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An electric field screen prevents captured insects from escaping by depriving bioelectricity generated through insect movements

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ABSTRACT

An insulated conductor wire (ICW) paralleled with an earthed net was used to observe movements by vinegar flies in relation to their electricity release. ICW was negatively charged to create a positive charge on the net. At particular voltages, flies were attracted to ICW. This attraction was triggered by the deprivation of the insect negative charge with the net. Eventually the insects became net positive and were drawn to the ICW negative charge. The attracted insects generated bioelectricity through skeletal muscular movements. However, the electricity produced was depleted by the net without neutralizing their positive charge in the insect body.

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1. Introduction

Agricultural crops suffer from pathogen infection and/or insect attacks during pre- and post-harvest stages. We have developed electrostatic methods for disinfecting bacterial and fungal plant pathogens [1,2] and for preventing airborne pathogens and flying insect pests from entering greenhouses [3,4]. These methods are aimed at reducing the use of agrochemicals such as fungicides and insecticides. An electric field screen is a practical and environmentally friendly tool for excluding pathogens and pests from plant cultivation [5] and storage [6] spaces.

The electric field screen consists of three parts: 1) insulated iron wires (ICWs) arrayed in parallel with a definite interval, 2) earthed stainless nets placed on both sides of the ICW layer and 3 mm from the ICW layer, and 3) a direct current (DC) voltage generator. The ICWs are linked to each other and to a voltage generator to receive a negative charge. The negative surface charge of the ICWs induces an electrostatic charge on both sides of the earthed nets (conductor), creating an opposite charge on the ICW side surface of the nets. An electric field forms between these opposite charges. Insects that enter the electric field are deprived of their negative charge and turn net positive [6].

According to our interpretation, the positive electrification of insects is vital to create an electrostatic force against the negative charge of the ICW. At the same time, this working hypothesis implies that the attraction force could be nullified if the positive charge of the attracted insect is neutralized by some bioelectric measures. Bioelectric power generation is a potential method for supplying the negative charge. In fact, some insects create electricity through muscular movement [7–11] and/or neural excitation [7,12]. We speculated that this biological neutralization leads to a loss or weakening of the attraction force of the electric field screen. Hence, we were interested in knowing whether the insects restrained in the electric field can generate electric power, and whether the electricity produced could compensate for the negative charge deprived by the electric field screen.

In the present study, we analyzed the dynamic relationship between the physical force of the electric field screen and the biological power exerted by the insects struggling to escape from the electrostatic attraction. For this purpose, we constructed a simple version of the electric field screen and video-recorded insect movements that were synchronized with measuring the electric current generated by the insects.

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2. Materials and methods

2.1. Simplified electric field screen

We constructed a pair of electrodes; one was an iron wire (20 cm length, 2 mm diameter) linked to a DC voltage generator (Kansai Denshi, Tokyo, Japan), and the other was an earthed stainless net (1.5 mm mesh size, 5×20 cm^2). An iron conductor wire was passed through a vinyl chloride sleeve (1 mm thickness) to make an insulated conductor wire (ICW). Both electrodes were arrayed in parallel at 3 mm intervals, and a galvanometer PC520M (Sanwa Electric Instrument, Tokyo, Japan) was integrated into the electric line of the earthed net (Fig. 1A). The ICW was negatively charged to dielectrically polarize a cover insulator; positively on the iron wire-side surface and negatively on the outer surface of the insulator sleeve [6]. The negative surface charge of the ICW polarized the earthed net to create a positive charge on the ICW side surface, and an electric field formed between the opposite charges of the ICW and the earthed net (Fig. 1B). In the present study, the ICW was negatively charged with voltages of 1–10 kV. The potential difference in the ICW surface was measured continuously with an FMX-003 field meter (Simco, Kobe, Japan) placed at 2.5 cm from the ICW during the entire period of charging and until the potential difference vanished after stopping voltage to the ICW (Fig. 1B).

