Techniques

Leaf Surface Electrostatics: Apparatus and Procedures Used Under Controlled and Natural Conditions

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ABSTRACT

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Described are the procedures and the apparatus used to measure the intensity of electrostatic fields associated with the surfaces of detached leaves in controlled experiments as well as under natural conditions. Under controlled conditions, the apparatus can be used to investigate the effects of changes in atmospheric humidity, red-infrared radiation, and air velocity on leaf surface electrostatic fields. To measure electrical field intensity, an electrostatic sensor (field mill) is positioned 10 mm above a leaf surface, using a standardized leaf disk 55 mm in diameter. Procedures are described to minimize electrical changes associated with handling of leaves, including the use of insulated scissors, insulated forceps, and rubber gloves.

If active discharge of conidia and sporangia of many dry-spored foliar fungal pathogens involves an electrostatic mechanism as has been proposed (1,2,4), for such a mechanism to exist, one must assume that leaf surfaces become electrostatically charged. In addition, one would expect surface electrical charges to relate to the principal physical factors that trigger active spore liberation, namely changes of atmosphere humidity and exposure to red-infrared radiation (IR). To determine whether leaf surfaces become charged, an apparatus was designed and procedures were developed for measuring electrostatic fields associated with detached leaves under various environmental conditions. This article describes and illustrates the apparatus and explains how it was used in controlled experiments (5) as well as under natural conditions (6).

DESCRIPTION OF APPARATUS

The apparatus to measure electrostatic fields associated with detached leaves is illustrated in Fig. 1. Mechanical details of the various components of the apparatus are shown schematically in Fig. 1B and C, with measurements in Fig. 1D. Not included is the humidification system, which is a part of a "spore release apparatus" that has been described in detail elsewhere (2).

Electrostatic field intensity sensor. This commercially available instrument known as a "field mill" (Model 107, MK II, Industrial Development Bangor (UCNW) Ltd., Bangor, North Wales, U.K.), is mounted in a holder 10 mm above the leaf surface as shown in Fig. 1A. The instrument is designed to sense the intensity of an electrical field emanating from a charged surface. The sensing area of the field mill (47 mm diameter) is centered directly over a leaf disk standardized at 55 mm in diameter.

The Model 107 field mill is a rotating vane-type instrument that measures the mean electrical field over several square centimeters of leaf surface without physically touching the leaf. The basic principles of operation, as described by the manufacturer, are as follows: ". . . a probe surface exposed to an electrical field has an electrical charge induced on it in proportion to its area and strength of the local electric field. With a defined capacitance to ground, this charge is manifest as a potential which can be presented to the input of a high impedance amplifier to generate a signal directly related to the strength of the electric field. Because the probe and its associated capacitance will have a finite leakage resistance to earth, the charge on the capacitance will leak away. By chopping the electric field with a rotating grounded vane, at a rate which is much faster than the decay RC time constant of the probe and amplifier input circuit, an a.c. signal is generated which relates accurately to the intensity of the electric field . . ."

Leaf chamber and method of mounting leaf. Details of the leaf chamber are shown in Fig. 1B and C. A leaf with a minimum width of 57 mm is placed on the top of the holder shown in Fig. 1C-21, where it is held in position with a polystyrene retainer ring (a modified petri dish top). The lip of the retainer ring exposed to the sensor was about 1 mm wide. (Note: an aluminum ring has replaced the polystyrene ring in current studies.) When the retainer ring is pressed into place, the edges of the leaf are bent down around the sides of the holder, thus exposing a standardized disk of leaf surface to the electrostatic sensor (55 mm diameter). In mounting the leaf, care is taken to grip only the edge of the leaf, using insulated forceps and rubber-gloved hands. An aluminum housing (Fig. 1C-17) is then placed over the leaf and this is held in place by four insulated spring clips (Fig. 1B). The lower edge of the housing is covered with a thin strip of airtight foam seal (Fig. 1A-9).

