Avoidance of an electric field by insects: Fundamental biological phenomenon for an electrostatic pest-exclusion strategy

2015 J. Phys.: Conf. Ser. 646 012003

(http://iopscience.iop.org/1742-6596/646/1/012003)

Avoidance of an electric field by insects: Fundamental biological phenomenon for an electrostatic pest-exclusion strategy

Y Matsuda[1], T Nonomura[1], K Kakutani[2], J Kimbara[3], K Osamura[4], S Kusakari[1] and H Toyoda[1]

[1]Faculty of Agriculture, Kinki University, Nara, Japan,

[2]Pharmaceutical Research and Technology Institute, Kinki University, Osaka, Japan,

[3]Research Institute, Kagome Co., Ltd., Tochigi, Japan,

[4]Technical Development Unit, Panasonic Environmental Systems and Engineering Co., Ltd., Osaka, Japan

E-mail: ymatsuda@nara.kindai.ac.jp

Abstract. An electric field screen is a physical device used to exclude pest insects from greenhouses and warehouses to protect crop production and storage. The screen consists of iron insulated conductor wires (ICWs) arrayed in parallel and linked to each other, an electrostatic DC voltage generator used to supply a negative charge to the ICWs, and an earthed stainless net placed on one side of the ICW layer. The ICW was negatively charged to polarize 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 earthed net. The current study focused on the ability of the screen to repel insects reaching the screen net. This repulsion was a result of the insect's behaviour, *i.e.*, the insects were deterred from entering the electric field of the screen. In fact, when the screen was negatively charged with the appropriate voltages, the insects placed their antennae inside the screen and then flew away without entering. Obviously, the insects recognized the electric field using their antennae and thereby avoided entering. Using a wide range of insects and spiders belonging to different taxonomic groups, we confirmed that the avoidance response to the electric field was common in these animals.

1. Introduction

An electrostatic-based crop protection method was previously developed as a spore precipitation screen for fungal pathogens [1] and as an insect exclusion screen for glasshouse and warehouse pests [2]. This structure consisted of a single-charged dipolar (SCD) screen in which earthed metal nets were placed on both sides of a spore precipitator to create dielectric poles. This screen was able to capture all insect pests that passed the through the screen net. In addition to insect-capture, we found that the SCD screen repels insects reaching the screen net [2,3]. The insects on the charged screen net placed their antennae inside the screen, then flew away without entering the screen. Insects apparently detected an electric field with their antennae and avoided entry. Nevertheless, this finding applied to a limited number of insect species: whiteflies (glasshouse pest) [3], and cigarette beetles and vinegar flies (warehouse and food processing factory pests) [2]. In this study, we clarify whether the insect-repelling functionality of the SCD screen is effective across insect species. We used a wide range of insects and spiders belonging to different taxonomic groups (13 orders, 45 families, 62 genera and species) and confirmed that the avoidance response to the electric field was common across these animals.

2. Materials and methods

2.1. Electric field screen

A copper conductor wire (2 mm diameter, 0.9 m length), insulated by passing through a transparent insulator vinyl sleeve (1 mm thickness, $1 \times 10^9\ \Omega$), was used to construct the SCD-screen. The insulated conductor wires (ICWs) were parallel and spaced at 5-mm intervals; they were connected to each other and to a negative voltage generator. Two earthed stainless nets were placed on one side of the ICW layer, with a separation of 3 mm (**Fig. 1**). The ICWs were negatively charged to dielectrically polarise the ICW insulator sleeve. The negative surface charge of the ICWs causes electrostatic induction in the earthed nets (conductor), creating an opposing surface charge on the ICW-side surface of the nets. An electric field forms between the opposing charges of the ICW layer and the earthed nets [2].

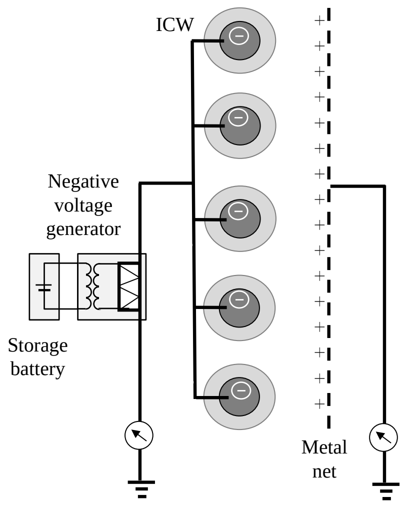

Fig. 1. Construction of an electric field screen.

