ORIGINAL RESEARCH PAPER
Volume-7 | Issue-5 | May-2018 | ISSN No 2277 - 8179 | IF : 4.758 | IC Value : 93.98
INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH

ELECTROCUTION OF MOSQUITOES IN A PIGGERY BY A NOVEL ELECTROSTATIC WINDOW SCREEN TO MINIMIZE MOSQUITO TRANSMISSION OF JAPANESE ENCEPHALITIS VIRUS

Engineering

Kakutani K	Pharmaceutical Research and Technology Institute, Kindai University, Osaka 577-8502, Japan
Matsuda Y*	Laboratory of Phytoprotection Science and Technology, Faculty of Agriculture, Kindai University, Nara 631-8505, Japan *Corresponding Author
Takikawa Y	Plant Center, Institute of Advanced Technology, Kindai University, Wakayama 642-0017, Japan
Nonomura T	Laboratory of Phytoprotection Science and Technology, Faculty of Agriculture, Kindai University, Nara 631-8505, Japan
Okada K	Agricultural, Food & Environmental Sciences Research Center of Osaka Prefecture, Osaka 583-0862, Japan
Shibao M	Agricultural, Food & Environmental Sciences Research Center of Osaka Prefecture, Osaka 583-0862, Japan
Kusakari S	Research Association of Electric Field Screen Supporters, Nara 631-8505, Japan
Miyama K	T-CUBE, Earth Environmental Service Co., Ltd, Osaka 567-0085, Japan
Toyoda H	Research Association of Electric Field Screen Supporters, Nara 631-8505, Japan

ABSTRACT

A novel electrostatic window screen was devised for installation in the windows of a piggery to prevent house mosquitoes (*Culex pipiens*) from transmitting Japanese encephalitis virus (JEV) to the surrounding human population. The apparatus consisted of three parallel stainless steel nets and a direct-current voltage generator. The central net (CN) was linked to the voltage generator to accumulate a negative charge, while the external nets (ENs) on either side of the CN were linked to a grounded line. The negative charge on CN positively polarized ENs through electrostatic induction, forming an electric field between CN and EN. The electrostatic discharge (arc and silent discharges) from the CN was dependent on the distance between the nets (pole distance) and the voltage applied to the CN. Adult mosquitoes were introduced into the electric field between the nets, which were charged with the voltages without triggering an arc discharge in the CN. Once the insects were introduced, they were subjected to an instantaneous and transient electric current by an arc discharge from the CN and violently ejected from the electric field. This electrocution was selective due to the high conductivity of the insect cuticle, and the number of electrocuted insects increased as the applied voltage increased. The proposed system was simple and easy to construct, and its scale could be increased through the use of larger nets corresponding to the size of the windows in specific livestock facilities. This study presents the experimental basis for the practical application of an electrostatic-based pest control method.

KEYWORDS

Electrostatic discharge, electric field, pest control, livestock raising facility

Introduction

In the design of modern livestock facilities, it is essential to ensure adequate ventilation. It is important that the building be designed to remove excess heat, water vapor, dust, gases, and odors and to provide a uniform distribution of air [1]. Passive or natural ventilation is the supply and removal of air through openings in a building. It is driven by the natural wind flow around the building and temperature differences between inside and outside the building. Mechanical ventilation is created by fans, thermostats, and air inlets, and is most commonly provided by using fans to blow air out of the building, with fresh air drawn in through inlets on the opposite side. Fans can also be placed within a facility to circulate the air and improve the uniformity of conditions.

