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Research Article

APPLICATION OF ELECTROSTATICS IN ARTIFICIAL POLLINATION IN AGRICULTURE

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Abstract: Electrostatic forces have been successfully incorporated in many industrial fields while working with particulate materials, which need to be deposited on target uniformly and minimizing the off-target movement (drift) resulting in wastage of material. This basic concept has been already introduced in automobile paint industries, electrostatic spraying systems (ESS) and dust settlement solutions *etc.* Pollen grains are immobile, hence cannot reach the stigma by themselves. Therefore, an external agent is required for transfer these pollen grains onto the stigma, which can be wind, water, animal, gravity or growth contact. Many plants are wind pollinated, *e.g.* grasses, small grain crops, and conifers, whereas some species rely on animals, primarily insects, to carry pollen from flower to flower. The idea of using electrostatic charge in artificial pollination is significantly promising and has shown positive results to primary investigations done by many of the researchers in this field. The concept of electrostatic non-contact detachment and deposition of charged pollens in plant pollination ensures less physical damage to pollen; therefore, it has better potential to increase the fruit set and its quality. Moreover, the system may be reliable, economic and much convenient while dealing with pollination of larger orchards, which is a very tedious job while working with manual method.

Keywords: *Electrostatic spraying, Drift, Pollination, Artificial pollination*

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Introduction

Pollination is a factor of prime importance in achieving a satisfactory crop yield and inadequate pollination has been found to be one of the major causal phenomena for low yield in field as well as horticultural crops [1]. Pollination is a key part of plant reproductive system. Pollen grains are immobile, hence cannot reach the stigma by themselves. An external agent is required for transfer these pollen grains onto the stigma, which can be wind, water, animal, gravity or growth contact. Many plants are wind pollinated, *e.g.* grasses, small grain crops, and conifers, whereas some species rely on animals, primarily insects, to carry pollen from flower to flower. From the view point of precision agriculture and competitive market scenario across the globe, pollination has significant role in production of quality fruits, vegetables and seeds having desired characteristics [2]. Along with the general cultivation practices such as the soil nutrition, irrigation, pruning, pesticide and disease control, the value of the crop also depends substantially on the level of pollination. Insufficient pollination results into unsatisfactory fruit size, shape and uniformity, which represents a decreased marketable value [3]. Artificial pollination has the advantage over natural pollination in that the grower can choose the parent plants and decide whether to pollinate the plant with its own pollen, *i.e.*, self-pollination or with pollen of a different plant of the same species, *i.e.*, cross pollination or even with another species for hybridizing. Artificial pollination and subsequent breeding allow for a sustainable supply of healthier and more disease resistant plants for the gardener. Though artificial pollination requires skills and specialized equipment to collect pollen grains from anther, drying and deposit them onto the receptive stigma without mechanical damage [4]. Nectarless-flower plants are more susceptible to high rate of pollen loss due to insufficient pollinators and pollen thieves, *i.e.* visitors that remove pollen with little or no contribution to deposition on stigmas *e.g.* honey-bees. Such species need to be protected from pollen loss and to be pollinated by artificial means [5-7].

The electrostatic forces utilized by the honeybee in natural pollination have been investigated researchers and confirmed as a significant factor in pollen detachment which is being studied from last two decades. Experimental tests have been showed that the average charge on a bee after active flight through the air was 23.1 pC. The observed forces required for detachment of pollen were in the range of $4x10^{-10}$ to $39x10^{-10}$ N for selected horticultural species. Mathematical modeling showed that there were possible chances when the accumulated charge on a honeybee was sufficient for non-contact pollen detachment [8]. In nature, during fair weather conditions average vertical electric field was found to be 100 V m^{-1}, while ground surface carried negative charge and air possess equal and opposite positive charge. As the plants are grounded to earth carry negative charge, but this charge was found to be uneven on plant body, especially concentrated near tips and spiked portions. Application studies of electrostatic pollination technique have been carried out for wind pollinated crops like Date-palm and showed significant rise in fruit set due to increased deposition of charged pollens, while reported less amount of pollens required to pollinate sufficiently [9]. Pollination is the process of pollen detachment from the male part, anther of one flower, travel through a media and deposition onto the female part, pistil of flower and thereby enabling fertilization and reproduction. Most of the plants depend on pollination process for generating seeds and fruits. Pollen grains are immobile, hence cannot reach the stigma by themselves. Therefore, an external agent is required for transfer these pollen grains onto the stigma, which can be wind, water, animal, gravity or growth contact. Many plants are wind pollinated, *e.g.*, grasses, small grain crops, and conifers, whereas some species rely on animals, primarily insects, to carry pollen from flower to flower. It starts with blooming of plant while the flower may be male, female or a complete flower. At the time of blooming male reproductive part of the flower *i.e.*, anther releases the pollen grains, but the detachment of pollen from the anther requires an external agent and suitable media to travel from anther to receptive stigma *i.e.*,

