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An electric field strongly deters whiteflies from entering window-open greenhouses in an electrostatic insect exclusion strategy

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Abstract Dual functions (insect repelling and capturing) of a single-charged dipolar electric field screen were evaluated to successfully exclude whiteflies from a window-open greenhouse. The screen consisted of three parts: 1) insulated conductor wires (ICWs) arrayed in parallel at 5 mm intervals, 2) two earthed stainless nets placed within 3 mm of both sides of the ICW layer, and 3) a voltage generator for the negatively charged ICWs. The screen formed two electric fields between the ICW-layer and the ICW-side surface of the earthed net and between the ICWs. At negative charging of 1.5–2.5 kV, all whiteflies reaching the outer surface of the screen net avoided entering the electric field and flew away from the screen. This avoidance was disturbed by 3 m s^{-1} wind, as the insects were compulsorily blown inside. However, almost all whiteflies (99.4 %) were captured with the ICW. These results indicate that the insect-capturing function is effective to complement a failure to repel. A greenhouse assay was conducted in the screen-attached and non-screened parts in which a greenhouse was divided with a partition. During the 3-month operation, the screen was durable and functional for excluding pests, and better air ventilation changed the climate conditions in the greenhouse. Thus, the present study demonstrated that our electric field screen can provide an airy condition for tomatoes in a window-open greenhouse and successfully exclude whiteflies using dual screen functions.

Keywords Physical control · Hydroponic tomato · Whitefly

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Introduction

Hydroponic tomato culture is conducted during the entire year in our greenhouses, and tomato plants frequently suffer from pathogen infections and/or insect attacks year round. Severe damage is caused to tomato plants by viral infections carried by insects. In particular, tomato yellow leaf curl virus (TYLCV) carried by the whitefly (*Bemisia tabaci*) is the most serious threat during high temperature seasons of the year (Tanaka et al. 2008). The whitefly has been difficult to control with insecticides because it feeds and oviposits mainly on abaxial leaf surfaces (Sharaf 1986), and because it has developed resistance to most classes of insecticides (Prabhaker et al. 1985; Palumbo et al. 2001; Horowitz et al. 2004; Nauen and Denholm 2005). Physical methods could provide an alternative means of managing this pest, as they would be compatible with other components of integrated pest management, have little impact on the environment, and reduce pesticide use, thus slowing the development of resistance to insecticides (Weintraub and Berlinger 2004). Insect-excluding fine-mesh-size woven screens have been extensively employed to minimize whitefly entry into greenhouses, but the disadvantage of screening is a reduction in ventilation, which can cause overheating and an increase in relative humidity. To solve this problem, an electrostatic insect exclusion technique was developed in our laboratory.

The electrostatic-based method was initially devised to collect mature conidia on powdery mildew conidiophores (Moriura et al. 2006a, b; Nonomura et al. 2009) and has been developed as a spore precipitation screen for tomato powdery mildew (Matsuda et al. 2006; Shimizu et al. 2007) and an insect exclusion screen for whiteflies (Tanaka et al. 2008), cigarette beetles, and vinegar flies (warehouse pest) (Matsuda et al. 2011). The first electrostatic spore precipitator was a screen that created a non-uniform electric field around insulated copper conductor wires arranged in parallel (Matsuda et al. 2006). The electric field generates an electrostatic force that was harnessed to attract fungal conidia entering the field. Unfortunately, the spore precipitator was ineffective for trapping major insects that fly into greenhouses. The second device used to solve this problem was a double-charged dipolar (DCD) screen in which paired insulator cylinders were arranged in parallel and oppositely charged with equal magnitude using two separate electrostatic voltage generators (Tanaka et al. 2008). This type of screen utilizes electric lines that move a positively charged particle from the positive to the negative pole (Griffith 2004; Halliday et al. 2005). The force was strong enough to capture adult whiteflies (body width, 0.1–0.3 mm), but the screen was ineffective for capturing much larger insects, as larger insects were stronger and could escape from the screen trap. The third device was a single-charged dipolar (SCD) screen, in which earthed metal nets were placed on both sides of the original spore precipitator to create dielectric poles (Matsuda et al. 2011). The SCD screen was able to capture larger insects with body widths ranging from 0.8–1.0 mm (cigarette beetles) to 0.8–1.2 mm (vinegar flies).