Humidity and temperature control. In laboratory experiments, the whole apparatus is located in a constant-temperature room. Humidified air at a constant flow rate is fed into the leaf chamber through one of the two entrance ports (Fig. 1A and B). Air temperature, velocity, and humidity are precisely controlled using a modification of an apparatus used in spore-release studies (2). Atmospheric humidity is measured precisely with a wet-dry bulb thermocouple psychrometer (2) and air temperature with thermocouples. Air velocity is measured with a hot-wire-type anemometer (Model 8500, Thermo-anemometer, Alnor Instrument Co., Niles, IL). Temperature and humidity are recorded

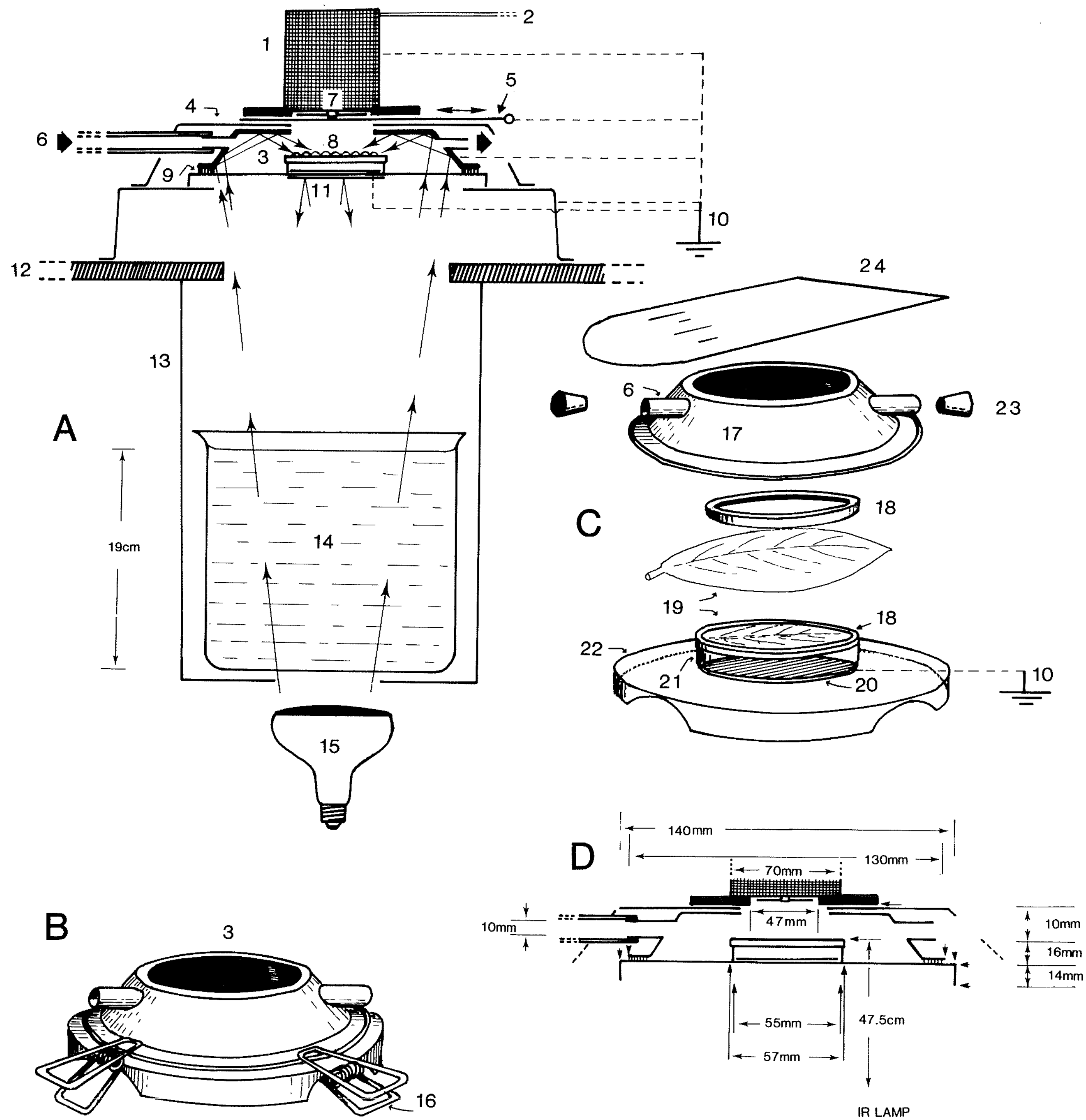

Fig. 1. Apparatus and instrumentation used to measure electrostatic field intensities associated with leaf surfaces under controlled and natural conditions. **A,** Sectional drawing of complete apparatus (humidity and temperature controls not shown); **B,** leaf chamber only; **C,** disassembled leaf chamber; and **D,** leaf chamber and electrostatic sensor dimensions. Numbered components: (1) electrostatic sensor (field mill), (2) recorder outlet, (3) leaf chamber, (4) electrostatic sensor platform, (5) removable electrical ground plate for zeroing sensor, (6) controlled air-supply inlet, (7) field mill sensing area (47 mm diameter), (8) leaf, (9) airtight seal, (10) electrical grounding of various components, (11) aluminum reflective tape below leaf holder, (12) bench top, (13) lamp housing, (14) Pyrex beaker light-filter (used with or without distilled water), (15) red-infrared lamp, (16) spring clip (four spaced around chamber), (17) leaf chamber housing (acts also as an red-infrared radiation reflector and an electrostatic shield), (18) leaf retainer ring, (19) leaf shown mounted and unmounted, (20) brass ground plate (disconnected during measurements), (21) leaf holder, (22) leaf chamber base, (23) rubber stopper, and (24) removable clear plastic film. (Note: drawings are schematic and not to scale.)

continuously on a print-type multichannel recorder (Multipoint, Model PM 8325, Philips, Netherlands). Output from the electrostatic sensor is recorded on a faster-responding pen-type single-channel millivolt recorder. In designing the apparatus, no attempt was made to obtain an even airflow over the leaf surface. At the constant flow rate used in controlled studies (5), velocities across a leaf surface varied from 0.5 to 1.5 m/sec, depending on the location of the anemometer.

