The influence of fair weather electricity on the charging of wind-dispersed pollen.

George E. Bowker1 and Hugh C. Crenshaw2

1Furman University, Department of Biology, Greenville, SC 29613 USA
2GlaxoSmithKline, Technology Development Department, RTP, NC 27709 USA

Abstract

Wind-pollinated plants reproduce by capturing pollen suspended in the air. Pollen grains are electrostatically charged and electric fields are present around plants due to the ambient fair weather electric field. A charged airborne particle in an electric field experiences an electrostatic force equal to the product of its charge and the electric field at its location. Consequently, electrostatic forces might affect pollen capture. This study determines the electrostatic charge of pollen from a common weed, the English Plantain or Plantago lanceolata, in the presence of the Earth’s fair weather electric field. Most pollen grains carry a charge when released from the plant (Average $2 \times 10^{-17}$ C, St. Dev $4.3 \times 10^{-16}$ C), with some negative and others positive. In the presence of the 100 V/m electric field, the plant developed a strong negative surface charge which was, in part, transferred to the pollen.

Pollen charge appears to be limited by the strength of the electric field at the pollen’s surface. When the electric field at the pollen’s surface exceeds the breakdown strength of air (3,000,000 V/m), the air ionizes and becomes conductive. The maximum charge depends on the pollen’s radius. No pollen grains were observed to exceed their predicted charge limit, with most pollen carrying less than one tenth of this charge.

Generally, pollen grains are electrostatically charged and may experience significant forces in the amplified electric fields around pointy plants in the Earth’s fair weather electric field.

Introduction

Electrostatic forces have the potential to influence the capture of wind-dispersed pollen, and thus, plant reproduction. Pollen grains, which contain a plant’s male reproductive gametes, are transported by the wind to the stigma, the plant’s pollen-capturing female reproductive structure, of a downwind plant. The vast majority of pollen grains land on non-fertile surfaces.

Typically, pollen release occurs during fair weather conditions. The 100 V/m fair weather electric field induces a strong negative surface charge on the top of the plant that increases in magnitude as the plant rises above its surroundings (Chalmers 1967). The plant’s charge will be concentrated on pointy plant features, such as a stigma which, for wind pollinated plants, is usually feathery or spiky in appearance. An electric field will be present around the plants, corresponding to the distribution of the plant’s charge. Consequently, if wind-dispersed pollen grains are charged, they will experience an electrostatic force as they encounter the electric fields around the plants. The force they experience will be equal to the product of their charge and the electric field at their location.

This study investigates four aspects of pollen charge: (1) What is the charge on wind-dispersed pollen after it is released from a plant; (2) How much of the plant’s negative charge, generated by the Earth’s fair weather electric field, is passed on to the pollen; (3) What is the expected discharge rate of the pollen; and (4) What is the maximum charge carried by pollen.

Materials and Methods

An experiment was conducted in the laboratory to measure the charge on pollen and to determine if the Earth’s fair weather electric field influences pollen charging. The charge on the pollen was extrapolated from measurements of the pollen’s settling velocity ($U_y$) and the velocity ($U_x$) produced by a known uniform electric field ($E$). Plantago lanceolata spikes (flowers, with stems attached) were placed 5 cm above a set of vertically oriented parallel plates (19.9 cm tall by 13.2 cm wide and separated by 1.89 cm using ceramic standoffs). The plants were electrically grounded and were tapped, releasing pollen from the anthers, the pollen producing flower structures.

When pollen entered the region between the plates, a horizontal “measuring” electric field of 63.4 kV/m was activated. The pollen’s velocity in the presence of the field, was videotaped under darkfield
conditions at 60 fields/s using a 4900 COHU video camera equipped with a macro lens. Images were analyzed using National Instruments Image Acquisition (NI-IMAQ) Version 2 and IMAQ Vision software.

For these pollen charge measurements, the pollen is assumed to be spherical (radius, \( a \)) with a density equal to that of water (1000 kg/m³) and moving at low Reynolds number. Consequently, the pollen’s velocity (\( U \)) is proportional to the gravitational and electrostatic force (\( F \)).

\[
F = 6\pi \mu U a .
\]

From the gravitational and settling velocities, the pollen’s charge (\( q \)) can be extrapolated

\[
quadrature \frac{6\pi \mu U}{2 \rho g} \rho_p \pi \mu^6 F ,
\]

where \( \rho_p \) is the pollen’s density, \( g \) is the acceleration of gravity, and \( \mu \) is the viscosity of air \((18 \times 10^{-6} \text{ kg/(m s)})\) in air (Vogel 1994).