In addition to an insect-capturing ability, we found that the SCD screen possesses an additional function to repel insects reaching the screen net (Matsuda et al. 2011). The insects on the charged screen net put their antennae inside the screen and then flew away from the screen without entering it. Obviously, the insects recognized an electric field by their antennae and avoided entry. This avoidance behaviour became conspicuous when increased voltage was applied to the ICW. Our interest in this study was to clarify whether the insect-repelling function of the SCD screen would be effective for preventing whiteflies from entering the greenhouse under different wind conditions, because it is possible that insects that land on the screen bed could be forced through the screen by strong winds.

In the present study, we designed some laboratory experiments to examine the contributions of both functions (repelling and capturing) of the screen to insect exclusion under different voltages and different wind velocities. We applied the SCD screens to an actual greenhouse to evaluate screen function under greenhouse conditions.

Materials and methods

Insect pest

Whitefly adults (*Bemisia tabaci* Gennadius, type B) were originally collected from greenhouse-grown tomatoes in Chiba Prefecture and maintained at the National Institute of Vegetable and Tea Science, Mie, Japan. The whiteflies were reared on tomato plants in a temperature-controlled greenhouse (26±2°C, 35–55 % relative humidity) at Kinki University (Tanaka et al. 2008). Male and female adults that multiplied on tomato plants were collected for experiments using an insect aspirator (Wildlife Supply, Binghamton, NY, USA).

Construction of the SCD screen and a simplified version

A copper conductor wire (2 mm diameter, 0.9 m length) was insulated by passing it through a transparent insulator vinyl sleeve (1 mm thickness, 1×10^9 Ω) and was used to construct the SCD-screen. The insulated conductor wires (ICWs) were parallel at 5 mm intervals and linked to each other and to a negative voltage generator (Max Electronics, Tokyo, Japan). Two earthed stainless nets (1.6 mm mesh) were placed on both sides of the ICW layer and at 3 mm from the ICW layer (Fig. 1a). The ICWs were placed inside the frame and sealed with silicone resin to make the screen waterproof. The ICWs were negatively charged to dielectrically polarise the ICW insulator sleeve. The negative surface charge of the ICWs causes an electrostatic induction in the earthed nets (conductor), creating an opposite surface charge on the ICW-side surface of the nets. An electric field forms between these opposite charges of the ICW layer and the earthed nets (Matsuda et al. 2011), whereas a static electric field forms between ICWs with the same charge (Matsuda et al. 2006).

We constructed a pair of electrodes as a simplified SCD screen: one ICW (20 cm length) linked to a voltage generator and an earthed stainless net (mesh size, 1.5 mm, 5×20 cm^2) (Fig. 1b). Both electrodes were arrayed in parallel at 3 mm intervals. This simplified screen was placed under a dissecting microscope. The ICW was negatively charged with 1.5 or 3.0 kV, and an insect was released on the outside surface of the net. The action of the insect was recorded using a video camera (Canon EOS X5) installed on the microscope.

Insect-repelling and capturing assay with SCD-screen

We constructed a transparent acrylic cylinder (length, 50 cm; diameter, 20 cm) furnished with an electric fan at one end to develop an insect-repelling and capturing assay (Fig. 1c). The opposite open end of the cylinder touched the screen net, and adult test insects were released inside from a hole at the upper side of the cylinder. The first experiment was conducted under a windless condition to eliminate the effect of wind on the avoidance actions of the insects. The ICWs were negatively charged with 0.2–5.0 kV to determine the relationship between the voltage applied to the ICW and the avoidance actions of the insects on the net. In this assay, we classified insects into four types based their actions: A) passing through the screen, B) walking on the net for a while and then leaving without entering the screen, C) leaving the net immediately (within 2 s) and D) being drawn inside the screen and captured by the ICW.

In the second experiment, we used the particular voltage (1.5 kV) at which the whiteflies strongly avoided entering the screen. We released 50 insects inside the cylinder with no wind because all insects stayed motionless on the wall of cylinder when they were subjected to an air current >0.5 m s^{-1}. The fan was operated when some of the released insects reached the screen simultaneously. The insects were blown at 3 m s^{-1} (at the screen net site) for 40 s, which was the wind speed close to the greenhouse windows. Release of the whiteflies continued until 2,000 insects were tested. During the 40 s wind period, we traced the blown insects and determined the rate of insects that passed through the screen. Experiments were repeated three times, and data are provided as means and standard deviations of three replications.