Red-infrared radiation. An infrared lamp (Sylvania 250W, 115V red-infrared) is located 47.5 cm below the leaf (Fig. 1A.). Radiation from the lamp is transmitted through the clear polystyrene bottom of the leaf chamber and then reflected from the sloped sides of the aluminum top of the leaf chamber onto the leaf surface located directly below the electrostatic sensor as shown in Fig. 1A. This arrangement allows electrostatic field strengths to be monitored while the leaf is actually being irradiated. IR intensity is measured with a radiometer in a special holder positioned on the same plane as the leaf. Normally, leaves are exposed to unfiltered IR but there is provision for a 20-cm-deep distilled water filter contained in a large Pyrex beaker (Fig. 1A).

Leaf chamber used as a moist chamber. A number of experiments were conducted at a constant air temperature on detached leaves in saturated (RH 100%) still air (5). To use the leaf chamber as a still-air, moist chamber, after mounting the leaf (Fig. 1C), a clear plastic film (Fig. 1C-24) is placed over the top opening of the leaf chamber housing and attached lightly at several points with adhesive tape; also, the entrance and exit ports are closed with rubber stoppers. Many moist chambers have been constructed so that replicated leaves can be used in experiments. Before measuring a leaf placed in a moist chamber, the plastic film used as a seal (Fig. 1C-24) is slid out from under the electrostatic sensor. To keep a tight seal during periods of incubation, weighted metal rings are placed on top of the plastic film. These rings allow leaves to be exposed to light during incubation. A saturated atmosphere within the moist chambers is maintained by placing moistened filter paper in the central well directly below the leaf (Fig. 1C). When a leaf is not being exposed to IR from below, a moistened disk of filter paper is placed on the bottom of the leaf chamber surrounding the central leaf holder. The central leaf holder (Fig. 1C-21) has perforated sides to allow air exchange.