The provision of sufficient ventilation could lead to the introduction of insect pests into the facility. There is a diverse range of serious pest problems in livestock production. Livestock pests feed on the blood, skin, and hair of animals [2], and their bites can cause physical and mental health issues for the animals. In addition to pest problems in the livestock, there are also concerns regarding the pest-mediated transmission of pathogens from livestock facilities to surrounding human communities. The rapid pace of urbanization in many parts of the world has created the need for urban animal husbandry to supply city residents with food. The potential transmission of emerging zoonotic diseases in urban areas has therefore become increasingly important. Mosquitoes carry many different disease pathogens and viruses that can infect vertebrates [2]. Our focus in this study was to prevent the mosquito-mediated infection of humans by Japanese encephalitis virus (JEV). JEV is a mosquito-borne, zoonotic flavivirus that causes encephalitis in humans and reproductive disorders in pigs [3]. Ardeid wading birds are the primary maintenance hosts, pigs are the main amplifying hosts, and *Culex* mosquitoes are the primary mosquito vectors for JEV [2]. Virus-infected pigs display no clinical signs except that pregnant sows may abort or have stillborn piglets [4]. In contrast, the disease is extremely serious in humans, especially children, with severe initial symptoms (fever, headache, and vomiting) followed by changes in the patient's mental status, neurologic symptoms, weakness, movement disorders, and seizures [5]. Lindahl et al. [6] reported that the presence of vectors (*Culex tritaeniorhynchus*) and amplifying hosts (pigs) in urban settings led to the rapid spread of JEV among humans in the neighboring area. Suppression of JEV in humans is generally best achieved through the vaccination of humans or swine, mosquito control measures, or a combination of both strategies [5]. An alternative approach to the control of these harmful pests is to prevent their passage into or out of animal husbandry facilities using an electrostatic device. For this purpose, we constructed a novel electrostatic screen to selectively kill insect pests that entered the electric field. The device was designed to be attachable to openings (e.g., windows) in the building.

The application of electrostatics has provided the theoretical and technical basis for the development of various practical instruments for the successful management of pathogens and insect pests in agricultural crops during various stages of crop production and preservation. Electrostatic principles have been applied in many ways, including capturing spores and insects using the attractive force generated in a static electric field (without an electric discharge) **[7-12]**, repelling insects by their aversion to an electric field [6, 13-14], disinfecting bacterial and fungal pathogens by ozone produced through streamer discharge [15], and instantaneously dislodging fungal pathogens from plants through exposure to a plasma stream produced through a corona discharge in an electric field [16]. Based on these successful applications, we developed a new electrostatic apparatus to kill insect pests using high-energy electrons produced within an electric field.

The main purpose of our research program was to develop a practical device with a simple structure that could be constructed easily and cheaply and that would function according to electrostatic principles. Our apparatus consisted of a trio of electrostatically charged stainless steel nets. We hypothesized that, due to the high conductivity of the insect body, only insects would be electrocuted by the arc discharge instantaneously generated within the apparatus. We tested the apparatus on insects to determine its effectiveness, and then optimized its configuration by determining the most appropriate conditions.

Materials and methods

Test mosquito

The house mosquito (*C. pipiens*) was used as a model vector of viral pathogens. Adult mosquitoes were purchased from Sumika Technoservice (Hyogo, Japan) and maintained in a growth chamber (25.0 ± 0.5°C, 12-h photoperiod at 4,000 lux) using our standard method. Newly emerged adult mosquitoes were used in the following experiments. The average body size of the adult house mosquito (i.e., mean length from head to wing tip in 20 adults) was 5.5 ± 0.37 mm.

Fig. 1

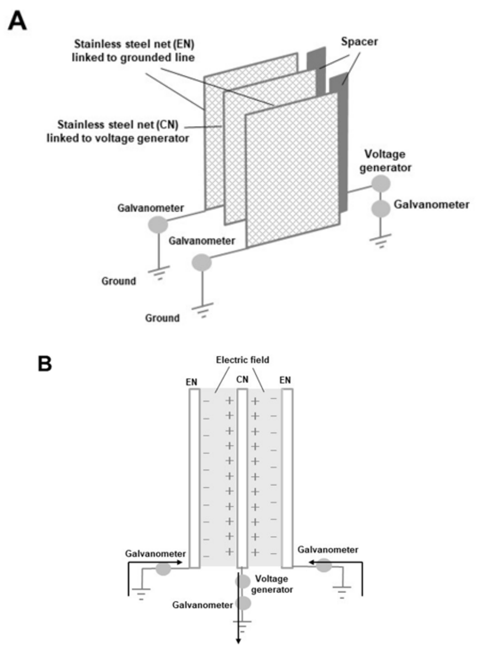
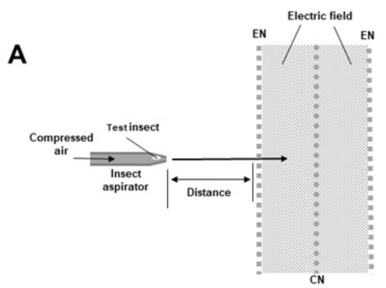


Figure 1. The electrostatic window screen for selectively removing house mosquitoes with accelerated electrons in an electric field. **A**: Three stainless steel nets were arranged in parallel at a defined interval to create an electric field between them. The central net (CN) was linked to a voltage generator to supply the negative charge, and the external nets (ENs) were linked to a grounded line. **B**: Cross-sectional view of the electric field formed between the CN and ENs. The negative charge on the CN positively polarized the ENs through electrostatic induction, forming an electric field. The arrows show the direction of electron movement.