Greenhouse application of SCD-screens

The screens were attached to the window frames ($1.8\times$ 0.9 m) of the greenhouse to test their ability to exclude adult whiteflies from the greenhouse. The A-shaped greenhouse (9 m length, 6 m width, 5 m height at the highest portion) was divided into three parts by a wall partition (Fig. 2). Screens were installed on the windows on both sides of two side parts and negatively charged with 1.5 kV. The door of one screen-attached part was locked throughout the experiment to avoid entry of whiteflies as researchers entered the greenhouse, whereas the entrance door in another screen-attached part was opened and closed 5–6 times a day for ordinary plant care. The windows of the middle part were not furnished with the screen and remained open throughout the experiment. Roof windows were not furnished with the screens because of structural difficulty and remained closed during the experiment. Two air-circulating fans in each part of the greenhouse were automatically operated when the inside temperature reached 30°C. The temperature changes in the three parts of the greenhouse were monitored at five locations in each part using temperature data loggers.

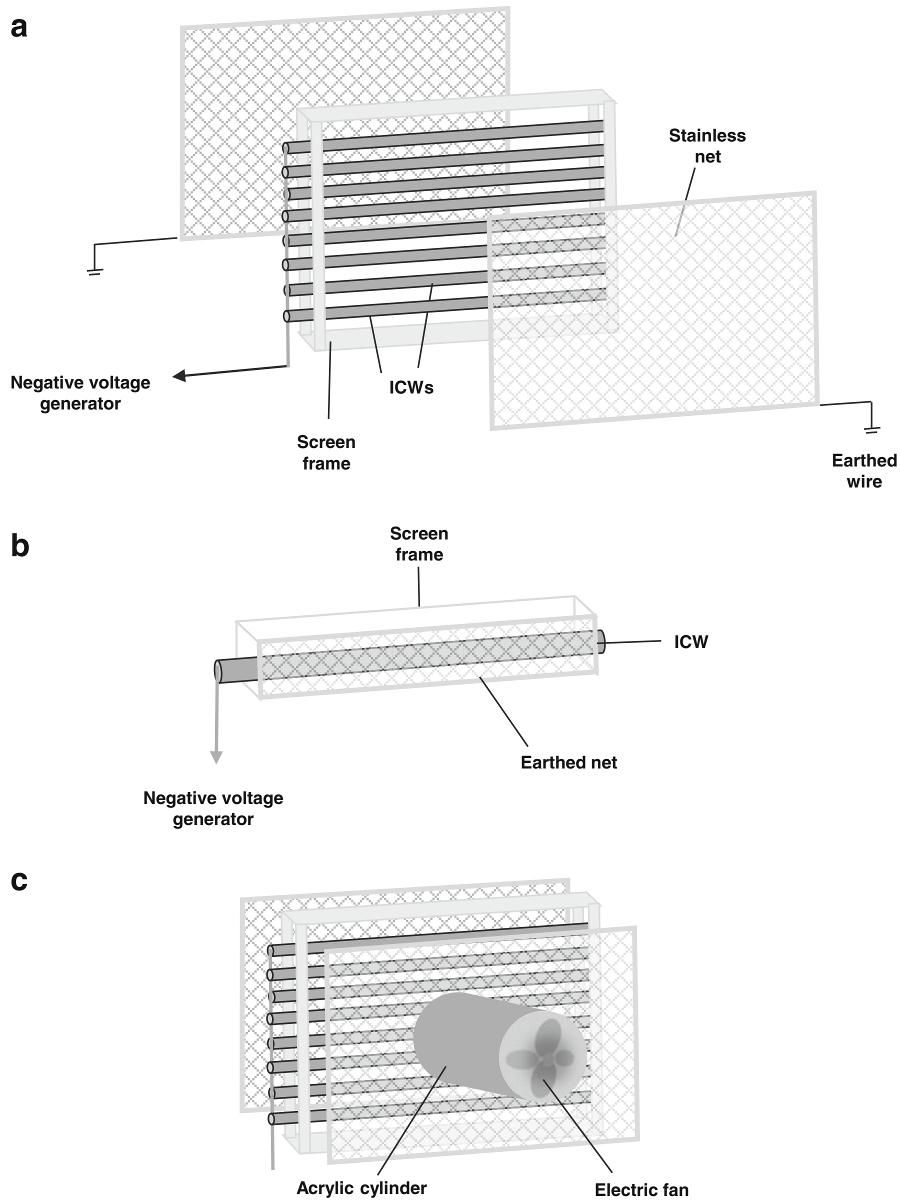

Fig. 1 Structure of the single-charged dipolar (SCD) screen (**a**), its simplified version for video-recording of insect behaviour (**b**) and the electric fan-furnished transparent acrylic cylinder to test avoidance of the screen by insects (**c**)

All side windows were automatically closed when the outside air speed reached 3 m s^{-1}. It took 40 s to completely shut them. The windows were opened again when the wind decreased to 1.5 m s^{-1}. Sixty insect-free, healthy, 40 day-old tomato plants were transplanted to hydroponic culture troughs in each part of the greenhouse and cultured for 2 weeks according