuelle prise de conscience en matiére d'environnement, une diminution de résidus d'aérosols qui, à son tour minimise la contamination de l'environnement peut s'obtenir avec la réduction des volumes de l'aérosol et l'amélioration de l'efficacité d'atomisation à travers l'emploi de gouttelettes atomisables d'une certaine taille. Des données publiées sur les particules atomisées qui sont collectées par certains insectes suggérent de toute évidence que les tailles optima de gouttelettes se situent en dessous de 60 μm.**

**Dans le but de déterminer cette taille optimale de gouttelettes, une expérience a été menée dans un tunnel aérodynamique pour évaluer l'efficacité de leur collection par le criquet. Cela a consisté à soumettre ce dernier à un éventail de tailles de gouttelettes atomisées.**

**Les criquets auxquels on a permis de voler dans le tunnel aérodynamique ont ensuite été exposés aux gouttelettes produites par un disque atomiseur tournoyant. Des particules atomisées recoltées au niveau de l'antenne, de la tête, de l'abdomen, des membres et des ailes ont été clasées et comptées. L'efficacité de collection avec un soume de vent reglé à des vitesses variant entre 2 m/sec et 6 m/sec a été calculée pour les différentes parties du corps, avec des gouttelettes ayant des tailles de 10–40, 40–60 et 60–80 μm. L'efficacité de collection pour la taille de 10–40 μm était comparativement plus élévée pour toutes les parties du corps du criquet.**

*Mots Clés*: Criquet, parties du corps, tunnel aérodynamique, gouttelettes d'aérosol, révélateur d'impact, efficacité de collection, tailles optima de gouttelettes

## INTRODUCTION

The use of modern effective insecticides and more efficient ultra low volume (ULV) spray techniques have kept plague outbreaks of locusts under control. These insects remain a threat to agriculture in the tropics, particularly in Africa. Since the early days of locust control, swarm spraying was the method of choice due to its speed and effectiveness in tackling large numbers of individuals. Theoretical and experimental studies on the factors involved in aerial curtain spraying such as pick-up of spray by flying locusts, the optimum toxicity to a moving swarm, etc., were undertaken in detail (Kennedy et al., 1949; Sawyer, 1951; Wooten and Sawyer, 1954; MacCuaig, 1958,1962). The early work evolved from spraying dilute oil solutions of 2.5% dinitro-ortho-cresol (DNOC) in large droplets 200–500 µm (Kennedy et al., 1949) to higher concentration of 20% DNOC in oil in smaller droplets of 100–300 µm (Wooten and Sawyer, 1954) and 60–300 µm (MacCuaig, 1962). Currently, effective insecticides are available and these can be applied in oil solutions at a much lower volume (ULV).

Low application rates will result in reduced wastage and lessen environmental contamination. If one aims at reducing spray volumes for economic and/or environmental reasons, the flying locust swarms remain the most attractive target since the insects are concentrated in large numbers over a small area. Spraying flying swarms require the use of small droplets that can remain airborne long enough to encounter the maximum number of locusts in the swarm, but large enough to impact efficiently on the locust body parts. Published data on sizes of droplets collected by some insects (Table 1) suggest that the optimum sizes were smaller than 60 µm.

Theoretical calculations (Spillman, 1976) taking air turbulence in normal outdoor environment into consideration also showed that droplets of this size have a very high probability of catch by flying insects. The present work was carried out with a view of further improving the refinement of the existing locust spray techniques through use of correct range of small droplet sizes. This will in turn lead to reduction in spray volumes, increase in work rate of spray aircraft and a possible reduction in environmental contamination.

## EXPERIMENTAL MATERIALS AND PROCEDURES

### *Test insects*

The insects used were adult African migratory locust, *Locusta migratoria migratorioides* R & F, reared and kept in cages in a laboratory room maintained at a temperature of 22°C.

### *Flight tunnel and working areas*

The experiments were conducted in an open wind-tunnel which was equipped with a variable windspeed controller. The spray working areas were determined on a string grid suspended on a Dexion frame, which was placed one and half metres away from the windflow outlet of the tunnel, on which water sensitive papers were fixed. The arrangement of the equipment is as shown in Fig. 1. Water was sprayed by the atomiser and droplet distribution on the water sensitive papers at different windspeeds similar to those planned for the experiments, were subjectively examined to determine the area covered by the spray. The best distribution was found in an area 40 x 40 cm in the centre of the grid. This was the area in which locusts interspaced with aluminium tubes were positioned for subsequent spray experiments.