female reproductive organ of plant. These agents and media may be physical phenomenon like wind, gravity or growth contact of plants and biological carriers like insects, birds or animals *etc.* Generally, most of the angiosperms are wind pollinated, while some others are partially wind and insect pollinated in nature. The crops like date-palms and coconut tree depend on wind as well as insects for their pollination.

Pollination phenomena can be resolved into two major groups as,

a. Self-pollination

b. Cross pollination

When the pollen grains deposit on the receptive stigma of same flower or the pollens of one flower deposit on receptive stigma of another flower of same plant known as self-pollination. On other hand, when pollens from flower of one plant deposit on stigmas of neighbouring plants of same species, called as cross pollination. While, hybridization is the process of pollination in which pollens of flower from one plant deposit on the stigmas of another plant of same family but different species.

Self-pollination keeps the characteristics of parent plant over the generations, but generation after generation offspring plants lose their disease resistance and product quality. While cross pollination gives an opportunity to improve disease resistance and plant vigour. Appropriate crop management and cross pollination can give better yield and quality. From the economic point of view pollination is one of the major influencing factors apart from the other cultivation practices like soil manipulation, nutrients, disease and pest control, irrigation *etc.* As pollination is the key factor in reproduction system of the plant, it has direct impact on crop yield, quality of produce in terms of bio-morphological characters and sensory evaluation which in turn influences the product market value.

Artificial Pollination

At present, keeping in mind the world scenario of crop production and population expansion in relation with the land under cultivation which remains the same; rather it decreases day by day. Crop productivity has to be optimized from all possible points of view to meet the future food demand. Here the concept of precision agriculture arises which states that optimum utilization of available resources to achieve maximum possible yield from the same land area and desirable quality, without jeopardizing environment. If the pollination process has been disturbed by any reason such as climatic factors or insufficient pollinators during period of bloom, may directly results in lower yield, undesirable bio-morphological changes and quality loss, leading mass economic drop. To overcome this situation artificial pollination techniques have been developed and being used from past many years.

Hand Pollination Method

Artificial pollination including manual detachment of pollen grains from anther, collection and storage and at the time of female blooming depositing them onto receptive stigma by hand or using suitable medium for dispersal of the pollen grains. This method is also known as Hand pollination and the degree of pollination depends upon viability of pollens and their deposition level on targeted plant organ. Hand pollination method is useful only on small scale such as small green house, garden *etc.* which has limited number of small plants. Also, as this method uses human interaction with delicate parts of flower, may incur damage to pollens and other flower parts. A trained and skilled person can only carry out this work, as it needs much care and precision to pollinate successfully.

In order to achieve sufficient level of pollen deposition on targeted plants, hand pollination is not enough adequate as it can be applicable for small and delicate greenhouse plants. In order to cover large orchard area, it is necessary to have a medium to carry pollens over a large area and height of the tall plants. For this prevailing wind or artificial air blast have been practiced over a long period of time.

Mechanical Pollination

For pollinating tall orchard trees mechanical devices have been developed which enable pollination of the plants having height more than 2.5 m, which is generally considered as out of vertical reach of normal human being. Artificial pollination done with the help of such mechanical devices is known as Mechanical pollination. These devices are generally made of long telescopic light metal or plastic tubing to reach the target as well as to reduce the handling load on the operator. This type of mechanical pollination device has been developed for artificial pollination of Date-palms [3]. The mentioned mechanical equipment has telescopic lance consisting of Aluminium tube and the plastic delivery tube tied to it, where dried pollen bottle is situated at the bottom end with appropriate pumping type hand blower device. In working condition, the operator has to adjust the stretch of telescopic lance according to the height of the palm tree at which target is situated. Once the lance has been set near to the target, dried pollens are pumped from bottle by creating air pressure which tend pollens to disperse from bottle to the target via plastic tubing. The assembly has one more metallic attachment to the top of lance having sharp hook shape used to slit open the female spathe during early stage of bloom. It helps to create more exposed area of female spathe to deposit the pollens.

