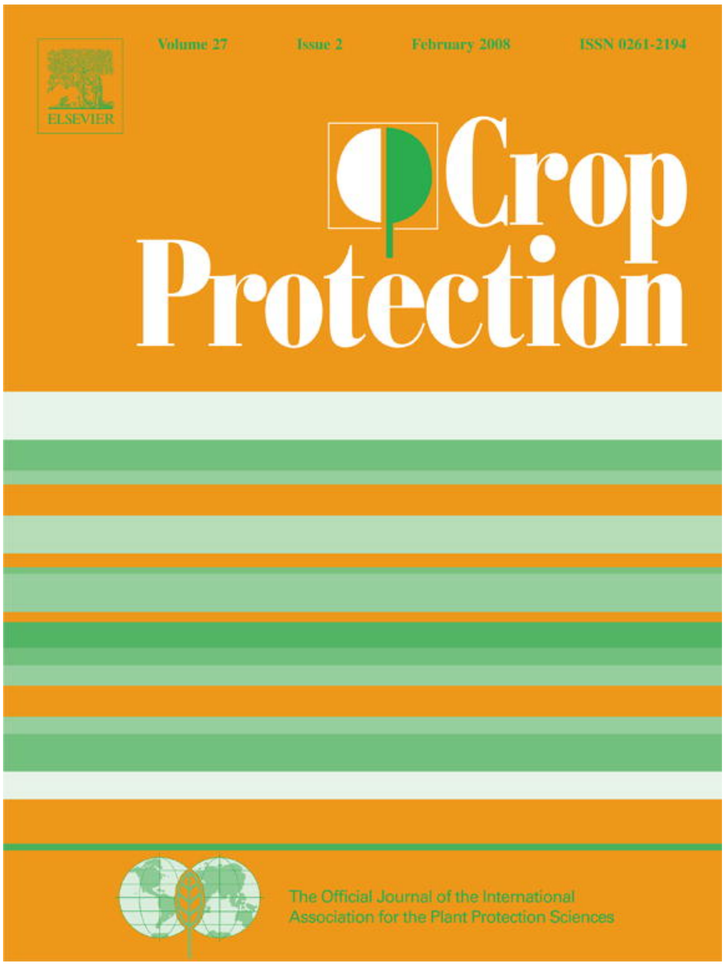
Volume 27
Issue 2
February 2008
ISSN 0261-2194
ELSEVIER
Crop Protection
The Official Journal of the International
Association for the Plant Protection Sciences

Available online at www.sciencedirect.com
ScienceDirect
Crop Protection 27 (2008) 215–221
Crop Protection
www.elsevier.com/locate/cropro

An electric dipolar screen with oppositely polarized insulators for excluding whiteflies from greenhouses

Norio Tanaka[a], Yoshinori Matsuda[a,*], Eiko Kato[a], Kiyoto Kokabe[a], Takeshi Furukawa[a], Teruo Nonomura[a], Ken-ichiro Honda[b], Shin-ichi Kusakari[c], Takeo Imura[d], Junji Kimbara[e], Hideyoshi Toyoda[a]

[a]*Laboratory of Plant Protection and Biotechnology, Faculty of Agriculture, Kinki University, 3327-204 Nakamachi, Nara 631-8505, Japan*
[b]*National Institute of Vegetable and Tea Science, Mie 514-2392, Japan*
[c]*Agricultural, Food and Environmental Sciences Research Center of Osaka Prefecture, Osaka 583-0862, Japan*
[d]*Nara Prefectural Agricultural Experiment Station, Nara 634-0813, Japan*
[e]*Research Institute, Kagome Company, Tochigi 329-2762, Japan*

Received 8 December 2006; received in revised form 16 March 2007; accepted 20 May 2007

Abstract

A new electrostatic insect-proof screen (electric dipolar screen) was developed using insulated conductor wire. Copper conductor wire is encased in a flexible transparent vinyl insulator sleeve and charged with an electrostatic voltage generator. Paired insulated conductor wires were placed in parallel with 5 mm of separation and oppositely charged with 15 kV DC using separate electrostatic voltage generators. A negatively charged conductor wire polarizes the insulator negatively at the outer surface and positively on the conductor side, and a positively charged conductor wire polarizes vice versa. A pair of insulated conductor wires with opposite surface charges was used as an electric dipole. An electric dipole creates an electrostatic force from positive to negative poles. This force was harnessed to trap whiteflies entering greenhouses. Dipolar wires were attached in parallel to a frame to construct an electric dipolar screen that could be fitted to greenhouse windows. The screen prevented adult whiteflies from passing through spaces (up to 30 mm) between the wires of the screen, and tomato plants inside remained free of whiteflies throughout the entire 3-week experiment, in contrast to heavy infestation of all plants in the uncharged area. Thus, the electric dipolar screen is a promising tool to physically exclude flying whiteflies from greenhouses.