to a method described previously (Nonomura et al. 2001). Ten yellow sticky plates (Y-plate) (Arysta Life-Science, Tokyo, Japan) per each part were hung from a crossbeam in the greenhouse at 1 m intervals to determine the number of whiteflies entering. At the end of the experiment (2 weeks after cultivation), we counted the number of whiteflies on the Y-plates, and the numbers on the screens were counted. Experiments were repeated six times at an interval of 2 weeks from July (when vigorous whitefly infestation was confirmed in other tomato greenhouses) to September 2010.

Results

In the first experiment, we examined whether whiteflies would avoid entering the screen when they

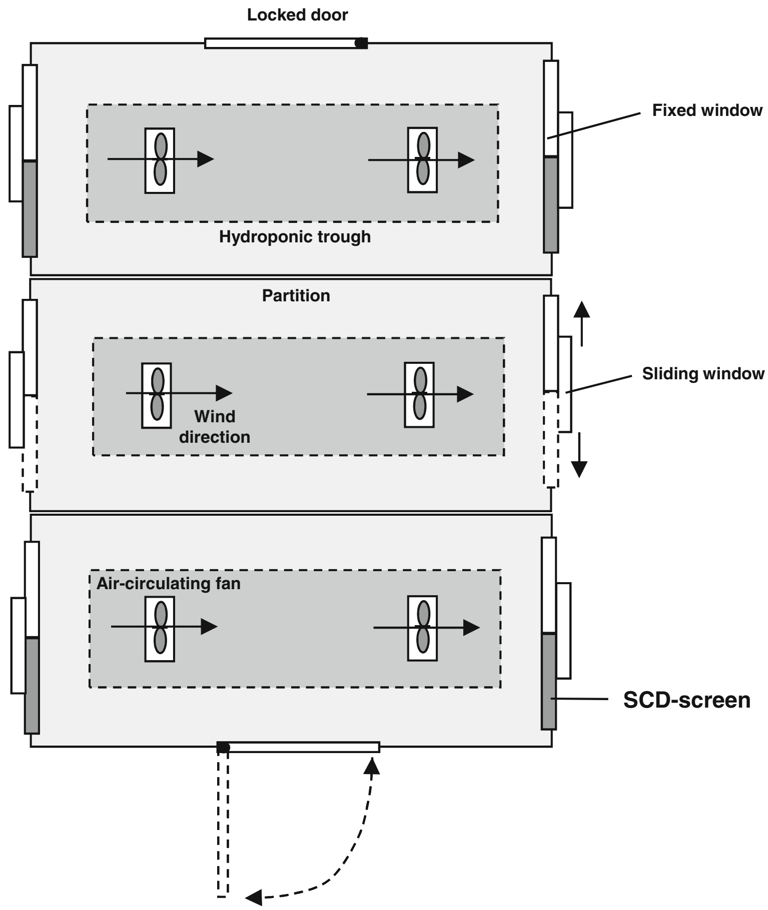

Fig. 2 Floor plan of the greenhouse divided into three parts by wall partitions. The single-charged dipolar (SCD) screens were attached to windows on both sides of the upper and lower parts

reached the screen net. Figure 3 shows the ratio of whiteflies with different actions on the net under a windless condition and at different voltages. When the screen was uncharged, insects reaching the screen net stayed or walked for a short period (2–15 s) and passed through the screen or left the net without entering the screen. At voltages <0.2 kV, we found no difference in the ratio of insects showing these actions. However, the number of insects entering the screen decreased with an increase in voltage (0.2–0.6 kV). No insect entered the screen at 0.8 kV. At this voltage, we found some insects leaving the net within 2 s after they reached the screen. At 1.5–2.5 kV, all insects showed a rapid exit. However, some insects were drawn inside before leaving from the net at a voltage of >2.5 kV and were captured by the ICW. This compulsory movement of the insects was more frequent when the ICWs were charged with larger voltages.