However, the developed mechanical tool incurs more drudgery to the operator while adjusting and holding the lance vertically and seems to be a tedious job while working with Date-palm orchards spread over tens of hectares. Also, it becomes very difficult to handle the lance in stable position when height goes beyond 3-4 m due to inertia forces and prevailing wind too. Therefore, the trees with height beyond 5 m are extremely difficult to work with and this shows the need of further more sophisticated and effective method to deliver pollens to the target height. Since, the existing methods are quiet drudgerious, require large quantity of pollens for achieving sufficient level of deposition and have been proved to be time consuming methods. Also, the wastage of pollens becomes uneconomical for bigger orchards. To minimize the pollen requirement and optimum deposition over the targets an alternative technique has to be adopted.

Electrostatics in artificial pollination

Electrostatic forces have been successfully incorporated in many industrial fields while working with particulate materials, which need to be deposited on target uniformly and minimizing the off-target movement (drift) resulting in wastage of material. Electrostatically charged particles have tendency to get attracted towards the oppositely charged object. This basic concept has been already introduced in automobile paint industries, Electrostatic Pesticide sprayers (ESS) and dust settlement solutions *etc.* Pollen grains are very sensitive part of flower, in hand or manual pollination there is chance of physical damage to the pollen grains while detaching pollens from anther by hand or any mechanical tool. This early stage damage can result into failure or inferior germination in future and degrade the quality of product. The idea of using electrostatic charge in artificial pollination is significantly promising and has shown positive results to primary investigations done by many of the researchers in this field. The concept of electrostatic non-contact detachment and deposition of charged pollens in plant pollination ensures less physical damage to pollen; therefore, it has better potential to increase the fruit set and its quality. Moreover, the system may be reliable, economic and much convenient while dealing with pollination of larger orchards, which is a very tedious job while working with manual method.

Materials and Methods

Electrostatics is the branch of engineering science which deals with the study and applications of static electricity. Furthermore, Electrostatics is the surface phenomenon governing electric charges accumulated on object body. It deals with the force which a point charge exerts on another point charge. By a point charge it means a charge that is located on a body whose dimensions are much smaller than other relevant dimensions. Charges are generally measured in coulombs (C). One coulomb is approximately equivalent to 6.24×10^{18} electrons; it is a very large unit of charge because one electron charge $e = -1.6019 \times 10^{-19}$ C.

Coulomb's Law

Coulomb's law states that the force (F) between two points charges Q_1 and Q_2 acts along the line joining them and directly proportional to the product of charges and inversely proportional to the square of distance (R) between them. It can be expressed mathematically as,

$F \alpha Q_1.Q_2 / R^2$ [Eq-1]

$F=K.Q_1.Q_2 / R^2$ [Eq-2]

Where, K is the proportionality constant. In SI units, charges Q_1 and Q_2 are in coulombs (C), the distance R is in metre (m), the force F is in newton (N) and $K=1/4\pi\varepsilon_o$. The constant ε_o is known as the permittivity of free space (in farads per meter) and has the value,

$\varepsilon_o = 8.854 \times 10^{-12}\ F/m = 10^{-9}/36\pi\ F/m$ [Eq-3]

Therefore,

$K=1/4\pi\varepsilon_o = 9 \times 10^9\ m/F \text{ or } N.m^2 / C^2$ [Eq-4]

It is possible to superimpose these electrons on any object, *e.g.* electrically neutral solid metal ball. The metals are known for their electrical conductivity, means electrons can more or less freely move within a material. In further deep sense, these electrons will blend in with the equally free moving valence electrons of the surface metal atoms. The reason for their equal distribution is an interaction between charged particles which is also known as Coulomb's interaction. Particles charged with the same polarity repel each other, while the particles with opposite polarity will attract each other. Thus, the electrons present on the metal ball will repel each other and spread evenly on the entire surface, without moving inside the metal ball. The theory of electrostatics is applicable for both conducting as well as non-conducting material like plastic. As being an agricultural object and part of plant body, pollen grain must have some content of water within it.

Polar nature of water molecule

Water is one of the stable compounds found in nature but contradicting from this phenomenon, water has a polar molecular structure which has one oxygen atom at one side and two hydrogen atoms on opposite side. Water molecule has a large value of electric dipole moment due to its polar structure and hydrogen covalent bonds. The electron-pair forming covalent bond gets attracted towards the oxygen atom and as a result oxygen side gets slight negative pole and hydrogen side slight positive pole which induces electric dipole moment within the water molecule. On the basis of electro-chemistry of polar molecules, fine water droplets can be charged electrostatically and therefore possibly pollen grains also.