Keywords: Electric lines of force; *Lycopersicon esculentum*; Pest management

1. Introduction

The whitefly *Bemisia tabaci* (biotype B) is a major pest in tomato cultivation (Perring, 2001). The greatest economic threat is due to the transmission of damaging plant viruses, primarily the Geminiviruses (Cohen and Berlinger, 1986; Oliveira et al., 2001). Whitefly has been difficult to control with insecticides because it feeds and oviposits mainly on the abaxial leaf surfaces (Sharaf, 1986), and because it has developed resistance to most classes of insecticides applied for its control (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 the pest, since 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 insecticide resistance (Weintraub and Berlinger, 2004).

Also, in Japan a viral disease caused by tomato yellow leaf curl virus is vectored by *B. tabaci* and is a major cause of loss of tomato crops grown in greenhouses nationwide (Ueda and Brow, 2006). To minimize whitefly entry to greenhouses, insect-excluding woven screens with a fine

*Corresponding author. Tel.: +81 742 43 5223; fax: +81 742 43 5271.
E-mail address: ymatsuda@nara.kindai.ac.jp (Y. Matsuda).

0261-2194/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cropro.2007.05.009

mesh size have been extensively employed, but the disadvantage of screening is a reduction in ventilation that causes overheating and an increase in relative humidity. To solve this problem, we used an electrostatic spore precipitator, which had been developed to control tomato powdery mildew (Matsuda et al., 2006). This device is so effective in attracting air-borne conidia from the air that tomato plants guarded by the spore precipitator remain uninfected (Matsuda et al., 2006). Despite the success of an electric field in pathogen control, a preliminary attempt to utilize this device for pest control was unsuccessful, because the electrostatic force of the spore precipitator was insufficient to maintain a hold on trapped whitefly adults.

Electric field lines in an electric field are formed between opposite charges (electric dipole) with equal magnitude (Griffith, 2004; Halliday et al., 2005), and are defined as an electric line of force that moves a positively charged particle toward a negative pole (Griffith, 2004; Halliday et al., 2005). In the present study, improvements are made in this force to attract and entrap flying whiteflies. Our general approach is to create electric field lines between insulated conductor wires (ICWs) with opposite surface charges. In our device, the conductor wire insulating material is dielectrically polarized when the conductor is charged (Matsuda et al., 2006). This type of insulator effectively creates an electrostatic attractive force without discharge (Moriura et al., 2006a, b) and is therefore applicable to the formation of an electric dipole. In this paper, we describe the development and feasibility of using this new type of pest exclusion, using an electric dipolar screen to exclude the whiteflies from greenhouses.

2. Methods

2.1. Plant and hydroponic culture

Tomato (*Lycopersicon esculentum* Mill cv. Moneymaker) was used in the present study. Tomato plants were hydroponically cultured under greenhouse conditions (Nonomura et al., 2001). Germinated seeds of Moneymaker were placed in polyurethane sponge supports ($3 \times 3 \times 3\,cm^3$) soaked in a culture solution and grown in a nursery greenhouse ($26 \pm 4\,°C$) for 3 weeks. Seedlings were transferred to culture troughs ($0.9 \times 3.0\,m^2$) in a propagation greenhouse (not temperature controlled) and cultured for another week. Thirty seedlings (15 plants per row in 2 rows) were grown in each culture trough. During the experiment, the culture solution (100 L) was circulated with a flow rate of 2 L/min with constant regulation of pH 6.0–6.5 and electrical conductivity (1.2 mS/cm).

2.2. Insect pest

Whitefly adults (*B. 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. For experiments, the whiteflies were reared on tomato plants in a temperature-controlled greenhouse ($26 \pm 2\,°C$, 35–45% RH) at Kinki University. Male and female adults multiplied on tomato plants were collected using an insect