The behaviour of the whiteflies on the net was video-recorded using a simplified SCD screen. The insects on the net entered the screen without hesitation when the screen was not charged (Video Supplement 1). The insects placed their antennae inside the screen and flew away from the screen without entering (Video Supplement 2). Obviously, all insects recognized the electric field by their antennae and avoided entrance when the screen was negatively charged with 1.5 kV. Interestingly, when 3 kV charged the screen, some insects were drawn inside the screen when they stuck their antennae inside because of the strong attraction by the ICW (Video Supplement 3). The ICW was able to capture these insects.

We also examined whether insects on the screen net were pushed inside the screen by the wind. The screen was negatively charged with 1.5 kV (lowest voltage that caused the insects to strongly avoid entering the screen). Figure 4 shows the tracks of the insects during a 40 s wind period and the ratio of the insects showing these tracks. Some insects remained on the net against the wind (Fig. 4a). The major case was capturing insects with the ICW in the A-field (Fig. 4b). In this

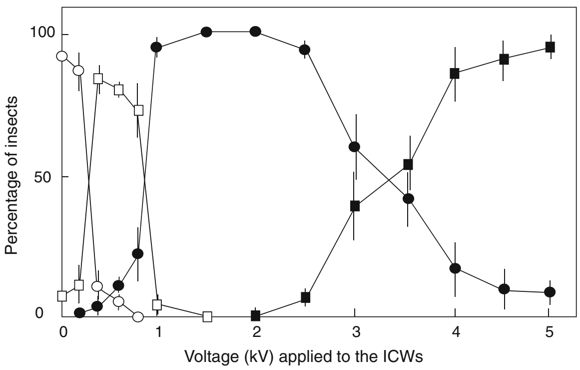

Fig. 3 Relationship between the voltages applied to the insulated conductor wires (ICWs) of the single-charged dipolar (SCD) screen and the actions by the whiteflies on the screen net under a windless condition. *White circles and squares* represent insects passing through the screen and walking on the net and then leaving without entering the screen, respectively, and *black circles and squares* represent insects being removed immediately from the net and being drawn inside the screen and captured by the ICW, respectively

field, all insects turned, and their wings were captured by the ICW. These insects vigorously flattened their legs but were unable to escape the screen trap. The whiteflies were rarely directly transferred to the B-field (Fig. 4c–f). In this field, the insects were captured only when their wings touched the ICW (Fig. 4c). The force of the ICW was not strong enough; thus, the whiteflies were able to move when they stood on their legs on the ICW (Fig. 4d, e). In the latter case, some insects moved and then were drawn to the A-field on the opposite side (Fig. 4d). Otherwise, the insects were pushed off the screen (Fig. 4e). The last case (Fig. 4f) was the direct passing of a whitefly through the screen, which was detected in one insect in three separate experiments. As a result, the frequency that the whiteflies could be forced to pass through the screen by the wind (Fig. 4e, f) was very low (0.61±0.17 %)

Table 1 shows the number of whiteflies trapped by the SCD screens on both sides and the Y-plates in all parts of the greenhouse. The survey of whiteflies trapped by plates in non-screened areas of the greenhouse indicated that numerous whiteflies visited the greenhouse during the experimental periods. However, no whitefly was detected on the Y-plates of the screen-installed and door-locked part, whereas some insects were detected on the plates in the screen-attached but door-unlocked part of the same greenhouse. The SCD screen was able to exclude insects completely while the door remained close. These results suggest that detecting the insects on the plates in the screen-attached part was due to the entry of whiteflies from the opened door. Importantly, the number of whiteflies trapped with the screens was considerably low (5–10 insects per screen) in both screen-attached parts.