Honey-bee and hummingbird charge

Researchers have been studied role of electrostatic forces in natural pollination by honeybee. This has revealed the concept of non-contact detachment of pollens from anther may have the influence of electrostatic forces accumulated on the body of honeybee hovering over the flower. Involvement of such force have been reported and confirmed by many researchers and can be applied for artificial pollination [10,11]. This concept can be applied for both cases, *i.e.*, for non-contact detachment of pollens from anther as well as deposition of pollens on the targets more effectively. The non-contact detachment method using electrostatic force may reduce physical damage to the pollens and flower, enabling safe and healthy pollination which ensures higher yield, better quality and expected market price. It is essential to study further more regarding the force required for safe non-contact detachment of pollens from anther, which is the significant factor for designing such equipment. This required force may vary from plant to plant with respect to their family and species.

Electrostatic charges on plants

As discussed earlier the plants grounded to the earth shall be at zero potential, though in nature due to the metabolic process of living plant body induces slight negative charge on the plant. But this charge has been found to be distributed asymmetrically on plant surface, concentrated near the sharp protruding body parts such as leaf tips, spikes and especially floral parts such as receptive stigma which is female reproductive part of flower. It has been observed that free falling pollens get attracted or slightly drifted towards receptive stigma, which confirms the electrostatic interaction between pollens and female part of flower.

Design of electrostatic charging device

The device can be designed for both electrostatic non-contact detachment as well as electro-deposition of pollens by gathering the information regarding major parameters.

Electrostatic non-contact pollen detachment device

The design electrostatic force generated by the device should have force value just little above the detachment force required for the particular plant species to ensure safe removal and minimum physical damage to the pollen grains and stamen. Measurement of required detachment force can be done by the protruding High Voltage Direct Current (HVDC) electrode which may be able to exert detaching force on the anther by carrying opposite charge in a predetermined electrical field. The electrical field intensity can be increased by increasing voltage potential or by reducing distance between electrode and grounded anther, vice versa. By knowing the detachment force value one can develop electric field near anther by suitable equipment to exert predetermined electrostatic force which may detach the pollen successfully without actual contact. If the electrical field intensity (E) and radius of pollen grain (R_p) are known, then charge induced (Q_p) on a pollen grain can be calculated as,

$Q_p=1.65(4\pi\varepsilon_o R^2_p E)$ [Eq-5]

Therefore, the force (Fp) experienced by the pollen gain can be calculated by using the formula given below,

$F_p = E \times Q_p$ [Eq-6]

Electrostatic charging of pollen grain and deposition

The device which may charge the pollen grains can be a spray nozzle or a simple orifice made up of suitable material. There are certain methods to charge the particulate matter.

Contact charging

The contact charging involves the direct conductive contact of the material to be charged and high potential voltage, in which charge transfer is done by conduction. Since, it requires a high voltage source, conductive nozzle and media (usually liquid) to transfer the charge. The high voltage terminal is connected to the nozzle through which material flows out and other one is grounded to earth. As soon as the material starts to flow through the charged nozzle, conductive charge transfer takes place from nozzle to the material. But due to direct contact between charged nozzle and material, there is a sudden voltage drop in the charging system which interrupts the charge transfer process and cause uneven charging of particles. Also, there may be chance of corrosion problem while using high voltage conductive metal nozzle in contact with liquid media.

Charging by corona field

Electrostatic charging of concerned material particulates by means of electrically ionized field is done by passing them through a high conductive thin medium such as ionized locally air gap between the high potential electrodes. Since any medium ionized by means of high voltage application becomes chemically reactive, utilization of corona method for imposing electrical charges on biological materials becomes objectionable.

Electrostatic charge induction by electrohydrodynamic process

The electrical shear stress elongates the liquid meniscus formed at the outlet of a capillary, to the form of a cone or a jet which next deforms and disrupts into droplets because of the electrical and mechanical forces. The droplets generated by the EHD method possess electrical charge, usually a few orders of magnitude greater than the elementary charge that dramatically changes their EHD properties.

Electrostatic Induction charging

The term 'induction' refers to influence any object without contact. In terms of electrostatic induction, a charged body which when placed in an electric field near another uncharged or electrically neutral object will induce equal charge with opposite polarity on that object. The requirement of centrally located electrode inside the spray nozzle as in case of contact charging can be eliminated by induction charging method, as induction electrode can be located around the spray nozzle where atomization takes place. Since, there is no any conductive contact between spray nozzle and high voltage direct current (HVDC) electrode; there is no electric hazard to the operator.