Table 1. Reported optimum droplet size range on some insects

| Insect | Droplet size | Authors |
|---|---|---|
| Bean weevil, *Acanthoscelides obtectus* | 15 µ | Smith and Goodhue (1942) |
| Boll weevil, *Anthonomous grandis* | 10 µ | Smith and Goodhue (1942) |
| Honey bees, *Aphis mellifera* | 1–10 µ | Latta et al. (1947) |
| Mosquitoes, *Aedes aegypti* | 34–81 µ | Latta et al. (1947) |
| Dead tsetse flies, *Glossina palpalis* | 10–30 µ | Hadaway and Barlow (1965) |
| Tobacco budworm, *Heliothis virescens* | 100 µ | Polles and Vinson (1967) |
| Spruce budworm, *Choristoneura fumiferana* | 20–50 µ | Himel amd Moore (1969a) |
| Boll weevil, *Anthonomous grandis* | 20–50 µ | Himel and Moore (1969a) |
| Boll worm, *Heliothis zea* | 20–50 µ | Himel and Moore (1969a) |
| Cabbage looper, *Trichoplusia ni* | 20–50 µ | Himel amd Moore (1969a) |
| Flying mosquito, *Aedes taeniorhynchus* | 25 µ | Lofgren (1970) |
| Flying mosquito, *Aedes aegypti* | 4–16 µ | Lofgren et al. (1973) |
| Western spruce budworm, *C. occidentalis* | 16–50 µ | Barry et al. (1977) |
| American bollworm, *Heliothis armigera* | 12–48 µ | Uk (1977) |

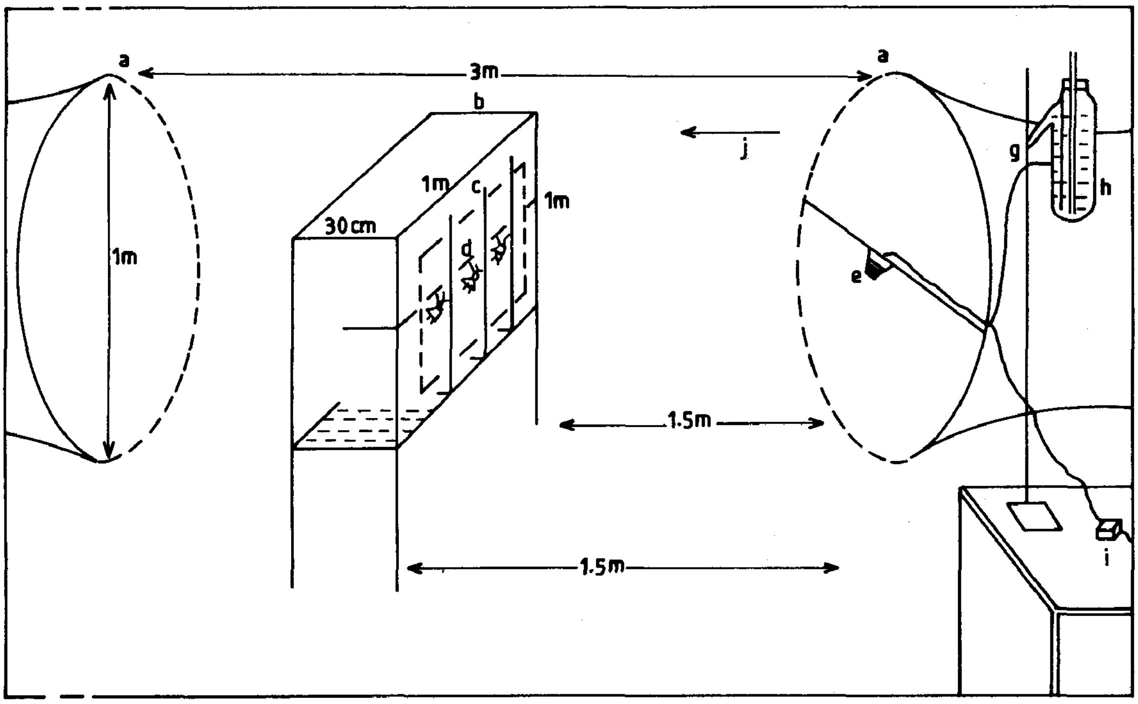

Fig. 1. Wind tunnel working area.
(a) Wind tunnel
(b) Dexion frame
(c) Vertical cylinders
(d) Locusts
(e) Head of mini valve
(f) Mini-valve
(g) Intra medic tubing
(h) Reservoir
(i) Source of power supply
(j) Direction of air flow

