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REVIEW ARTICLE

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Effect of Low Electrostatic Field on the Growth of Sprout Length during Germination of Gram and Pea Seeds

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ABSTRACT

Low electrostatic fields of magnitudes 18.75, 37.50, 56.25 and 75 (all in volt/meter or V/m) are applied during the growth of sprout length after germination and during post-germination of gram and pea seeds in open-air condition. The sprout length decreases with increase in electrostatic field and graphs show non-linear variations. Thus, this field has negative effect on the germination of seeds. This may have an impact in the process of preservation of seeds. The decrease in the growth of sprout length may be due to lesser diffusion through the cell wall or due to weakening of the activity of the other cell components leading to slower rate of cell division.

Keywords: Electrostatic Field, Electrostatic Potential or Voltage, Seed, Germination, Sprout, Pollution and Hazard.

INTRODUCTION

Electrostatic field produces charged particles in air and the movement of these charged particles cause radiation hazard. However, the present civilization is almost helpless without electricity and pollution hazards on plants and animals due to electrostatic field and potential or voltage is a common phenomenon. In this bio-material age, lots of data and information due to hazards of electrostatic field are pouring in. Applications of low dose electrostatic field are used in different disciplines and it is successfully applied in food processing and medical sciences. Here physical understanding of the variation of growth of sprout length of two leguninosae family members (subfamily: papilionaceae), viz. gram (*Cicer arietinum*) and pea (*Pisum sativum*) seeds with different applied low electrostatic fields will be dealt with. Germination commences when the quiescent dry seed begins to take up water (inhibition) and is completed when the embryonic axis elongates. The visible sign of completion of germination is the penetration by the radical of structures surrounding the embryo (inhibition pressure causes the testa to rapture). Mobilization of storage reserves to support seedling growth is a post germination event.

Thus, it is a combination of different topics of variety of subjects and we have to illustrate them in brief. In the next section a brief review on this line will be given after which there will be radiation hazard section, pollution section, electrostatic field and potential section, plant growth section and germination of seed section. The experiments with gram and pea seeds will appear after these sections.

BRIEF REVIEW

Recently Ahuja and Bhargava [Ahuja and Bhargava, 2001] informed about the health hazards due to electro pollution. They pointed out that dependence on electricity had increased day by day and they asked the question 'Is excessive exposure to emf harmful to our health?' They reviewed many papers to answer this question, specifically Lai and Singh [Lai and Singh, 1997], and concluded the oxidative damage to DNA and its subsequent disrepair. Kaiser [1998] observed that emf is a potential carcinogen. Rahman et al [1991] studied the seed growth, the sex, the expression and the yield treated with electric current. Pozhelene [1989] first tried with a seed-cleaning machine and transported rapeseed seeds on a conveyor belt through electrostatic field of 1.5, 1.8, 2.1, 2.4 and 3.0 kV/cm. He [Pozhelene, 1994] also summarized the electro physical methods of seed processing to improve germination. Lynikiene and Pozhelene [1998] studied the mechanical and electrical properties of seeds in a seed separation conveyor. Maximum germination of stimulated seeds was reached only after a resting period of 15 days for cruciferous crops (cabbage, turnip, radish and rape) and 20 days for grass, cereal and flax. Pozhelene [2000] described utilization of corona discharge field treatment in seed processing technology. High alternating electric field treatment on barley seed increases germination of seed [Pozhelene et al., 2003]. The treatment of cottonseed in electrostatic fields of 100, 200, 300, 400 and 500 kV/m for 30-second irradiation with laser rays of 632.8 nm at 5, 10, 25 or 50 mW for 10 s increases the fiber strength and germination of the resulting seeds [Nazarov and Fatoev, 1991]. dc electrostatic field and ac electric field of 60 Hz with strength ranging from 18 to 105 kV/m shortened the mean days to complete germination in lettuce cv. Sunny, Chinese cabbage cv. Tsumamina and radish cultivars Tokinashi and Kaiware seeds [Zhang et al., 1997], [Zhang et al., 2000]. Poa pratensis cv. Nasu and Filkin seeds were treated with electrostatic field (1, 2, 3, 4 and 5 kV/cm) of 60 mA/cm^2 [Qing et al., 1997] at 25^{o}C [Chen et al., 1999]. Isobe et al [1999] studied the effect of electrostatic field treatment (500 kV/m for 60 min) on physical states of cells associated with water in germinating morning glory seeds while Cheng et al [2000] studied the effect of high voltage electrostatic field on lipid pre-oxidation of aged cucumber seed. Weak tomato seeds were bio stimulated by electrostatic field (5 and 10 kV/cm) [Pietruszewski, 2002]. Pietruszewski and Kornarzynski [2002] also did the effects of presowing alternating electric field on the germination of tomato cv. Halicz. Pietruszewski et al [2003] used both analytical mathematical model and simulation model to study the effects of presowing alternating electric and magnetic field (50 Hz) on the germination of buckwheat seed. Effects of electrostatic and magnetic fields were discussed [Achremowicz et al., 2002]. Radiofrequency (39 MHz) heating of alfalfa seed with different electric field intensities show not much reduction of germination of seed [nelson et al., 2002]. Chakravartty and Sadhu [2003] showed stimulation and species dependence of low electrostatic field of strength 0, 3, 8, 10, 12, 15, 20 and 25 V/m on germination of seed and seedling growth of okra, radish and jute. Treatment with high electrostatic field shows higher germination percentage [Sheng, et al., 2004] and growth energy [Shmigel, 2004]. Avdeev et al [2005] discussed the effect of dielectric permeability of seeds on the electrostatic field. Yong et al [2005] showed improvement in the seed vigor and the germination energy of Chinese cabbage and cucumber seeds on high voltage electrostatic fields. However, there exist no clear opinion concerning the impact of the high electric field on germination and plant growth. Dymek et al [2012] reported the effect of pulsed electric fields of varying voltages (110, 160, 240, 320, 400 and 480 V) on radical emergence without affecting the gross metabolic activity of barley seeds. Mahajan and Pandey [2014] exposed chickpea (*Cicer arietinum*) seeds to electric field from zero to 1300 V for 15 min at three different temperatures (13°, 16° and 19°C) and the exposure of chickpea seeds to the electric field caused a change in water uptake capacity (and its coefficient) as compared to control. The sprout length of ground nut seeds in open-air condition changes with low electrostatic field and graphs show non-linear variations within temperature variation 14°C to 25°C [Ghorai et al., 2014]. Sidaway [1966] reviewed earliest investigations along this direction.