Fig. 4 Tracks of whiteflies blown inside the single-charged dipolar (SCD) screen by a 3 m s^{-1} wind. Dots represent whiteflies on the screen net, and arrow edges represent final points that the insects reached. The percentage of insects is given in parentheses

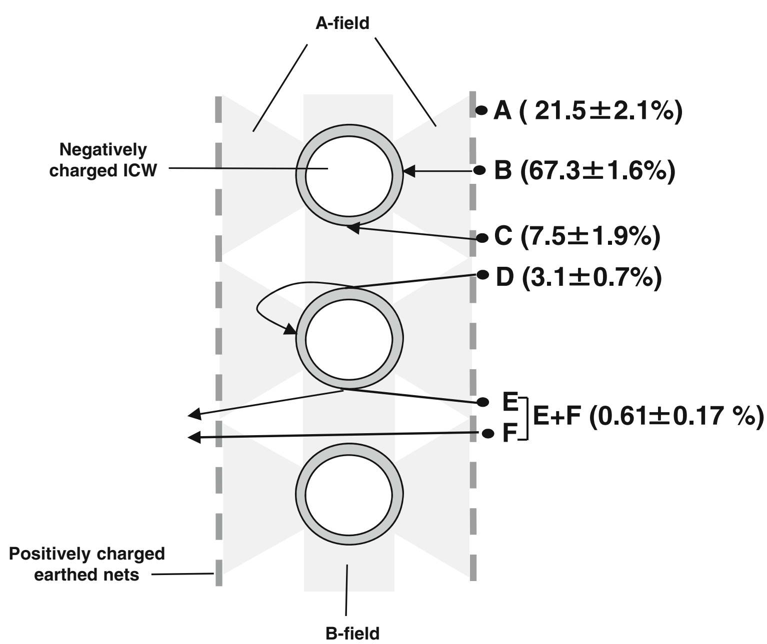

Table 1 Number of whiteflies trapped with single-charged dipolar (SCD) screens and yellow adhesive plates (Y-plates) in the divided parts of the greenhouse

Greenhouse parts		Traps	Experiments						Average
			1	2	3	4	5	6	
Screen-attached	Door-locked	Screens	8	12	13	9	6	8	9.3±2.7
		Y-plates	0	0	0	0	0	0	0 (0)[a]
	Door-unlocked	Screens	11	10	16	17	7	8	11.5±4.1
		Y-plates	17	25	27	19	9	11	18.0±7.2 (1.75±0.30)[a]
Non-attached		Y-plates	897	1097	1441	1211	663	716	1004.2±301.1 (100)[a]

[a] Percentage of whiteflies relative to the number of insects entering the non-screened part of the same greenhouse

As screen durability is the basic requirement to ensure long operation under changeable climate conditions, we carefully scrutinized the screen components at the end of experiment. We confirmed no cracking, warping, or distortion of the components. In particular, the uniformity in the distance between the conductor wires and the nets is essential for the screens to exert their electrostatic function (Matsuda et al. 2011), and this distance remained even after 3 months of operation.

Discussion

An electric-field screen is a physical device to create an electrostatic barrier in a space between opposite poles to which a high potential difference is applied (Matsuda et al. 2011). The energy level of this electrostatic barrier is designated as the electric-field strength (Moore 1997), which is determined by the applied voltage and the distance between opposite poles. The major aim of this study was to optimize the voltage applied to the ICWs in the fixed distance between opposite poles (the ICW and the earthed net) of the electric field screen, based on the avoidance responses of the insects to an electric field

In an electric field impressed with negative voltage, free electrons (negative electricity) in the field are pushed toward the opposite pole and transferred to the ground if the opposite pole is earthed (Jonassen 2002). In our previous studies, we found that insects were deprived of their negative electricity in the electric field; the insects became net positive and were drawn into the negative charge of the ICW (Kakutani et al. 2012b), and this insect-attraction mechanism by the electric-field screen was applicable to a diversity (eight orders including 15 families) of insects (Kakutani et al. 2012a). The amount of electricity was directly proportional to the increase in voltage, and the insects were damaged more seriously by longer periods of ICW restraint with larger voltages. In fact, adult whiteflies that were tightly captured with the ICW did not walk and fly normally when they were released after a 10 min restraint, and a 30 min restraint killed more than 80 % of the captured whiteflies (data not shown).