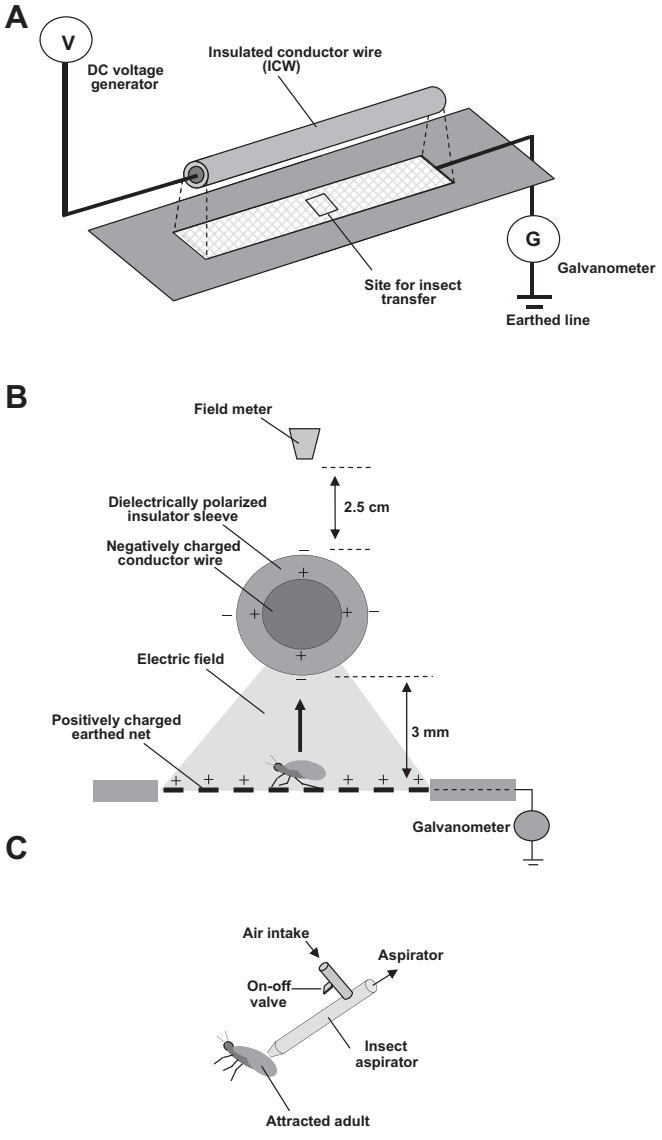

Fig. 1. Diagrams of a simplified electric field screen (A), the electrostatic details in the formation of an electric field (B), and the insect aspirator to transfer the flies (C).

2.2. Assay for insect discharge

Adult vinegar flies, *Drosophila melanogaster* (Drosophilidae), were purchased from Sumika Technoservice (Hyogo, Japan) and reared on blue medium (Wako Pure Chemical, Osaka, Japan) in plastic containers (20 cm in diameter, 20 cm high) in a growth chamber (25 ± 0.5 °C, 14 h photoperiod with 4000 lux). Newly emerging adults (15–24 h after eclosion) were used as active flies for the following experiments. Flies were transferred using an insect aspirator (Fig. 1C), a polypropylene tube (10 mm diameter) with a pointed tip (tip diameter, 1 mm) and whose opposite open end was linked to an aspirator (aspiration pressure, 1.2 kg/cm^2). All transferred flies walked and flew normally and appeared to be unhurt by the collection operation.

Vinegar fly adults were singly placed at a particular site of the earthed net to determine the range of voltages causing attraction to the ICW. Movements by the attracted flies were video-recorded with a charge coupled device (CCD) camera equipped with a dissecting microscope while applying voltage for 60 s. Movements were observed continuously until the insects were removed from the ICW after voltage to the ICW was stopped.

2.3. Current measurement

The electric current generated during a mechanical discharge (transfer of electricity from the charged ICW to a ground) and an insect discharge (transfer of electricity from the insect to a ground) was measured at different voltages with a current detector (detectable limit, 0.1 μA) integrated into the galvanometer in the earthed line. The magnitude and duration of the current were recorded in both discharges.

3. Results

First, we examined the occurrence of a mechanical discharge from the ICW under different voltage conditions. Current from the ICW was detected at >7.1 kV (Fig. 2). At 7.1–10.0 kV, the current magnitude rose from 0.1 to 10.5 μA as voltage increased. Current magnitude was continuous and constant at each voltage. In the following experiments, the insects were examined for their discharge at voltages of <7.0 kV to avoid concealing the insect discharge by larger electric currents derived from the ICW mechanical discharge.

Fig. 2 also shows the voltage ranges that resulted in insect attraction and insect discharge. An electrostatic force was initially detectable at 0.5 kV, because the flies seemed to erect their wings and brace against the ICW attraction force. Attraction of flies to the ICW was detected at voltages > 0.9 kV. However, at 0.9–2.8 kV (range A), the force was not sufficient to capture the insects with the ICW. In fact, the flies were drawn upwards but flew away from the electric field without being captured. For voltages >2.9 kV, the flies were attracted to the ICW, regardless of the voltage applied. At 2.9–4.0 kV (range B), the attracted flies twisted their bodies with vigorous strokes of their legs and then rolled over to remove themselves from the charged ICW. The time duration for removal was 2–20 s. These times were directly proportional to an increase in the voltage applied; eventually, all flies escaped the ICW within this voltage range. At 4.1–7.0 kV (range C), the attracted flies were completely prevented from removing themselves from the ICW during the period when voltage was applied. They struggled to remove themselves from the ICW for a short period but then became motionless.

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