*Spray liquid atomiser*

The spray liquid atomising equipment was a modified head of a mini-ULVA sprayer fitted with a 54 mm dia. spinning disc. The rotation of the disc was controlled by a variable potentiometer, fitted to the direct current motor, which regulated the voltage applied to the motor. Spray liquid was fed onto the spray disc by gravity flow through a Hamilton PTFE Hypodermic tubing (0.5 mm ID). The lower tip of the tube was adjusted so as to touch the spinning disc, thus allowing a continuous seepage of the liquid on to the disc to provide predictable atomisation. A two-way valve was provided on the tube to enable an instantaneous on-off control of the liquid flow. The upper part of the tube was attached to the reservoir made of a 250 ml plastic wash bottle. A heavy-wall glass tube (4mm ID) 20 cm long was pushed through a hole in the bottle cap to the bottom of the bottle. The tube was partially filled with liquid and consequently acted as a manometer to provide a constant head of pressure on the liquid in the reservoir, which in turn maintained the set flow rate to the spinning disc. The different flow rates were adjusted by changing the height between the spinning disc and the reservoir. All components were selected so that they were solvent resistant and not affected in anyway by the spray liquid used.

*Spray liquid*

The spray liquid was 1% solution of Saturn Yellow MF fluorescent dye dissolved to a saturation of 0.5% w/v in a 1:1 mixture of cyclohexanone/hexylene glycol. The droplets were easily visible on the locust and could then be measured and counted under illumination.

*Calibration of liquidflow rate and determination of droplet spectra*

Flow rate was measured by means of a 10 ml graduated cylinder and a stop watch. A flow rate of 3 ml/min was found most suitable for producing narrow spectra of small droplets. The flow was changed or maintained by adjusting the height of the reservoir bottle above the horizontal plane of the atomiser disc.Three speeds of rotation of the atomiser disc were used in an attempt to generate three ranges of droplet spectra by applying different voltages to the motor. Voltages of 9,12, and 15 were used to produce coarse, medium and fine spectra respectively. Real time droplet spectra was assessed using a Particle Measuring Systems OAP-260X probe attached to a PDS-300 micro-processor. Aluminium tubes 50 cm in length were used as vertical cylinders to collect droplets simultaneously with the locusts. Oil sensitive papers were snugly rolled around these tubes to collect the droplets. The number and size of droplets collected on the cylinders were compared with data produced by the probe. Data from droplets collected on cylinders was subsequently used to determine real time airborne droplet concentration using a method developed by May and Clifford (May and Clifford, 1967).To achieve a better droplet collection at a low windspeed of 2 m/sec aluminium tubes of 0.65 cm dia. were used, and for windspeeds of more than 2 m/sec tubes of 2 cm dia. were utilized.

### *Flying locusts*

Locusts were suspended on the Dexion frame, in the middle cross-section of the spray cloud, 1.5 m downwind of the atomiser. Each locust was suspended on a thin fuse wire (0.30 mm), by making a loop around the pronutum between the first and second pair of legs. The aim was to allow the locusts to fly as freely as possible. Since the locusts were left to fly for 2–3 min, this would not significantly affect the movements of the thoracic muscles which would otherwise affect the wing beat frequency. The wing beat frequency was checked from time to time on different batches of locusts with a stroboscope. The frequency varied between 20–25 Hz. This frequency was in a similar range as that reported by Wooten and Sayer (Wooten and Sayer, 1954). Three locusts interspaced with three vertical cylinders were used for each droplet size range at each windspeed and replicated three times.

### *Exposure of locusts to spray*

The suspended locusts would begin to fly only when there was windflow in the tunnel. They soon attained a steady wing-beat rhythm and sustained flight when the antennae, thorax, abdomen and hind legs were held at an angle of about 17° to the horizontal. Spray which had been calibrated at a flow rate of 3 ml/min was then released by turning on the mini valve to allow the liquid to seep onto the spinning disc. The valve was turned off after 2 seconds. Spray exposure was carried out for each of the coarse, medium and fine droplet spectra at windspeeds ranging from 2 m/sec to 6 m/sec.