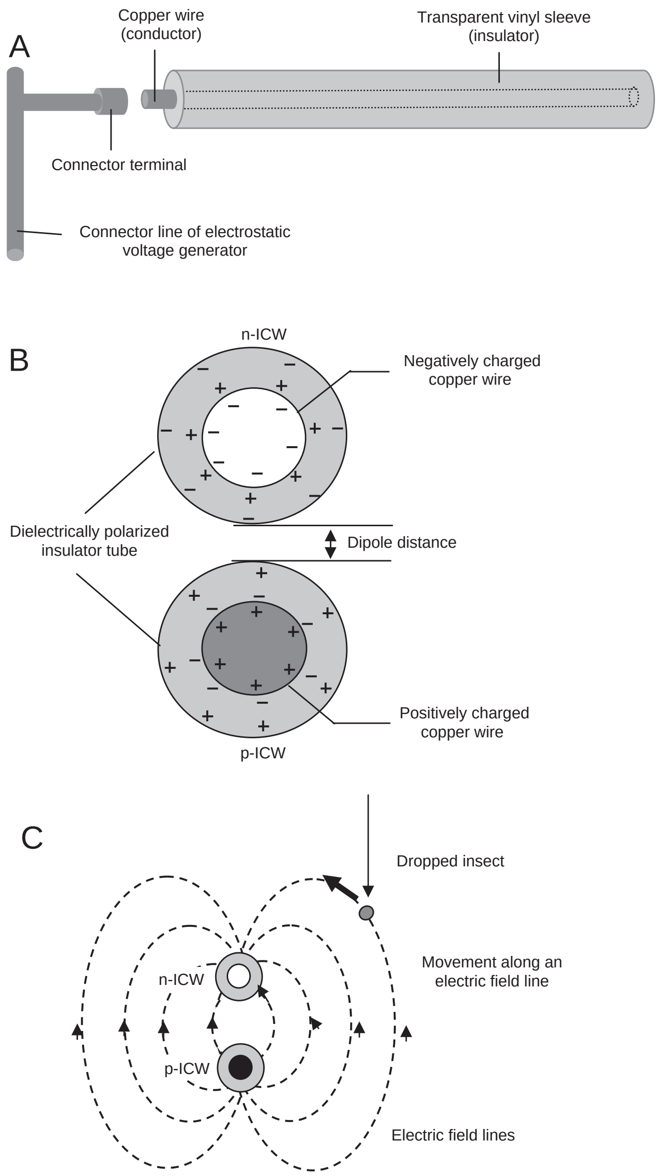

Fig. 1. Schematic representation of an electric dipole with oppositely charged insulated conductor wires (ICWs). (A) A copper wire (conductor) covered with a transparent vinyl sleeve (insulator). The insulated conductor wire was linked to an electrostatic voltage generator and negatively or positively charged with 15 kV DC. (B) A pair of oppositely charged ICWs used for an electric dipole. A negatively charged conductor wire polarizes an insulator sleeve negatively on the outer side and positively on the side of the conductor wire (upper), and a positively charged copper wire polarizes a sleeve vice versa (lower). The dipole distance between ICWs was fixed at 5 mm. (C) Possible mode of insect trapping by an electric dipole. Oppositely charged ICWs create a uniform electric field between them, and theoretical electric field lines were drawn from p-ICW to n-ICW. Dropped insects move to n-ICW along these lines.

aspirator (Wildlife Supply, NY, USA) and released onto test plants for infestation.

2.3. Electric dipole

A copper conductor wire (2-mm diameter, 1.5-m length) was passed through a transparent insulator vinyl sleeve (1-mm thickness) to make an ICW (Fig. 1A). The ICW was linked to a connector terminal of an electrostatic voltage generator and negatively or positively charged with 15 kV DC (highest effective voltage). A charged conductor wire dielectrically polarizes an insulator sleeve; a negatively charged conductor wire polarizes the sleeve negatively on the outer surface and positively on the inner conductor wire surface (n-ICW), and a positively charged conductor wire polarizes the insulator vice versa (p-ICW) (Fig. 1B). A pair of ICWs with opposite and equal surface charges was used to make an electric dipole. In a uniform electric field between dipoles, electric lines of force (electric field lines) are formed from a positive to negative pole, creating a motive force for charged objects within the field (Fig. 1C), depending on the distance between poles and the voltage applied to the poles (Griffith, 2004; Halliday et al., 2005). *B. tabaci* adults have a net overall positive surface charge in this field.

Attraction of whitefly adults was examined using dipolar ICWs. In this experiment, two ICWs were vertically or horizontally placed at a distance of 5 mm and oppositely charged with two separate voltage generators (Fig. 2). Whitefly adults, reared at 10 °C for 10 h for cold paralysis, were dropped from the cut end (0.5-mm tip diameter) of an Eppendorf tube placed 1 cm from p-ICM or n-ICM, and their passive motion to the ICW was tracked. All experiments were conducted in a chamber controlled at 10 °C to keep the whiteflies alive but inert, which is useful for tracing a whitefly's trajectory because it removes variables introduced by flight or other motions. Ten whiteflies were used for each experiment, and experiments were repeated five times.