Materials used in construction and their electrical grounding. Because many plastic materials are good dielectrics and can become highly charged under certain conditions, considerable care was taken in designing the apparatus so that errors would not be introduced by extraneous electrostatic fields not directly associated with the leaf being measured. This was achieved by using various grounded metal shields (Fig. 1A) and by avoiding the direct exposure of the electrostatic sensor to plastic. As a further precaution, a grounded brass plate 55 mm in diameter was placed 16 mm directly below the leaf (Fig. 1C-20) to serve as an uncharged background. During actual measurement of leaf surface fields, the grounded brass plate was disconnected, but it was reconnected both before and after measurement to bleed away possible induced charges.

OPERATING PROCEDURES

The apparatus is used to measure electrostatic fields associated with detached leaves under controlled conditions in which the air in the leaf chamber is either moving or still. A simplified version is used for measuring electrostatic fields of detached leaves under natural conditions.

Handling of leaves. Leaves must be handled with extreme care and if suitable precautions are not taken, erroneous measurements will result. To remove leaves from a plant, hands must be covered with clean rubber gloves. The leaf must be detached with electrically insulated scissors while an edge is held with insulated forceps. Insulated forceps can be purchased from many scientific suppliers, but satisfactory insulated scissors must be constructed from phenolic board, a nonconductive material commonly used in electrical projects. (Details on this mounting of the leaf were covered in the preceding section.) Time between detaching a leaf and measuring its surface electrostatic field strength is normally well under 30 sec.

Measurement of leaves in a controlled airstream. The leaf is mounted in the leaf chamber and air is introduced through one of the two entrance ports on the side of the housing (Fig. 1A-6). Humidity and exposure to IR can be varied while keeping air temperature and velocity of airflow constant. Under these conditions, leaf surface electrostatic field strengths can be monitored continuously by feeding signals into a millivolt recorder. Using the specified humidification system (2), atmospheric humidity can be changed rapidly (1–2 min) and precisely over any range between RH 100 and 20%.

Measurement of leaves in still air. In still air experiments under controlled conditions, the entrance and exit air ports to the leaf chamber housing are plugged with rubber stoppers and the top of the housing may or may not be sealed with a plastic film during incubation, depending on the type of experiment to be conducted. In a typical experiment involving saturated still air (5), leaf chambers are sealed as described previously, and replicated chambers with leaves are incubated under different conditions. After the treatments, the chambers are placed individually under the electrostatic sensor and the leaf's field intensity is measured. When experiments combine periods of static air with periods of moving air (5), this is easily achieved with the apparatus.

Measurement under natural conditions. When the apparatus is used for measuring intensity of electrostatic fields associated with leaves of plants grown under natural conditions, only the top portion of the apparatus is used, ie, only that portion above the bench (Fig. 1A). Leaves are removed and mounted following the precautions already described and immediately measured under the ambient conditions present at the time of measurement. All field measurements are accompanied by concurrent measurements of the relevant meteorological factors, with main emphasis on atmospheric humidity, air temperature, wind velocity, and lighting conditions. Electrical grounding during field studies is accomplished by connecting the apparatus to a 1.5-m copper rod driven about 1 m into the soil.

DISCUSSION

The apparatus and procedures described in this article have been used extensively in controlled studies (5) and under natural conditions (6). Use of the apparatus is limited to fairly large leaves because the sensing area of the Model 107 electrostatic sensor is 47 mm in diameter (Fig. 1D). A second disadvantage is that measurement of electrostatic field intensities is restricted to detached leaves. Results of leaf measurements under natural conditions (6) suggest that detached leaves, when properly handled, do reflect the natural electrical microclimate of leaf surfaces; my current challenge is to devise a procedure to measure undisturbed leaves attached to plants grown under natural conditions.

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