Among all the discussed methods for electrostatic charging of particulate matter or finely atomized spray, the electrostatic induction charging method seems to be best suited for the conductive agricultural sprays like pesticide application and pollen grains for electrostatic pollination. The charging method is of non-contact and chemically non-interfering type, hence can be used for both detachment and deposition of pollen grains; as the electrostatically charged particles have shown higher deposition levels and lesser off-target movement.

Neutralization Process and Dispersal Time

The neutralization process by which airborne particles lose their charge and reach the electrostatic equilibrium with air takes significant interval of time, as the air has low electrical conductivity. The average time for an object to lose 63% of its charge was experimentally measured to be approximately 440 seconds [12, 13]. Dispersal time which is generally very short as compared to neutralization time, is the time required by pollen to fall through air to the ground, depending upon the settling velocity of pollen and plant height. It is now clear, if the pollen grains are charged at the time of release, they may carry substantial amount of charge throughout their dispersal if the dispersal time is short relative to the neutralization time. Therefore, concept of electrostatically charged pollen deposition can be effectively utilized in artificial pollination with suitable carrying media.

Electrostatic Pollinators at present

Today, the electrostatic pollination method is in routine use for Date-palms in Arab countries, for Larch in forestry and Pistachio pollination *etc.*

Autonomous Date-palm Pollinator

The pollinator works on blower mechanism with nozzles and charging electrodes connected HVDC power supply ranging 20-40 kV. It is equipped with an autonomous blow direction system which controls the spray and changes the rotating blower head direction with respect to plant position marked by sensors. This system facilitates faster working and lesser pollination material and less labor requirement too. The pollinator can be installed on tractor as well as utility vehicle.

Electrostatic Duster for Larch

The pollinator is carried by a four-wheel drive tractor and composed of three main components: 1. Front pollination tank designed to encompass the tree, 2. Electrostatic dusting device and 3. power unit. The electrostatic dusting device composed of three components: i) a control module in the tractor cab, which regulated the voltage and which also adjusted pressure and flow rates of the air stream that blew the pollen; ii) a pollen conveyer, fixed to the tank, which delivered pollen to the gun; iii) an electrostatic gun (Ransburg-Gema, model AP 761) fastened on the top of the tank and driven by a rotating arm. At each rotation (20 s duration), it blows 1.25 g of pollen in a dry air flow (1 bar pressure). An integrated cascade power supply maintained the high voltage, adjustable from15 to 80 kV. A nozzle situated at the tip of the gun contained four electrodes which electrostatically charged pollen grains.

Electrostatic Pollinating Pistol for Larch

The selected pollen is applied using a portable electrostatic pistol (Gema Voltstatic model 11024, ITW Gema, Indianapolis, USA) adapted from the model developed by Philippe and Baldet (1997) [14]. The pistol and its accompanying equipment are attached to a cart designed by the Direction de la recherche forestière to make easy rapid moves within the tunnel.

Discussion

The idea of using electrostatic charge in artificial pollination is significantly promising and has shown positive results to primary investigations done by many of the researchers in this field. The concept of electrostatic non-contact detachment and deposition of charged pollens in plant pollination ensures less physical damage to pollen; therefore, it has better potential to increase the fruit set and its quality. Moreover, the system may be reliable and much convenient while dealing with pollination of larger orchards, which is a very tedious job while working with manual method. Regarding economic basis the system working on the discussed concept will require very less amount of pollens as compared to other present methods as well as expected to be a time saving method.

Conclusion

The previous studies in this regard have shown excellent outputs of introducing electrostatic charge in pollination and conclusive on following points.

Compared to conventional pollen blowing, electrostatic dusting has shown three times more pollen deposition on the flowers.

Depending on the amount of pollen used, applying an electrostatic charge to the pollen could raise fruit set by an average of 85% to 175%.

Electrostatic pollination could double the full seed percentage without reduction in viability.

The same or higher yield can be obtained by using pollen almost less than 50% compared to manual method when working with electrostatic pollen deposition.

Application of research: Artificial pollination of agricultural crops applying electrostatic charges, to increase the target deposition and uniformity of distribution.

Research Category: Artificial pollination, electrostatic particle charging

Abbreviations:

HVDC – High Voltage Direct Current
kV – kilovolt
C – coulomb
E – electrical intensity
pF – picofarad

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