2.4. Whitefly attraction with an electric dipolar screen

ICW pairs were arrayed in parallel to form an electric field line barrier plane. In this system, n-ICWs were oriented toward the outside to attract the whiteflies (Fig. 3A). Between 25 and 108 ICW pairs were attached to a rectangular frame ($1 \times 1.5\,m^2$) to test electric dipolar screens with different wire spaces (Fig. 3B). This screen was attached to one face of a box frame ($1.0 \times 1.5 \times 1.5\,m^3$), where the opposite face was open, and other faces were shielded with a transparent acrylic plate. A sticky yellow trap plate ($25 \times 40\,cm^2$) (Bug-Scan, Biobest, Westerlo, Belgium) was suspended from the ceiling of the box frame. Inside and outside ICWs were oppositely charged with 15 kV DC using positive and negative voltage generators, respectively. Tomato plants were infested with a total of 50 male and female whitefly adults, and 1 month later a tomato plant bearing 150–200 adult whiteflies was placed 1 m from the electric dipolar screen. Whiteflies were blown from the plant toward the screen (1.0 m/s at the plant) by a mechanical fan placed 40 cm from the plants. After 3 h of continuous blowing, the whiteflies on the trap plate and screen wires were counted. Non-charged screens with different spacings were used as controls. Experiments were repeated five times, and data were given as means and standard errors.

2.5. Application of an electric dipolar greenhouse screen

Electric dipolar screens were attached to the window frames of a greenhouse to test their attraction and exclusion of adult whiteflies. A greenhouse ($6 \times 6\,m^2$, 3–5 m high) was divided into three parts (L, R1 and R2) by a window-integrated wall partition, and the electric dipolar screens were attached to both inside and outside windows of R1 and R2 (Fig. 4A and B). Other windows were not furnished with an electric dipolar screen. Sixty tomato plants were transplanted into hydroponic culture troughs of L and infested with male and female whitefly adults (20 whiteflies of each sex per plant). After 1 month

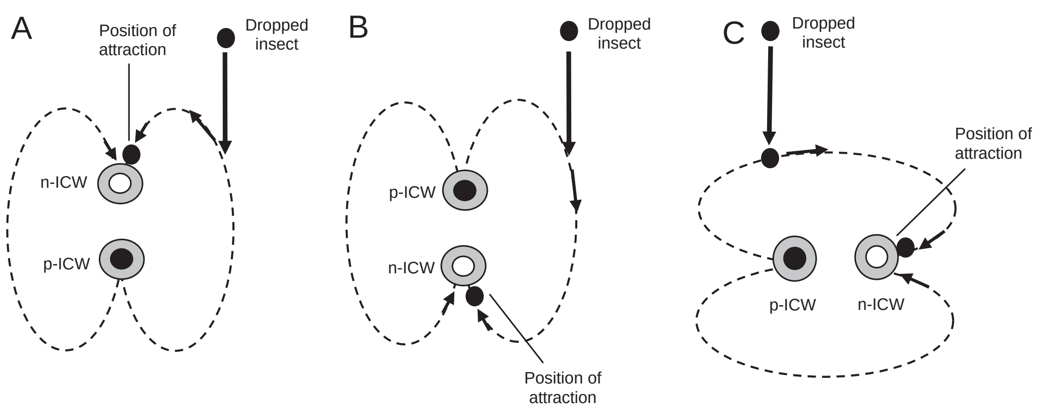

Fig. 2. Trajectories of dropped whiteflies to dipolar ICWs. Adult whiteflies, reared at 10 °C, were dropped at different positions, and their trajectories from dropping sites to attraction positions were tracked. All whiteflies moved onto the n-ICW of a dipole, irrespective of initial dropping positions (A–C). Note the movement of whiteflies along electric field lines between dipoles (see Fig. 1C).