Newland et al. (2008) reported that cockroaches detect electric fields with their antennae. Cockroaches, when subjected to an electric field, deflected their antennae against the attraction forces, moving their antennae towards the electrode. The force was created as a result of uneven charge distribution on the cockroach, with negative charges being attracted to the oppositely charged electrode. In our previous study (Matsuda et al. 2011), we showed that adult cigarette beetles and vinegar flies sense an electric field with their antennae to avoid entering the screen. Moreover, we found a similar avoidance response of adult whiteflies to an electric field in this study. We recorded a video of whiteflies on the net placing their antennae inside the screen to probe the electric field and hesitating to enter the screen. The attraction force of the screen at >3.0 kV was strong enough to draw the whiteflies inside when they put their antennae into the electric field. However, a 1.5–2.5 kV force was weaker, and whiteflies could resist this drawing force or return immediately after they were drawn inside the screen net. In our understanding, this weaker drawing force is a signal for the whiteflies to quickly move off the screen net because the insects recognized the field but stayed or walked on the net for longer times at lower voltages. From these results, we considered that the SCD screen, negatively charged with 1.5–2.5 kV, can function as an insect-repelling screen net. This voltage range is considerably lower than that of a SCD screen used for capturing warehouse insect pests (5.1 kV) (Matsuda et al. 2011) and a DCD screen for capturing whiteflies (15.0 kV) (Tanaka et al. 2008).

Applying lower voltages was useful for minimising needless atmospheric electric current from the insulated conductor, because the negative electricity of the insulator is also transferred to the net in a high voltage-mediated electric field (Kakutani et al. 2012a). This electricity transfer depends on the voltage applied to the ICWs, the insulation resistance of the ICW cover sleeve, and air conductivity between the ICWs and the earthed net. In particular, air conductivity changes in response to a change in water-vapour concentration (relative humidity) in the air; the air conductivity becomes higher, that is, higher amounts of electricity are transferred in higher relative humidity conditions (Jonassen 2002). Apparently, this phenomenon is more remarkable when applying higher voltages. From this point of view, the use of the lowest voltage (1.5 kV) for repelling insects is acceptable for economical and safe use of this screen. In fact, we confirmed that this voltage caused no detectable electric current from the ICWs in the tested relative humidity range of 30–99 % (data not shown).

The problem was unsuccessful repelling by the SCD screen. The wind was a possible factor in obstructing successful insect repelling by the screen. We anticipated occasions in which whiteflies on the net would be forcibly pushed inside by the wind before they left the screen. Nevertheless, during the wind-blowing assay, we frequently observed that the whiteflies clung to a net string and became motionless. Hence, we wanted to know the frequency of the insects that were drawn into the screen and to confirm successful capturing of these insects with the ICW.

Successful insect capture depends on the formation of an electrostatic barrier with no spaces through which the insects can pass. Two types of electric fields (A- and B-fields) were formed around the ICWs on the SCD screen (Fig. 4). The present assay clearly revealed that the attraction force of the ICWs at 1.5 kV was strong enough to capture all whiteflies that were blown inside the A-field. However, parallel ICWs with negative charges created a static electric field (B-field) with no electricity transfer between the ICWs or insects (Matsuda et al. 2006), but the attraction force was weaker. In this field, catching the whitefly wings with the ICW was essential to prevent them from leaving. In fact, the wing-caught insects remained restrained during the 40 s of wind blowing. The A-field, at the opposite side, was also functional as a final barrier to impede the escape of insects that passed through the B-field. The aim of the experiment was to determine the lowest frequency (0.6 % of the whiteflies blown) that whiteflies could all pass inside the electrostatic barriers of the SCD screen. This low frequency is acceptable based on the practical viewpoint discussed below. From these results, we concluded that the insect-capturing function of the SCD screen complements unsuccessful repelling of insects.