RADIATION HAZARD

The word radiation hazard [Wikipedia] is the most uncomfortably complicated issue in our complicated high tech modern world. This is due to ignorance, misunderstanding of what radiation hazard does, and how it can be harmful. Radiation means the process of emission of energy in the form of wave or particle outwardly. Dictionary meaning of hazard is risk, danger, or obstacle and so it is the sudden and unexpected natural or manmade phenomenon or event leading to loss of life and property. Radiation hazard describes the hazards of electromagnetic radiation (gamma rays, X rays, ultraviolet rays, visible range, infrared rays, microwave, etc.), neutrons, alpha particles, beta rays, gamma rays, neutrinos, beams of high-energy protons, electrons, positrons, pions, muons etc., produced by accelerators, catastrophically destructive cosmic rays (from which we are shielded by our atmosphere, except when we fly across country in an airliner) and so on ad infinitum, to fuels, electronic hardware, ordnance, and personnel. Simple example of radiation is light and heat from the sun. All these are constant companions in our environment due to natural or man-made radioisotopes. Everyone is constantly exposed to most of these types of radiation.

The basic unit of radiation dose used to be the ‘rad’, defined in terms of the energy deposited by ionizing radiation per unit mass of exposed matter (e.g. flesh or bone)1 rad = 100 erg/gram. Early work on radiation hazards was based on X ray exposure and the units used were rad. More recently, it has been officially supplemented by SI unit ‘gray’ in honor of British physicist and radiation biologist Louis Harold Gray, 1 gray = 100 rad = 1 Joule/kilogram. Later it was found that different types of radiation were found to be more or less destructive than X rays for different types of tissues. So an empirical Relative Biological Effectiveness (RBE) was invented to account for these differences. A new unit was then constructed by combining the RBE with the dosage in rads, namely the rem, defined by rem (R) = RBE×rad. Today the standard international unit for measuring "effective dosage" is the seivert, named after Rolf Sievert, a pioneering Swedish radiation physicist. Converting between rem and seivert is just like converting between rad and gray1 seivert = 100 rem (R).