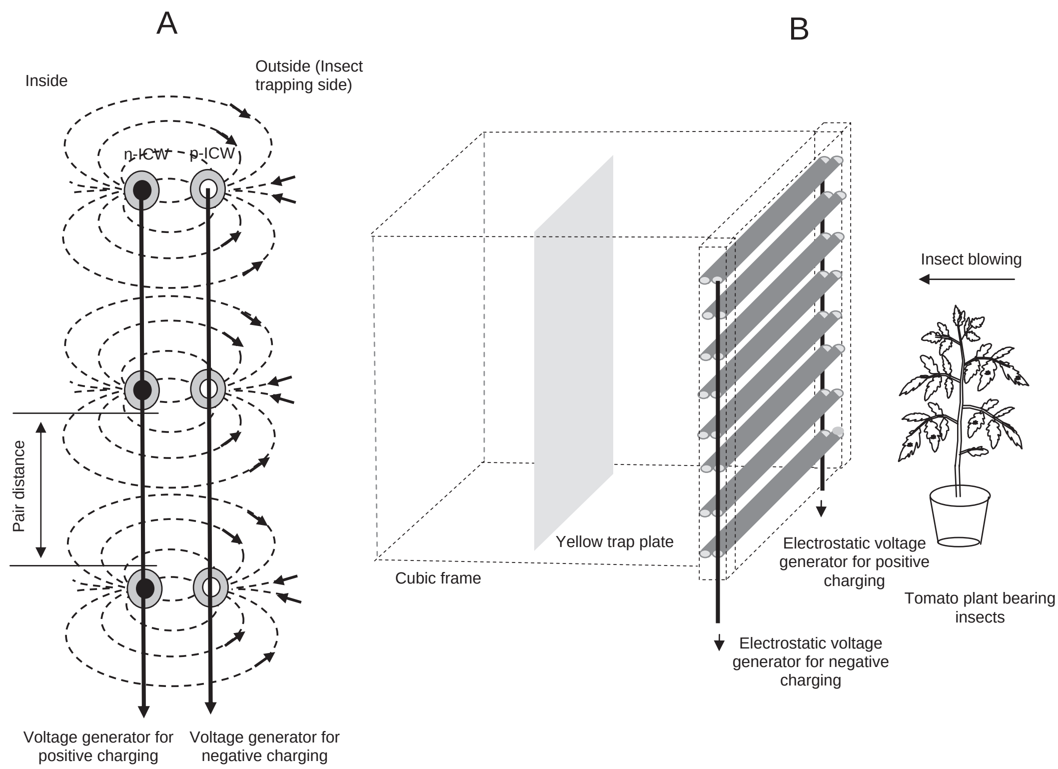

Fig. 3. An electric dipolar screen with oppositely charged ICWs for trapping flying insects. (A) Barrier of electric field lines to prevent whiteflies from passing through spaces between pairs of ICWs. The distance between pairs was changed to determine the optimal spacing that excludes *B. tabaci* adults. Inner and outer ICWs were linked with separate electrostatic voltage generators for positive and negative charging, respectively. (B) An electric dipolar screen attached to a box frame. Pairs of ICWs were attached in parallel to a rectangular frame to make an electric dipolar screen. The screen was then attached to a face of the frame, where the opposite face was open, and the other faces were shielded with transparent acrylic. A yellow sticky trap (Bug-Scan) was suspended from the ceiling of the box frame to monitor whiteflies passing through the screen. ICWs were oppositely charged with 15 kV DC, and whitefly adults were blown from tomato plants toward the screen by an electric fan (1.0 m/s). After continuous blowing for 3 h, whiteflies on the sticky trap and on the ICWs were counted.

of whitefly release, healthy tomato plants were transplanted into culture troughs of R1 and R2. The electric dipolar screens of R2 were oppositely charged with 15 kV DC (30-mm wire interval), and all windows of the greenhouse were opened. The number of whiteflies on both inside screens and plants in R1 and R2 was determined daily for 3 weeks to monitor the transmigration of whiteflies multiplying on the infested plants in L. The total number of whiteflies on plants was determined by collecting all whiteflies from plants using an insect aspirator. Data were given as means and standard errors of three separate experiments.

3. Results

Dipolar ICWs actively attracted and held *B. tabaci* adults (Fig. 4C). In a dipole system of oppositely charged ICWs, the whiteflies remained tightly adhered to the wire insulation during the electrification. All whiteflies were dead after the 6 h ICW electrification period. Fig. 2 shows trajectories of individual whiteflies from a dropping point to the ICW. The electric dipole attracted adult whiteflies only to n-ICW, irrespective of where the whiteflies were dropped (Fig. 2A–C), and moved along the theoretical trajectories predicted by the electric field lines between p- and n-ICWs (Fig. 1C). The trajectories of moving whiteflies were identical for each drop position during all freefall trials.

Using pairs of oppositely charged ICWs, we constructed an electric dipolar screen to trap flying or wind-propelled whiteflies. Spacing between the ICW pairs was optimized as a distance for effectively preventing whiteflies from passing through the screen (Table 1). Almost all of the whiteflies infesting the source plant took flight, and half of them moved toward the screen under the 1.0 m/s wind conditions. The maximum spacing between the wires that prevented pass-through to the sticky trap was 30 mm, and spacings at or below 30 mm prevented whiteflies from passing through the gap between the wires.

To evaluate the practicality of an electric dipolar screen on a greenhouse scale, source and trap plants were separated by charged and uncharged screens. Whitefly adults first appeared on seedlings in the area (R1) with uncharged screens 2–3 days after a partition was opened to allow movement of whiteflies from the source plants (Fig. 5A). It was obvious that uncharged wires and insulating sleeves themselves do not have an attractive