Fig. 2



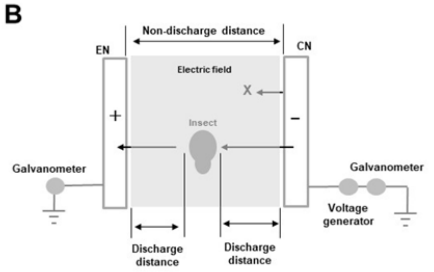


Figure 2. The discharge assay (**A**) and selective electron shooting of insects inside the electric field of the screen (**B**). Insect-mediated electron movement (insects impacted by electrons) from the central net (CN) side to the external net (EN) side. Electron movement occurred instantaneously when the insect entered the electric field where the opposite poles (CN and EN) were arranged at a non-discharge distance. The arrows show the direction of flow of free electrons between the CN and ENs via the insect in the electric field.

Electrostatic apparatus

The structure of the electrostatic window screen is shown in **Figure 1A**. Three identical stainless steel nets (15 mm mesh) were arranged in parallel with 15-mm spacing between nets to create opposite poles. The nets were mounted in a polycarbonate (insulator) frame that could be attached to a window. The central net (CN) was connected to a direct-current voltage generator (maximum electric current, 1,000 μA) (Max-Electronics, Tokyo, Japan) and negatively charged with different voltages; the external nets (ENs) were placed in front of and behind the CN and linked to a grounded line. Polypropylene slips (insulators) (15 mm thick) were placed between the nets as spacers to maintain the distance between electrodes (pole distance). The negative surface charge on the CN caused an electrostatic induction in the ENs, creating the opposite charge on the EN surface facing the CN. An electric field formed between the oppositely charged CN and EN (**Fig. 1B**). The transfer of free electrons from the CN to the EN was measured using two PC7000 galvanometers (Sanwa Electric Instrument, Tokyo, Japan) integrated into the grounded lines. Three types of electrostatic window screen with different net sizes were constructed: 45 × 45 cm (small or S-screen), 90 × 90 cm (mid-sized or M-screen), and 180 × 90 cm (large or L-screen).

Discharge assay

In the first experiment, the three types of screen were negatively charged with 1-10 kV to produce a mechanical discharge (arc discharge) from the CN projection point. In addition, a silent discharge [**18**], which was constantly generated from the EN-side surface of the CN, was measured in the voltage range (1-10 kV), causing no mechanical discharge. The electric current was estimated as the sum of the silent and mechanical discharges or as the insect-mediated discharge (see text below) with a built-in galvanometer. Experiments were conducted at 25°C and under different relative humidity (RH) conditions (40, 60, and 80%).

In the second experiment, the three types of screens were negatively charged with different voltages (1-10 kV) to determine the range of voltages that caused electrocution in all insects introduced into the screen and the magnitude of the insect-mediated transient electric current (caused by arc discharge) at given voltages. Test mosquitoes were collected with an insect aspirator and blown between the nets by passing compressed air through the tip of an insect aspirator (**Fig. 2A**). Wind speed was measured at the surface of the net using a sensitive anemometer. In these experiments, the insects were blown at 3 m/sec (the average airflow speed of the well-ventilated pigpens in our district). All experiments were conducted under the RH and temperature conditions noted above. The insect-mediated discharge was recorded by the built-in galvanometer as a transient electric current. After the insects had passed through the electric field, mortality was evaluated. We used 20 adults for each voltage and RH condition tested. The experiments were repeated five times, and data are presented as mean and standard deviation (SD). Significant differences among treatments were determined using Tukey's method.

Results and Discussion

Our research was part of an ongoing effort to support the sustainable development of urban animal husbandry, allowing it to develop in harmonious relationship with local communities. This relationship has

Table 1. Magnitude of the transient electric current mediated by house mosquitoes introduced into the electrostatic window screen under different voltage and relative humidity (RH) conditions and their mortality.