### *Assessment of droplet deposition on locust body parts*

The spray exposed locusts were transferred to a killing jar containing ethyl acetate vapour. They were kept into the capped jar for 15 min to ensure complete kill. For ease of microscopic examination, antennae, wings and hind legs were cut off from the main body and examined separately. Droplet counts and measurements were carried out in a dark room under a binocular microscope fitted with an eye piece graticule and illuminated with a soft, ultra-violet light.

### *Assessment of airborne droplet concentration*

The airborne droplet concentration was estimated from vertical cylinders which were exposed to spray at the same time as the locusts. Droplet stains on the HN380 oil sensitive papers which had been rolled on the vertical cylinders were sized and counted, on a selected strip 0.5 cm wide, using a Flemming Particle size Analyser (Type 526). Stain sizes were then converted to true droplet size using a spread factor calibration graph. The true droplet size diameters were corrected for collection efficiency using a method developed by May and Clifford (1967). The corrected collection efficiency was used to estimate the total number of droplets passing through the area intercepted by the locust body parts during exposure to spray.

### *Droplet collection efficiency of locust body parts*

The different locust body parts were measured and their surface areas estimated. Surface area values of each locust body part were obtained from measurements on five locusts.The surface areas, for antennae, legs and abdomen refer to the area normal to the horizontal path of the droplets. The normal area being the cross section of the body part multiplied by the sine of the angle of that body part, with respect to the horizontal. Since wings move in a complex pattern during flight, (Weis-Fogh, 1956), no attempt was made to determine their area normal to the droplet path. Instead the plan area of both surfaces of each wing were measured. To estimate the collection efficiency of each body part, the counted droplets were first normalized into the number of droplets per unit area ($cm^2$) of cross section of the body part which intercepted the spray cloud (May and Clifford, 1967). The number of droplets of a selected size class per $cm^2$ of the body part was obtained by dividing the number of droplets of that size class by the surface (normal) area of the body part. The values of droplets of the selected size class per unit of normal area of the body part were divided by the values of the calculated airborne droplet concentration per unit area of cross section covered by spray to obtain the collection efficiency of that body part.

## RESULTS AND DISCUSSION

When an insect flies through a spray cloud, there will be a characteristic optimum droplet size at which collection efficiency is maximum (Townsend, 1948). An experiment was conducted in a wind-tunnel to assess droplet collection efficiency of locusts when subjected to a spectrum of droplet size ranges with the aim of determining the optimum droplet size collected. Droplets collected on various parts of a flying locust were counted and sized. Droplet collection efficiency for different body parts in the size range of 10–40 µm, 40–60 µm, and 60–80 µm at windspeeds ranging from 2 m/sec to 6 m/sec were calculated. The number of droplets collected by different locust body parts are presented in Figure 2a to 2f. The results show a general increase in the number of droplets collected by the body parts with an increase of windspeed. Smaller locust body parts collected fewer droplets. Impaction was by windflow since there was no motion of the locust through the air.

The body part collection efficiencies for droplets grouped in 10–40 µm, 40–60 µm, and 60–80 µm size classes are presented in Fig. 3a to c. In addition to the effect of windspeed on the collection of droplets by locust body parts, the occasional high and low droplet counts on oil sensitive papers, which were later used to calculate body part collection efficiencies, resulted in irregular collection efficiency values. Consequently no possible collection efficiency values were obtained after calculation for the 10–40 µm and 60–80 µm size group at wind speed of 2 m/sec and for the antennae for the 60–80 µm size group for all windspeeds considered. The collection efficiency for the various locust body parts were as follows:

### *Antennae*

There was a gradual increase of the number of droplets collected by the antennae with an increase of wind-speed. Only droplets below 60 µm were collected by the antennae. The calculated collection efficiency increased with windspeed up to 5 m/sec. However, as the wind-speed was increased to 6 m/sec, there was a drop in calculated collection efficiency. This suggests that catch efficiency of spray droplets on smaller parts of an insect, decreases as wind turbulance increases. The collection efficiency was higher for the 10–40 µm droplet range when compared to those in the 40–60 µm size range.