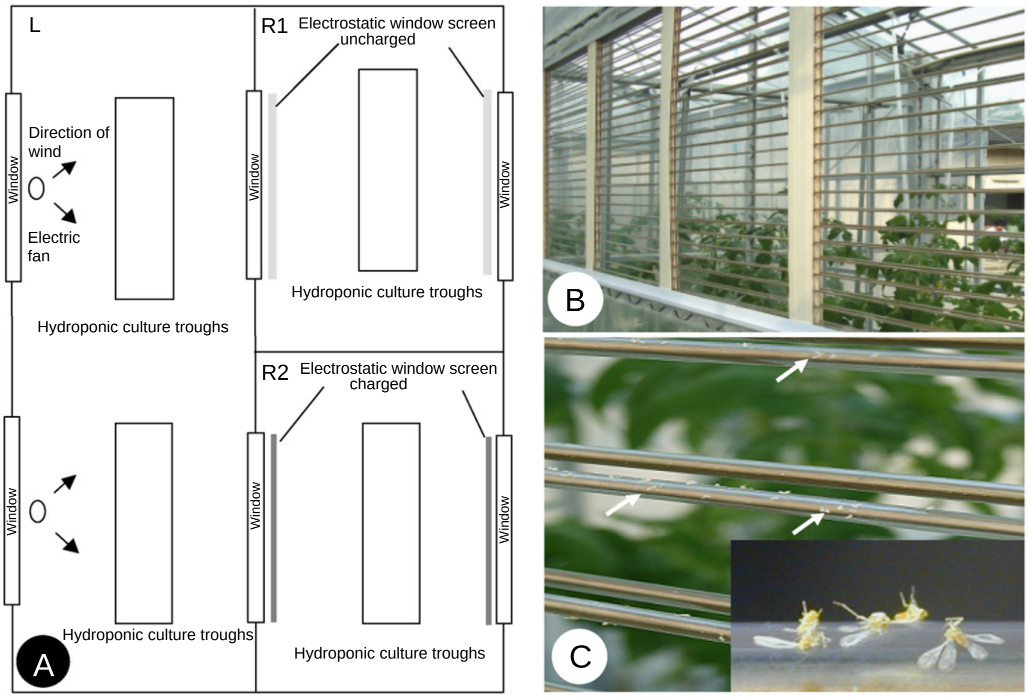

Fig. 4. Greenhouse-scale electric dipolar screen for trapping whiteflies. (A) Floor plan of a greenhouse that was divided into three parts (L, R1 and R2) by windowed partitions. Electric dipolar screens were attached to windows on both sides of R1 and R2. (B) An electric dipolar screen attached to windows of a partition. (C) Whiteflies (arrows) attracted to n-ICWs of the screen. Inserted photograph shows adult whiteflies tightly attracted to n-ICW of an electric dipole.

Table 1
Optimization of spacing between the pairs of n- and p-ICWs of an electric dipolar screen

Spacing (mm) between ICW pairs[1]	Charge	Mean number of whiteflies			% Capture with the screen
		Moved toward the screen	Attracted to		
			ICW pairs	Trap plate	
10	Yes	74.4±10.8[a]	74.4±10.8[a]	0[a]	100[a]
20	Yes	70.4±11.1[a]	70.4±11.1[a]	0[a]	100[a]
30	Yes	73.2±11.2[a]	73.2±11.2[a]	0[a]	100[a]
40	Yes	116.6±13.7[b]	72.6±8.9[a]	44.0±8.9[b]	62.6[b]
50	Yes	117.6±13.1[b]	70.0±8.9[a]	47.6±8.7[b]	59.5[b]
10	No	75.2±8.2[a]	3.0±2.2[b]	67.0±10.8[c]	4.0[c]
30	No	75.6±9.9[a]	2.6±2.1[b]	68.4±10.5[c]	3.4[c]
50	No	75.6±11.7[a]	1.2±1.3[b]	67.2±11.8[c]	1.6[c]

Data were given as means and standard error of five replications. Different letters indicate significance ($P<0.05$) according to Tukey's method.

[1]An electric dipolar screen with varying spaces between the ICW pairs was attached to a box frame and whitefly adults on tomato plants were blown toward the screen by an electric fan.

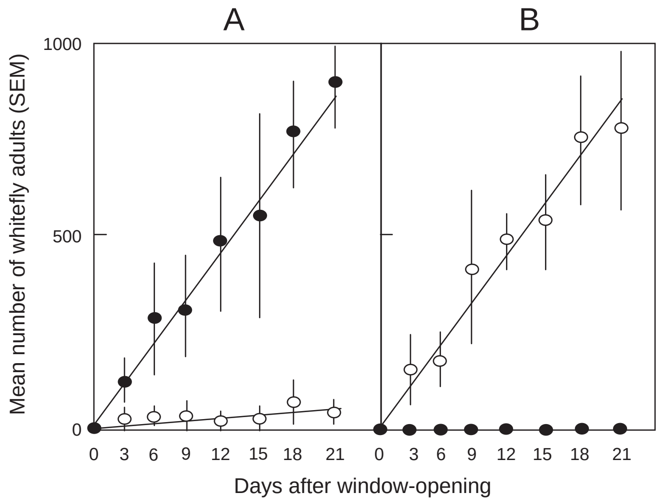

Fig. 5. Attraction of whitefly adults using the electric dipolar screen with oppositely charged ICWs. A greenhouse was divided into three parts (L, R1 and R2) with a window-integrated partition (see Fig. 4A). Electric dipolar screens were attached to the windows on both sides of R1 and R2. The screens of R2 were oppositely charged with 15 kV DC. Whitefly adults on the electric dipolar screen (open) and test plants (dark circles) in R1 (A) and R2 (B) were counted daily for 3 weeks.