To determine if the plant’s negative charge is transferred to its pollen, a 100 V/m electric field was imposed on several electrically grounded Plantago lanceolata plants located at three heights (0 m, 0.14 m, and 0.9 m) above the ground. The 100 V/m electric field was created by placing a second pair of aluminum plates (13 cm tall by 9.8 cm wide and 5.08 cm apart) above the “measuring” plates (fig. 3.1). The Plantago spike was placed perpendicular to the 100 V/m plates. The stem of the Plantago spike was electrically grounded and was inserted through an insulated hole in the lower voltage plate. To recreate the field at 0 m above the ground, one of the plates was held at ground potential and the other was placed at a potential of 5.05 volts. To recreate the field at 0.14 meters, one plate was placed at a potential of 14 volts and the other plate was held at a potential of 18 volts. Thus, there was a potential difference of 14 volts between the plant and the plates, giving the plant a strong negative charge. To simulate a plant at 0.95 m, the plates were placed at 95.4 and 99.4 volts respectively.

Assuming that the air is isotropic (the electrical properties are the same in all directions), the conductivity is independent of electric field strength, and the concentration of charge carriers is invariant, the discharge rate in air is dependent only on the conductivity and permittivity of air.

The discharge rate for a charged airborne pollen grain is governed by the flow of current leaving it

\[
I = \frac{dq}{dt} = \int_{\text{Surface}} j \cdot dS = \int_{\text{Surface}} \sigma E_{\text{pol}} \cdot dS = \sigma \int_{\text{Surface}} E_{\text{pol}} \cdot dS = \sigma \frac{q}{E_a} ,
\]

where \( I \) is the discharge current, \( j \) is the current density \((\text{A/m}^2)\), \( E_{\text{pol}} \) is the electric field at the surface of the pollen, \( \sigma \) is the conductivity of the air (assumed constant), and \( dS \) is an infinitesimal piece of surface area \((\text{S})\) on the pollen grain. The current equals the charge on the pollen \((q)\) multiplied by the ratio of the air’s conductivity \((\sigma, 1.8 \times 10^{14} \text{C/(m V s)})\) and permittivity \((\varepsilon_a, 8.854 \times 10^{-12} \text{farads/m})\) (Nolan 1940). Solving for the charge remaining on the pollen grain \((q)\) as a function of time \((t)\),

\[
\int \frac{dq}{q} = \int \frac{\sigma}{\varepsilon_a} dt \Rightarrow q = q_0 e^{\frac{(t-t_0)}{\varepsilon_a/\sigma}} ,
\]

where \( q_0 \) and \( t_0 \) represent the pollen’s initial charge and initial time, respectively. The pollen grain loses its charge exponentially, with a time constant \((\varepsilon_a/\sigma)\) of approximately 440 s.

If the electric field at the surface of the pollen grain exceeds the breakdown strength of air \((3 \times 10^6 \text{ V/m})\), the air surrounding the grain ionizes and the pollen grain discharges rapidly. Consequently, the surface electric field limits the maximum charge for the grain. Assuming the pollen grain is spherical, with uniformly distributed charge, the pollen’s surface electric field \((E_{\text{pol}})\) is

\[
E_{\text{pol}} = \frac{q}{4\pi \varepsilon_0 a} ,
\]

where \( a \) is the radius of the pollen. Solving for the pollen’s charge and replacing \( E_{\text{pol}} \) with the breakdown strength of air gives the maximum charge \((q_{\text{max}})\) for each pollen grain (Fig. 2).

\[
q_{\text{max}} = 12 \times 10^6 \pi \varepsilon_0 a^2 .
\]
The maximum charge is proportional to the square of the pollen’s radius.