Types of screen	RH (%)	Magnitude (uA) of insect-mediated transient electric current							Mortality (%) of insect						
		1	2	3	4	5	8	10 (kV)	1	2	3	4	5	8	10 (kV)
L-screen	40	0	22.1 ± 8.4 a	35.8 ± 4.6 a	70.8 ± 7.7 a	124.1 ± 10.7 a	154.6 ± 13.4 a	196.6 ± 15.3 a	0	22.0 ± 4.5 a	100	100	100	100	100
	60	0	24.7 ± 8.7 a	36.0 ± 5.1 a	73.7 ± 5.1 a	127.5 ± 14.1 a	159.2 ± 12.0 a	197.5 ± 17.9 a	0	23.0 ± 5.7 a	100	100	100	100	100
	80	0	26.9 ± 7.7 a	39.7 ± 7.7 a	75.3 ± 5.8 a	131.7 ± 12.6 a	162.5 ± 14.5 a	208.6 ± 18.7 a	0	25.0 ± 3.5 a	100	100	100	100	100
M-screen	40	0	16.5 ± 5.8 b	23.5 ± 5.5 b	37.5 ± 4.7 b	66.7 ± 7.7 b	110.2 ± 11.5 b	143.1 ± 15.4 b	0	0	24.0 ± 6.5 a	100	100	100	100
	60	0	18.2 ± 6.6 b	24.3 ± 4.8 b	38.4 ± 5.3 b	68.1 ± 7.6 b	113.7 ± 11.4 b	148.4 ± 16.1 b	0	0	26.0 ± 6.5 a	100	100	100	100
	80	0	19.3 ± 8.2 b	25.7 ± 3.3 b	40.6 ± 5.3 b	71.8 ± 8.9 b	117.1 ± 10.5 b	154.1 ± 14.4 b	0	0	28.0 ± 8.4 a	100	100	100	100
S-screen	40	0	0	8.1 ± 7.6 c	26.0 ± 6.9 c	36.8 ± 5.7 c	74.0 ± 8.1 c	102.7 ± 8.1 c	0	0	0	36.0 ± 8.9 a	100	100	100
	60	0	0	8.8 ± 6.9 c	27.9 ± 5.5 c	37.7 ± 4.3 c	77.2 ± 6.5 c	104.7 ± 8.5 c	0	0	0	38.0 ± 8.4 a	100	100	100
	80	0	0	10.4 ± 7.2 c	28.8 ± 3.7 c	40.4 ± 5.6 c	81.6 ± 8.0 c	109.4 ± 9.2 c	0	0	0	39.0 ± 6.5 a	100	100	100

Twenty adult insects were used for each voltage/RH combination. Means and standard deviations were calculated from five replicates. Letters (a–c) indicate significant differences within each column ($p < 0.05$) according to Tukey's method.

Fig. 3

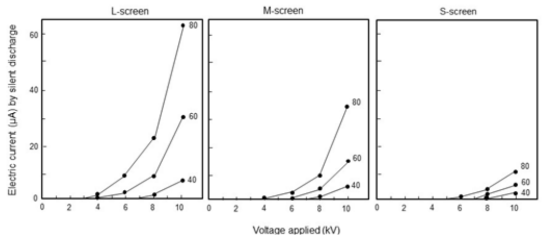


Figure 3. Relationship between the applied voltage and magnitude of current generated by the silent discharge from the central net (CN) of the three types of electrostatic window screen under different relative humidity (RH) conditions. The numbers in the figure represent RH (%).

In this novel electrostatic device, we formed an electric circuit in which the electricity (free electrons) moved from ground to ground (**Fig. 1B**). High voltages produced by a Cockcroft circuit [17] in the voltage generator were used to electrify both electrodes by adding electricity to the CN and discharging electricity from the ENs. The flow (electric current) of the accumulated electricity into the CN was dependent on the voltage applied to the electrode, pole distance, and air conductivity between both electrodes. The current was proportional to increases in voltage and inversely proportional to increases in distance. Air conductivity varies in response to variations in the water vapor concentration in the air, with air conductivity becoming higher (i.e., higher electrical transfer) as RH increases [18]. In the present study, the pole distance was fixed, and the voltage was changed to effectively electrocute the mosquitoes with the electrostatic device under different RH conditions.