effect. No whiteflies were detected on the wires of the uncharged electrostatic window screen. Seedlings in the charged screen area (R2), however, remained free of whiteflies throughout the experiment (Fig. 5B). By direct observation of the screen insulation sleeve surfaces, we confirmed that numerous whiteflies were attracted to the wire surface and that their number increased during the experiment of 3 weeks (Fig. 4C).

4. Discussion

The present work was designed to describe the structure and performance of the newly proposed electrostatic insect-proof screen and the physical principle of operation. The effective use of this innovative device demonstrates that a physical barrier can be used to exclude certain pest species, and as a result presents a safe and environmentally innocuous alternative to pesticides under greenhouse-scale conditions. This is particularly important as physical exclusion methods can result in a reduction in applied chemical pesticides, which is a highly desirable outcome for a public with an increasing interest in safe food production, and because physical barriers do not carry a risk of the development of resistance.

ICWs can produce a non-uniform electric field around them when used as a mono-polar charge (Matsuda et al., 2006). In the highly divergent electric field around ICWs, a dipole develops on objects that enter this field (Cross, 1987). As a result, the electrostatic force provided by opposite charges between objects and insulator surfaces attracts nearby objects. This electrostatic force has been used to physically trap air-borne powdery mildew conidia (Matsuda et al., 2006; Moriura et al., 2006b), but was insufficient to trap flying whiteflies, which have a far greater momentum. An electric dipole creates a uniform electric field between opposite poles, where an electrostatic force is generated along theoretical electric field lines drawn from a positive to negative pole (Griffith, 2004; Halliday et al., 2005). The electromotive force produced by oppositely charged ICWs was sufficient to trap flying whiteflies entering the greenhouse. Further work will be needed to determine the optimal conditions for excluding other insects. It may be possible to calculate the exclusion ability of a particular dipole screen from an 'exclusion index', determined by the mean weight and maximum velocity of a flying insect, its ability to generate a surface charge in a dipole and the strength of the field. Future dipole screens can thus be designed with particular pests in mind, and adapted to local conditions.

When the spacing between pairs of oppositely charged ICWs was optimized, the electric dipolar screen worked effectively to attract whiteflies that were mechanically blown off the plants toward the screen. In greenhouse conditions, insect exclusion in our system was so satisfactory that the screen-guarded plants remained free of whiteflies throughout the entire experiment. Plants in the guarded area were continuously exposed to wind with a velocity of 1.0 m/s from an electric fan, which is greater than the air stream (0.4–0.8 m/s) produced by the greenhouse ventilator. This result suggests that the electric dipolar screen can be used to trap whiteflies in a well-ventilated greenhouse.

A 30-mm spacing between the ICW pairs was effective under the highest practical voltage, and completely prevented whiteflies from passing through the spaces between the wires. This interval is much larger than the 50-mesh, 0.2–0.3-mm intervals of insect-proof nets that are used conventionally to prevent the entry of tobacco whiteflies (Teitel et al., 1999; Weintraub and Berlinger, 2004). The use of such fine-mesh nets inhibits the levels of ventilation required to control temperature and humidity in greenhouses, especially during the summer season (Molina-Aiz et al., 2005). An electric dipolar screen would thus greatly improve greenhouse conditions with a high efficacy of plant protection from insect pests and diseases.

The electric dipolar screen described in this study is easy to construct, and therefore mass production of the screen is possible on a commercial scale, and using cheaper insulating materials can further reduce the cost. We used a transparent insulator as a shield to minimize shading by the electrostatic window screen, but other insulator-shielded conductors are available. Non-insulated, electrified conductors also produce an electrostatic force but can create a negative charge through spark discharge. In the electric dipolar screen presented here, the wire conductor was shielded with an insulator cover to prevent spark discharge by the electrified conductor. There is no negative charge flow generated during operation of the electric dipolar screen, suggesting that the screen operates without significant energy loss except for the electricity required to operate the voltage generators. A rough calculation indicated an additional use of 1.2 kWh per month, or about 30 ¥, with all 30 lateral-side windows of our standard greenhouse ($7.2 \times 20\,m^2$) which were furnished with screens sized to the window frame ($1.2 \times 1\,m^2$) (data not shown). The windows of a greenhouse are the most important sites for the electrostatic device. The electric dipolar screen can be automatically operated at the time of window opening and be stopped at least 6 h after window closing. This approach would be useful not only for insect exclusion, but also to reduce operating costs and to increase the lifespan of the electric dipolar screen. An electric dipolar screen is currently being developed for practical application. The shape and size of the screen will be modified to make the device more amenable to common sites of attachment.