An additional objective of the present study was to monitor window-installed SCD screens for their insect-repelling performance under greenhouse conditions. We conducted a 2 week survey of invading whiteflies because a longer survey would include whiteflies that multiplied on tomato plants in the greenhouse. During the six experiments, a continuous infestation of whiteflies was evident from an increase in the number of insects trapped by the Y-plates hung inside the non-screened part of the greenhouse. This suggests that the remaining two parts of the greenhouse were also exposed to infestation by whiteflies. Under these conditions, in which the entrance door was locked and no person entered during the experimental period, we obtained a satisfactory result in the one screen-attached part; we did not detect any whiteflies on the Y-plates in all separate experiments. The lack of detection of whiteflies on the plates does not necessarily mean there was no entry of insects into the greenhouse. Therefore, we intensively checked all parts of all tomato plants grown in this part at the end of each experiment and confirmed no eggs, pupae, or whitefly adults on the plants. These results indicate that this part of the greenhouse was guarded by the SCD screens, although the screens were exposed to wind on several days. Moreover, the result that very few whiteflies were captured with the screen ICWs in this part supports our explanation that the screens repelled the whiteflies reaching the screen net and kept the greenhouse pest free.

We obtained a considerably high insect-exclusion rate (average, 98 %) in another screen-furnished part where workers went in and out of the entrance door several times per day. This rate was calculated from the number of whiteflies trapped with the Y-plates in this and the non-furnished parts. These results suggest that whiteflies entered the greenhouse from the entrance door when it was opened. The entry number was very low, but may not be negligible because of the threat for secondary infestation by whiteflies that multiply on tomato. From the viewpoint of plant protection against viral disease, it was important to determine whether the SCD screen reduces the potential for viral infection carried insects, and to estimate that reduction in infection potential. For this purpose, we routinely surveyed trapped whiteflies for their virus- carrying potential using a commercial TYLCV-detecting kit (Nippon Gene, Tokyo, Japan). Virus-carrying whiteflies represented less than 10 % of the screen-trapped insects, and all insects on the Y-plates were virus-negative. These results suggest that the present screen is effective for reducing virus transmission by vector insects by up to 10 % on greenhouse tomatoes. Further infection is reduced by limiting the subsequent spread of virus through secondary infestation by the viruliferous whiteflies that multiply on the diseased tomato plants. In our opinion, the SCD screen is a basic tool for pest exclusion and can be used in combination with supplementary methods such as chemical and biological control measures for crop protection.

In addition to the insect-exclusion ability, some advantageous characteristics of the SCD screen justify its practical application in greenhouses. The present screen resulted in better air penetration for ventilation because of the use of airy side nets. The mesh size (1.6 mm mesh) of the net was considerably larger than those (0.3–0.4 mm mesh) of our conventional woven screen. In fact, the screen-installed greenhouse was well ventilated in combination with a ventilation fan to maintain the same favourable temperature ranges as those in a window-open non-screened greenhouse. Water resistance is vital to avoid electric leakage by rainwater. Sealing of the screen was effective to prevent entrance of rain and dew and made it possible to use the screens on rainy days or to wash them with a jet of water after use. The safeguard in the screen structure is production of the electric field inside the screen, insulation of conductor wires, and the use of earthed nets. As mentioned earlier, the electric field formed between the negative charge on the ICWs and the positive charge on the ICW-side of the nets (Matsuda et al. 2011). The outer surfaces of the nets possess no charge and, therefore, are safe when the net surface is touched. Insulation of charged ICWs protects against suppression of the electric current through arc discharge (Matsuda et al. 2006, 2011; Tanaka et al. 2008). In an emergent case when an insulator sleeve is broken by accident, the earthed nets act as a safety device to flow an electric current from the charged ICW into the ground. Electric power consumption by the present screen system is low for practical use. Our screen system has a simple structure consisting of three components: ICWs, earthed nets, and a voltage generator. The voltage generator is a booster to raise the voltage (from 100 V to 1.5 kV in this case) for charging the ICWs. The negative charge accumulating in the ICWs creates an electric field to polarize the earthed nets (Matsuda et al. 2011), which is an electrostatic phenomenon called electrostatic induction of a conductor put in an electric field (Halliday et al. 2005). Insulating the conductor wires was useful to suppress the electric current from the charged ICWs to the earthed nets. No generation of electric current implies no consumption of electric power by the screen itself. Actually, the only driving part needing an electric power supply is the voltage generator, and its electric power is 5 watts, equivalent to a small electric bulb.

The electric field screen has been patented in Japan (Patent No. 4771310) in 2011 and in the USA (Patent. No. 8105418) in 2012 and will be produced and sold by a Japanese manufacturer (Panasonic Environmental Systems and Engineering Co. Ltd.).

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