### *Head*

The position of the head relative to moving droplets presented a frontal surface (0.5 /cm$^2$), for direct droplet impaction. Droplets in the 10–40 µm and 40–60 µm size class, impacted much more frequently than those in the 60–80 µm range. The number of droplets collected was proportional to wind-speed. The calculated collection efficiency was above 75% for droplets of 10–40 µm size, whereas for 40–60 µm and 60–80 µm size group, it was below 20%. The low collection efficiency for the other size group was due to the high numbers of droplets collected on the oil sensitive papers, which were later used in the calculation of collection efficiency, compared to those counted on the head.

### *Hind legs*

When the locusts were induced to fly, the legs were extended away from the body particularly at lower wind-speed, but as the windflow was increased, the legs were retracted and pressed along the abdomen. Thus, although the normal surface area was calculated at 0.63 cm$^2$, these movements presented variable surface areas on which droplets impacted. Even though the number of droplets collected showed a progressive increment with increase in wind-speed, the overall low numbers of droplets counted on the legs could have been due to shielding effect of the beating wings, which could have intercepted or deflected away droplets that would have impacted on the legs. The collection efficiency for the 10–40 µm size range varied between 30 and 40%, whereas that for droplets in the 40–60 µm and 60–80 µm was below 20%.

### *Ventral part of the abdomen*

More droplets in the 10–40 µm and 40–60 µm size class were collected when compared to those in the 60–80 µm size range. The numbers collected increased with an increase in wind speed. It is possible that the beating wing could have shielded and or deflected the droplets away from the abdomen. The collection efficiency for droplets in the 10–40 µm size range was above 50% whereas that for the 40–60 and 60–80 µm size was below 30%.

### *Wings*

Both forewings and hindwings collected droplets in all the size ranges than the rest of the locust body parts. Where droplets were collected, the density was high. However, when one takes the number of droplets per cm$^2$ over the whole wing, (14.8 cm$^2$ and 28.3 cm$^2$ for the fore and hind wings, respectively), the resultant values and consequently that of calculated collection efficiency are low. Therefore when the nominal area of the wing during flight is compared to that of the