References

Cohen, S., Berlinger, M.J., 1986. Transmission and cultural control of white-fly borne viruses. Agric. Ecosyst. Environ. 17, 89–97.

Cross, J.A., 1987. Dielectrophoresis. In: De Barr, A.E. (Ed.), Electrostatics: Principles, Problems and Applications. Adam Hilger, Bristol, pp. 269–276.

Griffith, W.T., 2004. Electrostatic phenomena. In: Bruflodt, D., Loehr, B.S. (Eds.), The Physics of Everyday Phenomena, A Conceptual Introduction to Physics. McGraw-Hill, New York, pp. 232–252.

Halliday, D., Resnick, R., Walker, J., 2005. Electric field. In: Johnson, S., Ford, E. (Eds.), Fundamentals of Physics. Wiley, New York, NY, pp. 580–604.

Horowitz, A.R., Kontsedalov, S., Ishaaya, I., 2004. Dynamics of resistance to the neonicotinoids acetamiprid and thiamethoxam in *Bemisia tabacci* (Homoptera: Aleyrodidae). J. Econ. Entomol. 97, 2051–2056.

Matsuda, Y., Moriura, N., Ikeda, H., 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.

Molina-Aiz, F.D., Valera, D.L., Pena, A.A., Gil, J.A., 2005. Optimization of Almeria-type greenhouse ventilation performance with computational fluid dynamics. Acta Hortic. 691, 433–440.

Moriura, N., Matsuda, Y., Oichi, W., Nakashima, S., Hirai, T., Sameshima, T., Nonomura, T., Kakutani, K., Kusakari, S., Higashi, K., Toyoda, H., 2006a. Consecutive monitoring of lifelong production of conidia by individual conidiophores of *Blumeria graminis* f. sp. *hordei* on barley leaves by digital microscopic techniques with electrostatic micromanipulation. Mycol. Res. 110, 18–27.

Moriura, N., Matsuda, Y., Oichi, W., Nakashima, S., Hirai, T., Nonomura, T., Kakutani, K., Kusakari, S., Higashi, K., Toyoda, H., 2006b. An apparatus for collecting total conidia of *Blumeria graminis* f. sp. *hordei* from leaf colonies using electrostatic attraction. Plant Pathol. 55, 367–374.

Nauen, R., Denholm, I., 2005. Resistance of insect pests to neonicotinoid insecticides: current status and future prospects. Arch. Ins. Biochem. Physiol. 58, 200–215.

Nonomura, T., Matsuda, Y., Bingo, M., Onishi, M., Matsuda, K., Harada, S., Toyoda, H., 2001. Algicidal effect of 3-(3-indolyl)butanoic acid, a control agent of the bacterial with pathogen, *Ralstonia solanacearum*. Crop Prot. 20, 935–939.

Oliveira, M.R.V., Henneberry, T.J., Anderson, P., 2001. History, current status, and collaborative research projects for *Bemisia tabaci*. Crop Prot. 20, 709–723.

Palumbo, J.C., Horowitz, A.R., Prabhaker, N., 2001. Insecticidal control and resistance management for *Bemisia tabaci*. Crop Prot. 20, 739–765.

Perring, T.M., 2001. The *Bemisia tabaci* species complex. Crop Prot. 20, 725–737.

Prabhaker, N., Coudriet, D.L., Meyerdirk, D.E., 1985. Insecticide resistance in the sweetpotato whitefly, *Bemisia tabaci* (Homoptera: Aleyrodiae). J. Econ. Entomol. 78, 748–752.

Sharaf, N., 1986. Chemical control of *Bemisia tabaci*. Agric. Ecosyst. Environ. 17, 111–127.

Teitel, M., Barak, M., Berlinger, M.J., Lebiush-Mordechai, S., 1999. Insect-proof screens in greenhouses: their effect on roof ventilation and insect penetration. Acta Hortic. 507, 25–34.

Ueda, S., Brow, J.K., 2006. First report of the Q biotype of *Bemisia tabaci* in Japan by mitochondrial cytochrome oxidase I sequence analysis. Phytoparasitica 34, 405–411.

Weintraub, P.G., Berlinger, M.J., 2004. Physical control in greenhouses and field crops. In: Horowitz, A.R., Ishaaya, I. (Eds.), Pest Management. Springer, Berlin, pp. 301–318.