In the first experiment, we determined the voltage that would cause a mechanical discharge from the CN due to the non-uniform structure of the nets used for the screen. The projection point on the CN generated the mechanical discharge (arc discharge). As the voltage applied to the CN was increased, the screen eventually caused a mechanical discharge at ≥10.1 kV regardless of changes in RH. This result implied that at ≤10.0 kV, the screen could be operated without causing a mechanical discharge, even with changes in RH.

The electrostatic device was configured so that two non-insulated conductor nets faced each other to produce an electric field. In this electric field, a silent discharge constantly occurred from the EN-side surface of the CN to the ENs. **Figure 3** shows the relationship between the applied voltage and the generation of the silent discharge. In all types of screen, the electric current produced by this discharge became greater in direct proportion to increases in the applied voltage in the range of 5-10 kV (S-screen), 4-10 kV (M-screen), and 3-10 kV (L-screen). The electric current was greater as the net size of the screen increased. Furthermore, the electric current became greater with increased RH for all screens tested.

Measurements with an ion detector showed that the electrostatic window screen ionized the air in the electric field with ozone generation (data not shown). The ionized air in the electric field was extremely active and could destroy or inactivate various microo rganisms, including viruses [19], and deodorize malodorous gases passing through the field [19]. Various effluvia generated in the livestock facilities present serious environmental problems [1]; therefore, the ability of the electrostatic window screen to remove odors may be a useful additional feature.

In the subsequent experiment, we applied various voltages that did not cause a mechanical discharge from the CN, and we introduced a conductor that transmitted electricity (free electrons) according to its capacity [20] into the space between the nets of the screen. Our hypothesis was that this conductor material could act as a temporary recipient of electrons from the CN and as a donor of electrons to the ENs due to the shorter pole distances. Insects were suitable bio-conductors for this purpose (**Fig. 2B**). Many previous studies [21-26] have reported that the cuticle, an outer protective layer that covers the bodies of many invertebrates, is efficiently electrified due to its high conductivity. Adult house mosquitoes possess this cuticle structure [10]. In this experiment, we conducted an assay to determine the validity of our hypothesis. **Table 1** lists the magnitude of the instantaneous transient electric current mediated by adult mosquitoes introduced into the test screens. The screens were negatively charged with different voltages (1-10 kV) under different RH conditions. Once the insects were introduced, electrons moved instantaneously from the CN to the EN and were grounded through the insect in the voltage ranges of 2-10 kV in the L- and M-screens and 3-10 kV in the S-screen. This electron movement was simultaneously recorded as a transient electric current of the same multitude by two galvanometers. However, the magnitude of the electric current was conspicuously different among the screens used, even when the same voltage was applied. These results indicate that different amounts of electricity (free electrons) accumulated on the CN and were released toward the insect. The magnitude of the increase in current corresponded to increases in CN area (i.e., increases in the electrical capacitance of the CN). In all screens, the magnitude of the current became larger as the applied voltage increased. Higher currents generated a larger impact, knocking insects out of the air. The RH conditions did not cause any significant difference in the insect-mediated transient electric current in all screens. **Table 1** shows the mortality rate of mosquitoes introduced into the screens. The lowest voltage that could kill all insects by an electric shock was 3, 4 and 5 kV in the L-, M- and S-screens, respectively. These voltages generated similar levels (approximately 35 μA) of insect-mediated transient electric current, indicating that this level of electric current was necessary to effectively electrocute insects in the screen electric field. At lower voltages, the electric shock was insufficient to kill the insects because there was less accumulation of free electrons on the CN.

The results obtained in the study met our expectations and confirmed the applicability of the new method for preventing virus-transmitting mosquitoes from escaping livestock facilities. Obviously, this device would also be effective for preventing insect pests from entering facilities (i.e., to keep animals free from various pests). Theoretically, the method is applicable to all insect pests that possess a conductive cuticle layer. In livestock pest control, ectoparasite control can be one of the most expensive and time-consuming activities, with a range of flies being common ectoparasites of animals in warmer climates [2]. During the preliminary assay, we confirmed the successful application of the present electrostatic screen to the electrocution of various livestock pests (data not shown).

In addition to its insect-electrocution ability, the device had several other advantageous characteristics that would justify its practical application in livestock facilities. The screen resulted in better air penetration for ventilation due to the use of spacious nets. The mesh size (12 mm) of the net was considerably larger than those (0.8–1.5 mm opening) of conventional woven insect nets. The installation of conventional woven insect nets to the openings of the facility used in this study caused a reduction in ventilation efficiency [1]. The electrostatic screen functioned by preventing insect pests from getting into and out of the livestock facility, while maintaining strong air penetration. This was a vital outcome of the current study.