2.2. Insect avoidance assay

The avoidance assay was conducted using two pieces of apparatus: a transparent acrylic cylinder (30 cm diameter, 40 cm length) partitioned into two parts with the SCD-screen (screen-cylinder) placed horizontally, and a screen-cylinder with a straw pole placed upright on the bottom (**Video supplement 1**). The ICWs were negatively charged with a range of voltages (0.1–8.0 kV). Test insects were released at the bottom of the screen cylinder to observe their actions as they flew up (for flies) or climbed an erect straw (for ladybird beetles) or cylinder wall (for others) to the earthed net of the screen. The assay involved 57 insect species and 5 spider species (**Table 1**). These organisms were collected on the university campus throughout the year. Screens with different mesh sizes (1.6–5.0-mm mesh) were used depending on the body size of the test insects and spiders. Twenty adults were used for each insect (and spider) and per voltage tested, and the experiments were performed five times.

3. Results and discussion

The avoidance assay showed that all test insects and spiders were deterred from passing through the screen net. The initial voltage at which the insects avoided the screen net varied among species (**Table 1**). Insects reaching the net placed their antennae inside the screen and subsequently refused to enter. The videos show examples of these movements for a leaf beetle scrambling up a wall and a ladybird beetle climbing a straw pole (**Video supplement 1**). In contrast, spiders (with no antennae) inserted their legs and then moved from the screen net without entering (**Video supplement 2**). In all cases, this avoidance behaviour became conspicuous when increased voltage was applied to the ICW. As may be expected, smaller insects or insects with longer antennae showed avoidance behaviour for lower applied voltage. However, at >2.0 kV, all insects and spiders moved from the net immediately after they reached it, regardless of body size. Thus, the present study demonstrates that an electric field across the screen acts as an electrostatic pest exclusion barrier. In previous papers, the electric field screen was shown to capture insects blown inside the space between the ICWs and the screen net [2,4,5]. From these results, we conclude that the insect-capturing capability of the singly charged dipolar electric field screen complements unsuccessful insect repulsion.

.

4. Conclusion

The aim of the present work was to generalise the insect-repellent function of an electric field screen for pest exclusion to ensure safe production and preservation of crops. A broad range of insects and spiders were used for this purpose, and all were deterred from entering the screen. At a particular voltage (2.0 kV) applied to the ICWs of the screen, the screen was effective in repelling all targets approaching the screen net. These results demonstrate the importance of pest repulsion as a primary function in physical pest management.

Table 1. Insects avoiding a dipolar electric field

Order	Family	Genus and species	Common name	Voltage (kV) of avoidance
Coleoptera	Anobiidae	*Lasioderma serricorne*	Cigarette beetle	0.8
	Attelabidae	*Euops splendidus*	Leaf-rolling weevil	1.8
	Bruchidae	*Callosobruchus chinensis*	Azuki bean weevil	1.2
	Cerambycidae	*Chlorophorus annularis*	Bamboo longicorn beetle	2.8
		Phytoecia rufiventris	Chrysanthemum longicorn beetle	1.9
	Chrysomelidae	*Argopistes coccinelliformis*	Ladybug mimicking leaf beetle	3.2
		Aulacophora femoralis	Cucurbit leaf beetle	1.3
		Chrysolina aurichalcea	Mugwort leaf beetle	1.9
		Gallerucida bifasciata	Dioscorea leaf beetle	2.8
		Gastrophysa atrocyanea	Japanese green duck leaf beetle	1.2
		Gonioctena rubripennis	Wisteria leaf beetle	2.8
		Lema cirsicola	Leaf beetle	2.8
		Ophraella communa	Ragweed leaf beetle	1.2
	Coccinellidae	*Coccinella septempunctata*	Seven-spotted ladybird beetle	2.4
		Aiolocaria hexaspilota	Ladybird beetle	1.2
		Epilachna vigintioctopunctata	Twentyeight-spotted ladybird beetle	2.4
		Harmonia axyridis	Asian ladybird beetle	2.1
	Curculionidae	*Anosimus decoratus*	Weevil	2.5
		Episomus turritus	Weevil	4.3
		Eugnathus distinctus	Weevil	3.2
		Nesalcidodes trifidus	Snout weevil	4.3
	Elateridae	*Pectocera fortunei*	Click beetle	2.1
	Meloidae	*Epicauta gorhami*	Blister beetle	0.4
	Mordellidae	*Mordella brachyura*	Tumbling flower beetle	3.2
	Oedemeridae	*Xanthochroa atriceps*	False blister beetle	4.5
	Rhynchophoridae	*Sitophilus oryzae*	Rice weevil	4.5
	Tenebrionidae	*Plesiophthalmus nigrocyaneus*	Mimawari beetle	4.5
		Tribolium castaneum	Red flour beetle	2.4
		Uloma latimanus	Black fungus beetle	0.5
Hemiptera	Aleyrodidae	*Bemisia tabaci*	Sweet potato whitefly	0.9
	Aphididae	*Myzus persicae*	Green peach aphid	1.5
	Cicadellidae	*Nephotettix cincticeps*	Green rice leafhopper	0.3
	Tettigellidae	*Bothrogonia ferruginea*	Black tipped leafhopper	0.5
	Lygaeidae	*Geocoris varius*	Large white-spotted seed bug	1.2
		Metochus abbreviatus	Large white-spotted seed bug	0.8
	Pentatomidae	*Eurydema rugosa*	Cabbage bug	1.1