**Results**

Pollen is electrostatically charged (average $2 \times 10^{-17}$ C, St. Dev. $4.3 \times 10^{-16}$ C). In the absence of the 100 V/m field (fig. 1A), the *Plantago* pollen grain charges were distributed almost uniformly about zero with the average pollen grain possessing a slight positive charge. When the measuring electric field was off, the pollen fell straight down (average $5 \times 10^{-17}$ C, St. Dev. of $1.5 \times 10^{-16}$ C). As the 100 V/m plates were charged to mimic increasing height above the ground, the negative tail of the *Plantago* pollen charge distributions became longer and thicker, suggesting that the plant’s negative charge was, in part, being transferred to the pollen (fig. 1).

Once suspended in the air, the pollen will discharge with a time constant of about 440 s. This time is roughly constant, depending on the conductivity and permittivity of the air. However, if the electric field at the pollen grain’s surface becomes too large, the air will ionize and the pollen will rapidly discharge. The maximum charge on the pollen prior to ionization depends on the radius of the pollen (fig. 2).

Maximum pollen charges found for several plant species are shown (fig. 2), none of which exceed the calculated limiting value.

**Discussion**

Pollen capture is essential for plant reproduction. Wind pollinated plants release clouds of pollen, which are transported by the wind, landing mostly on non-reproductive surfaces but sometimes on a plant stigma. The physical nature of the process is certainly reflected in both plant and pollen grain morphology. Aerodynamic and gravitational forces will influence capture, but electrostatic forces may also contribute. The electrostatic force on the pollen equals the product of the charge on the pollen and the electric field at the pollen’s location. The fair weather electric field will create a negative charge on the surface of plants. Thus, these plants will be surrounded by electric fields. The fields will be strongest near points, such as the edges of leaves and the tips of a feathery stigma.

Pollen grains are charged, some positive and some negative (fig. 1A). Consequently, they will experience a force as they approach the charged plant. Only the positively charged pollen will be attracted to the negatively charged plants.

During pollen release, some of the plant’s negative charge is transferred to the pollen (fig 1). However, the transfer of negative charge is limited. This is fortunate for both the plant and the pollen grains because the negatively charged pollen grains will be repelled and will not be captured. The plant at 0.95 m has about ten times the negative charge of the plant at 0.14 m, yet there is only a slight shift in the pollen charge distributions. Prior to release, the pollen is contained within the anthers. The plant’s negative charge will be on the outside of the anthers and not in direct contact with the pollen.

Airborne pollen will maintain a charge for a fairly long period of time. The time constant, or the time for the pollen to lose 63% of its charge is about 440 s. Thus, after a period of time, the negatively charged pollen grains will lose their charges and be captured. An upper limit appears to be imposed on the pollen grain’s charge. The electric field generated by this charge cannot exceed the breakdown strength of air (fig. 2). Generally, a higher radius of curvature corresponds to a larger surface electric field. Wind-dispersed pollen is usually smooth, round, and dry, lacking the spiky exine characteristic of most insect-dispersed pollen. It is possible that by being smooth, pollen grains are minimizing their surface electric fields, thereby increasing their maximum charges.

Atmospheric electricity has the potential to be important in pollination, affecting the morphology and reproductive success of both plants and pollen grains. The local electric fields around plants and the resulting forces on pollen grains remain largely undescribed.

**Acknowledgements**

This work was supported by a National Science Foundation predoctoral fellowship (GEB), an equipment grant from Keithley Electronics, and a Sigma Xi grant in aid of research. Thanks also to S. Vogel, G. Ybarra, and S.E. Law.

**References**


Figure 1: A frequency histogram showing number of pollen grains as a function of pollen grain charge (femto-Coulombs, fC) for Plantago lanceolata. The plant’s negative charge increases with plant height. A. 100 V/m field off.; B. field on, height 0 m; C. field on, height 0.14m; D. field on, height 0.95m. The distributions become more negative as plant height increases.

Figure 2: The maximum charge on a pollen grain ($q_{\text{max}}$) before the surface electric field exceeds the electric breakdown strength of air ($3 \times 10^6$ V/m) as a function of pollen grain radius. Maximum pollen charges for seven plant species: Juniperus virginiana (Juniper), Acer rubrum (Red maple), Ulmus alata (Winged elm), Plantago lanceolata (English plantain), Pinus taeda (Pine), and two species of Cedar, Cedrus atlantica and Cedrus deodara. Pollen charges were measured using the same technique used to measure Plantago pollen charge. In all cases, the maximum charge observed was less than the theoretical maximum.