In both arc and silent discharges, the electric current increased in direct proportion to the increase in applied voltage, RH (only for silent discharge), and net size. These characteristics are due to the electrostatic nature of the screen. However, the magnitude of the current (20–500 μA) was negligible from a practical viewpoint. Another advantageous characteristic of the electrostatic screen was its structural safety. The screen structure produced an electric field inside the screen, and the nets were grounded. As mentioned earlier, the electric field formed between the negative charge on the CN and the positive charge on the CN side of the ENs. The outer surfaces of the ENs possessed no charge, so the net surface could be safely touched. An additional safeguard was the current limiter (maximum limit, 1000 μA) integrated into the electric circuit of the voltage generator, which automatically switched off the generator if excess current was generated by an unexpected event.

Electric power consumption by the screen was low during its practical use. The device had a simple structure consisting of three components: one CN, two ENs, and a voltage generator. The voltage generator was a booster to raise the voltage (from 1 to 10 kV in this case) and charge the CN. The negative charge accumulating on the CN created an electric field to polarize the ENs, an electrostatic phenomenon described as the electrostatic induction of a conductor placed in an electric field [20]. The only component needing an electric power supply was the voltage generator, and its electric power was only 5 watts, equivalent to a small electric bulb.

To summarize, the novel electrostatic window screen is a promising tool to create a pest-free space for raising animal livestock. The device could be constructed at low cost because of its very simple structure. The recent trend in urban livestock farming requires that virus-free animals be bred for supply in an environmentally controlled livestock facility, which could be facilitated by the use of the new device.

Conclusion

This study demonstrated an effective application of basic electrostatics for electrocuting insect pests as they enter or leave livestock facilities. The proposed electrostatic device is a unique product that was specifically developed for the purpose of insect control. The structure of the apparatus is simple, and no special techniques are required for its construction. The device can operate at low electric power consumption to kill insect pests capable of transmitting viral pathogens. The study demonstrated that the method can be used for efficient pest control in livestock rearing facilities, removing the need for insecticidal treatments.

Acknowledgments

This work was supported by JSPS KAKENHI Grant Number 16K00803.