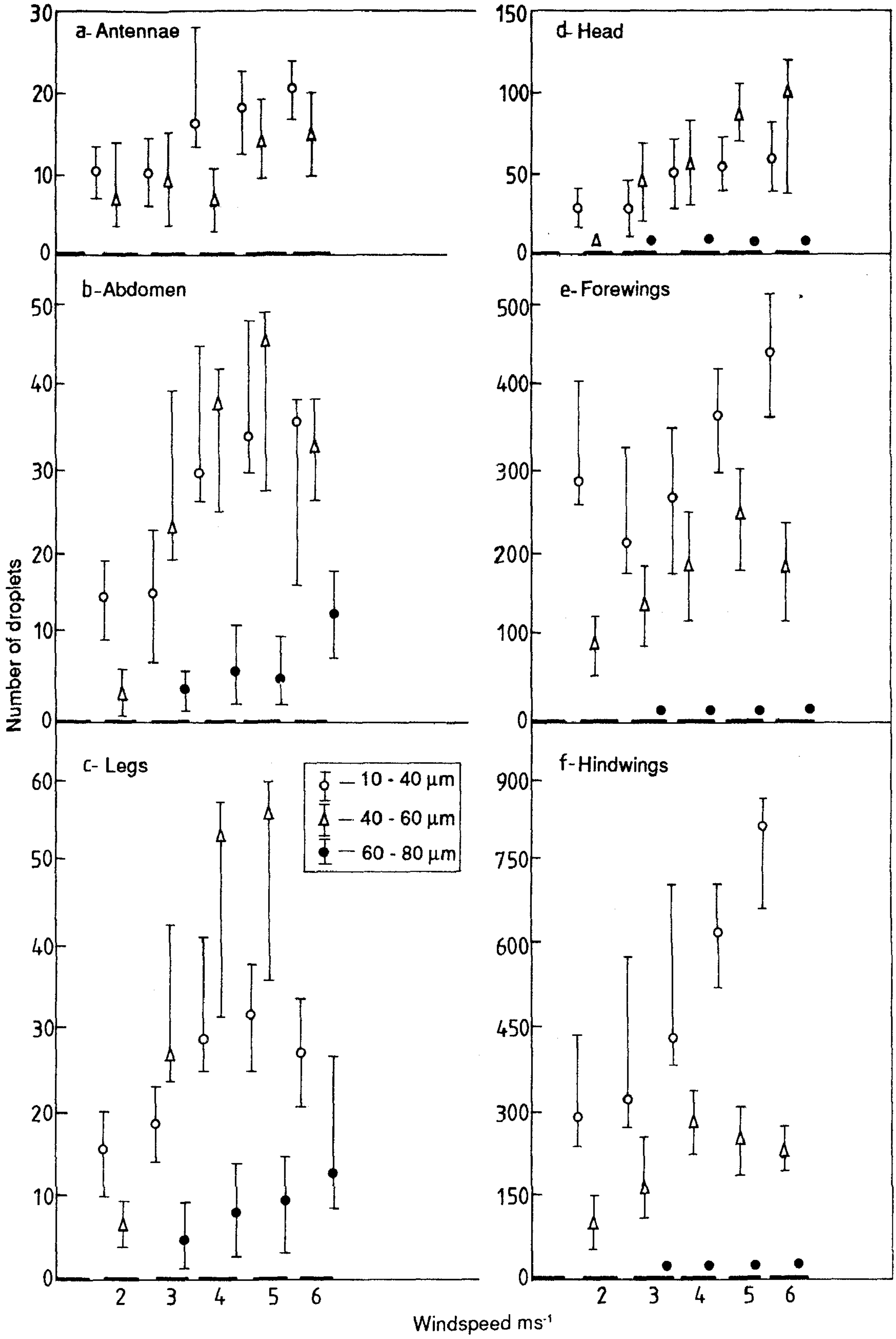

Fig. 2 (a)–(f). Mean number of droplets, in three size ranges, collected by locust body parts at different windspeeds.

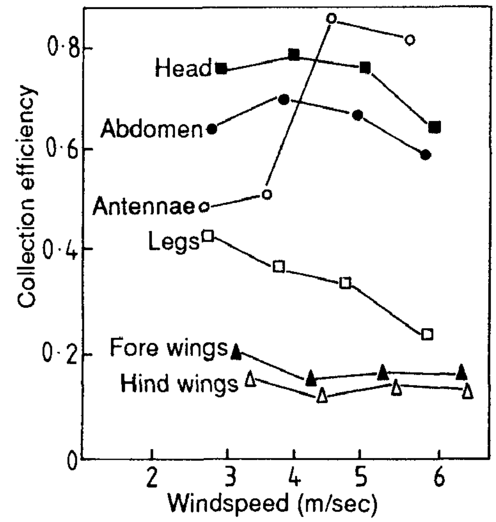

Fig. 3 (a). Droplet range 10–40 μm.

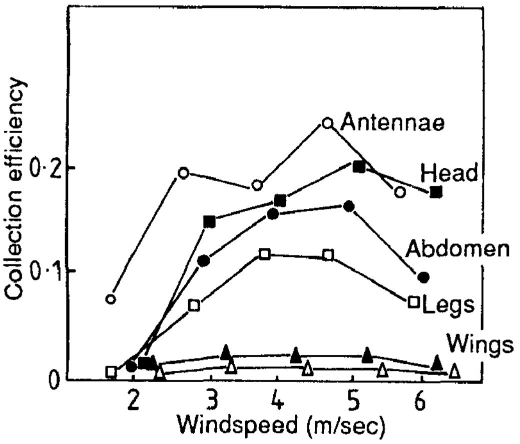

Fig. 3 (b). Droplet range 40–60 μm.

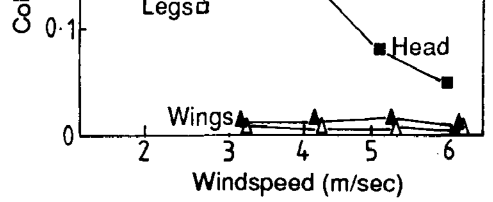

Fig. 3 (c). Droplet range 60–80 μm.

Fig. 3 (a)–(c). Droplet collection efficiency by individual parts of the locust body.

wind carrying the droplets, the beating wing is an inefficient collector of droplets.

The paper has presented data obtained from experiments conducted in a wind-tunnel. The observations were made on the influence of variable windspeed regimes on collection of spray droplets by different parts of the locust. The number of droplets collected and calculated collection efficiency was repeatedly higher for droplets in the 10–40 μm size range than those in the 40–60 μm and 60–80 μm size range. These results suggest that flying locusts efficiently collect droplets which are less than 40 μm in size and that the optimum size could be around 40 μm.

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