(Continue to Table 1.)

Diptera	Agromyzidae	*Liriomyza sativae*	Tomato leaf-minor	1.2
	Bibionidae	*Bibio japonicus*	Love bug	0.8
	Culicidae	*Aedes albopictus*	Asian tiger mosquito	0.5
	Drosophilidae	*Drosophila melanogaster*	Vinegar fly	1.7
	Ephydridae	*Scatella stagnalis*	Greenhouse shore fly	1.7
	Psychodidae	*Clogmia albipunctatus*	Bath room fly	1.7
Hymenoptera	Anthophoridae	*Tetralonia nipponensis*	Long-horned bee	1.6
	Chalcididae	*Brachymeria lasus*	Chalcid wasp	0.9
	Formicidae	*Formica japonica*	Japanese wood ant	0.2
	Sphecidae	*Sphex argentatus*	Digger wasps	4.2
Lepidoptera	Geometridae	*Biston robustus*	Lilac beauty	1.4
	Tineidae	*Tineola bisselliella*	Common clothes moth	1.4
Blattodea	Blattellidae	*Blattella germanica*	German cockroach	1.8
	Blattidae	*Neostylopyga rhombifolia*	Harlequin cockroach	1.2
Thysanoptera	Thripidae	*Frankliniella occidentalis*	Western flower thrips	1.2
Mantodea	Mantidae	*Tenodera aridifolia*	Praying mantis	0.7
Psocoptera	Liposcelidae	*Liposcelis bostrychophilus*	Book louse	0.6
Dermaptera	Anisolabididae	*Dermaptera* sp.	Earwig	0.7
Orthoptera	Tetrigoidea	*Acridium japonicum*	Bolivar	1.1
Isopoda	Armadillidiidae	*Armadillidium vulgare*	Pill bug	1.6
	Rhinotermitidae	*Coptotermes formosanus*	Oriental termite	1.6
Araneae	Araneus	*Araneus ventricosus*	Orb-weaving spider	2.2
	Pardosa	*Pardosa astrigera*	Wolf spider	2.1
	Pisauridae	*Dolomedes sulfureus*	Fishing spider	2.3
	Thomisidae	*Thomisus labefactus*	Crab spider	2.8
	Uloboridae	*Octonoba varians*	Zebra spider	2.3

Acknowledgement

This work was supported in part by JSPS KAKENHI Grant Number 25450375 from the Ministry of Education, Culture, Sports, Science and Technology, Japan

References

[1] Matsuda Y, Ikeda H, Moriura N, Tanaka N, Shimizu K, Oichi W, Nonomura T, Kakutani K, Kusakari S, Higashi K and Toyoda H 2006 A new spore precipitator with polarized dielectric insulators for physical control of tomato powdery mildew *Phytopathology* **96** 967

[2] Matsuda Y, Nonomura T, Kakutani K, Takikawa Y, Kimbara J, Kasaishi Y, Osamura K, Kusakari S and Toyoda H 2011 A newly devised electric field screen for avoidance and capture of cigarette beetles and vinegar flies *Crop Protection* **30** 155

[3] Nonomura T, Matsuda Y, Kakutani K, Kimbara J, Osamura K, Kusakari S and Toyoda H 2012 An electric field strongly deters whiteflies from entering window-open greenhouses in an electrostatic insect exclusion strategy *European Journal of Plant Pathology* **134** 661

[4] Kakutani K, Matsuda Y, Haneda K, Sekoguchi D, Nonomura T, Kimbara J, Osamura K, Kusakari S and Toyoda H 2012 An electric field screen prevents captured insects from escaping by depriving bioelectricity generated through insect movements *Journal of Electrostatics* **70** 207

[5] Matsuda Y, Kakutani K, Nonomura T, Kimbara J, Kusakari S, Osamura K and Toyoda H 2012 An oppositely charged insect exclusion screen with gap-free multiple electric fields *Journal of Applied Physics* **112** 116103