References

1. Gates RS, Casey KD, Xin H, Wheeler EF, Simmons JD (2004) Fan Assessment numeration system (FANS) design and calibration specifications. Trans ASAE 47: 1709-1715.
2. Hurk AF, Ritchie SA, Johansen CA, Mackenzie JS, Smith GA (2008) Domestic Pigs and Japanese Encephalitis Virus Infection, Australia. Emerg Infect Dis 14: 1736-1738.
3. Uchil PD, Satchidanandam V (2001) Phylogenetic analysis of Japanese encephalitis virus: envelope gene based analysis reveals a fifth genotype, geographic clustering, and multiple introductions of the virus into the Indian subcontinent. Am J Trop Med Hyg 65: 242-251.
4. Rosen L (1986) The natural history of Japanese Encephalitis Virus. Annu Rev Microbiol 40: 395-414.
5. Tiwari S, Singh RK, Tiwari R, Dhole TN (2012) Japanese encephalitis: a review of the Indian perspective. Braz J Infect Dis 16: 564-573.
6. Lindahl JF, Chirico J, Boqvist S, Thu HTV, Magnusson U (2012) Occurrence of Japanese encephalitis virus mosquito vectors in relation to urban pig holdings. Am J Trop Med Hyg 87: 1076-1082.
7. Matsuda Y, Ikeda H, Moriura N, Tanaka N, Shimizu K, Oichi W, Nonomura T, Kakutani K, Kusakari S, Higashi K, Toyoda H (2006) A new spore precipitator with polarized dielectric insulators for physical control of tomato powdery mildew. Phytopathology 96: 967-974.
8. Matsuda Y, Nonomura T, Kakutani K, Takikawa Y, Kimbara J, Kasaishi Y, Kusakari S, Toyoda H (2011) A newly devised electric field screen for avoidance and capture of cigarette beetles and vinegar flies. Crop Prot 30: 155-162.
9. Matsuda Y, Kakutani K, Nonomura T, Kimbara J, Kusakari S, Osamura K, Toyoda H. (2012) An oppositely charged insect exclusion screen with gap-free multiple electric fields. J Appl Phys 112: 116103(-1)-116103(-3).
10. Kakutani K, Matsuda Y, Haneda K, Nonomura T, Kimbara J, Kusakari S, Osamura K, Toyoda H (2012) Insects are electrified in an electric field by deprivation of their negative charge. Ann Appl Biol 160: 250-259.
11. Nonomura T, Matsuda Y, Kakutani K, Kimbara J, Osamura K, Kusakari S, Toyoda H (2014) Electrostatic measurement of dischargeable electricity and bioelectric potentials produced by muscular movements in flies. J Electrostat 72: 1-5.
12. Takikawa Y, Matsuda Y, Kakutani K, Nonomura T, Kusakari S, Ito H, Osamura K, Toyoda H (2015) Electrostatic insect sweeper for eliminating whiteflies colonizing host plants: a complementary pest control device in an electric field screen-guarded greenhouse. Insects 6: 442-454.
13. Matsuda Y, Nonomura T, Kakutani K, Kimbara J, Osamura K, Kusakari S, Toyoda H (2015) Avoidance of an electric field by insects: fundamental biological phenomenon for an electrostatic pest-exclusion strategy. J Phys (Conference Series), 646: 0120031-0120034.
14. Nonomura T, Matsuda Y, Kakutani K, Kimbara J, Osamura K, Kusakari S, Toyoda H (2012) An electric field strongly deters whiteflies from entering window-open greenhouses in an electrostatic insect exclusion strategy. Eur J Plant Pathol 134: 661-670.
15. Shimizu K, Matsuda Y, Nonomura T, Ikeda H, Tamura N, Kusakari S, Kimbara J, Toyoda H (2007) Dual protection of hydroponic tomatoes from rhizosphere pathogens Ralstonia solanacearum and Fusarium oxysporum f. sp. radicis-lycopersici and airborne conidia of Oidium neolycopersici with an ozone-generative electrostatic spore precipitator. Plant Pathol 56: 987-997.
16. Nonomura T, Matsuda Y, Kakutani K, Takikawa Y, Toyoda H (2008) Physical control of powdery mildew (Oidium neolycopersici) on tomato leaves by exposure to corona discharge. Can J Plant Pathol 30: 517-524.
17. Wegner HE (2002) Electrical charging generators, in: McGraw-Hill Encyclopedia of Science and Technology-9th Edition (ed. E. Geller et al.), New York, The Lakeside Press, 42-43.
18. Jonassen N (2002) Electrostatic effects and Abatement of static electricity. In: Electrostatics. Kluwer Academic Publishers, Massachusetts, pp. 75-120.
19. Nishizawa K, Nojima H (2001) Air purification effect of positively and negatively charged ions generated by discharge plasma at atmospheric pressure. Jpn J Appl Phys 40: 835-837.
20. Halliday D, Resnick R, Walker J (2005) Electric fields, in: Fundamentals of Physics (ed. S. Johnson and E. Ford), New York, John Wiley & Sons, 580-604.
21. Ishay JS, Shimony TB, Shalom AB, Kristianpoller N (1992) Photovoltaic effects in the oriental hornet, Vespa orientalis. J Insect Physiol 38: 37-48.
22. McGonigle DG, Jackson CW (2002) Effect of surface material on electrostatic charging of houseflies (Musca domestica L). Pest Manag. Sci. 58: 374-380.
23. McGonigle DG, Jackson CW, Davidson JL (2002) Triboelectrification of houseflies (Musca domestica L.) walking on synthetic dielectric surfaces. J Electrostat 54: 167-177.
24. Honna T, Akiyama Y, Morishima K (2008) Demonstration of insect-based power generation using a piezoelectric fiber. Comp Biochem Physiol Part B Biochem Mol Biol 151: 460.
25. Kakutani K, Matsuda Y, Haneda K, Sekoguchi D, Nonomura T, Kimbara J, Osamura K, Kusakari S, Toyoda H (2012) An electric field screen prevents captured insects from escaping by depriving bioelectricity generated through insect movements. J Electrostat 70: 207-211.
26. Moussian B (2010) Recent advances in understanding mechanisms of insect cuticle differentiation. Insect Biochem Mol Biol 40: 363-375.