All of these units are meaningless until one has some idea of how bad one of them is for us. (i) Instant Death: 5000 R or 50 Grays, i.e. half a million ergs of energy deposited in every gram of our body wipe out our central nervous system immediately when delivered all at once. Thus, it is a monumental radiation dose to kill outright. (ii) Overnight Death: Approximately 900 R or 9 Grays to the whole body will accomplish the same thing as 50 Grays but it takes about a day. (iii) Ugly Death: A somewhat lower dose, around 500 R or 5 Grays causes severe radiation sickness (i.e. nausea, hair loss, skin lesions, etc.) as the body's short-lived cells fail to provide new generations to replace their normal mortality. If we survive the initial radiation sickness and avoid infection, we shall probably recover completely in the short term; but we are very likely to develop cancer in later years (usually some 10-20 years later!) and our offspring, if any, will have a high probability of genetic mutations. (iv) Sub-Acute Exposures: From a whole-body dose of around 100 R (1 Gray) delivered in less than about a week; we are unlikely to notice any immediate severe symptoms. However, we are likely to develop leukemia in 10-30 years, and there is a significant chance of genetic mutations in our offspring. In fact, the overwhelming majority of all radiation induced cancer fatalities on the Earth can be attributed directly to far ultraviolet from our favorite nuclear fusion power plant in the sky: the Sun. (v) Marginal Exposures: The average exposure from natural sources of radiation is on the order of 300 mR per year.

These forms of radiation are certainly beneficial as long as they do not get out of control. For example, visible light in the form of a high power laser can inflict damage, as can excessive heat or even microwave radiation. We cannot maintain health without both heat and light, and a certain amount of near UV may be required for natural vitamin D production in the skin. All electromagnetic radiation from ultraviolet towards gamma rays is exclusively and unambiguously bad for the individual because they cause ionization of atoms and molecules inside cells, leaving behind a variety of free radicals, which are types of molecules that quickly react chemically with other nearby molecules. When these free radicals react with the DNA molecules in which are encoded all the instructions to our cells for how to act and how to reproduce, some of these instructions can be scrambled. The simplest detectable damage to a DNA molecule is a single-strand break in which one of the strands of the double helix is broken by a chemical reaction with a radical, which is repaired in a few hours. If, however, the DNA molecule with a single-strand break is subjected to further damage before it has a chance to heal itself then it may sustain a double-strand break (two breaks in the same strand), which seems to be far less able to repair. Their reparable damage usually takes place only after a large fraction of DNA molecules have already sustained temporary damage - and that the temporary damage is mostly repaired in a short time. The cell containing the defective DNA may be unable to reproduce itself, so that although it may be able to function normally for its remaining natural lifetime, when it dies a natural death it will not have a new cell to replace it. If the cell in question happens to be a gamete destined for fusion with a member of the opposite sex, the resulting individual will have some scrambled instructions in the construction manual and will probably not grow up normally. In almost every case, this will be fatal to the foetus and in almost all the remaining cases it will be detrimental to the survival of the individual, although such mutations have presumably played a role in evolution to date.

POLLUTION

The word pollution [Wikipedia] and its remedy are very much familiar to us. From the primitive age till date there are several examples of pollution on environment due to natural disasters (viz. flood, cyclone, hurricane, typhoon, tornado/twister, earthquake, tsunami, land slide, drought, forest fire, volcanic eruption, etc.) and due to artificial or man-made disasters (viz. bus, train, plane accident, nuclear and industrial accident, war, global warming, nuclear experiments under sea, oil spill over sea, biological disaster, terrorist attack, etc.) and these change the pattern of human life or more specifically civilization.

Pollution produces hazards to the biotic components of the biosphere. A simple example of hazards is the lightning and thunder-stroke on a tall palm or coconut tree or the movement of money plant on the electric pole. Pollution means the presence of harmful substances in air, water and land that can cause harm or discomfort to the biotic component of biosphere. Biosphere is the intersection of lithosphere (solid part of the earth or earth’s crust), hydrosphere (liquid part of the earth or water bodies) and atmosphere (gaseous part of the earth or air). Thus, biosphere is the natural world where we live and its behavior is the environment. The components of this biosphere are biotic component (living component, all the organisms, plants and animals), abiotic component (non-living component, natural resources, sunlight, air, water, soil, temperature, rainfall, wind, salinity) and environment. The harmful and undesirable constituents in environment are pollutants and there are several types of pollutions, viz. soil pollution, water pollution, air pollution, noise pollution and industrial pollution. Pesticides, dumping waste, fertilizers, irrigation with salty water, and salt accumulation in arid and semiarid regions pollute soil. Sediments, organic and inorganic compounds, and waste, infectious organisms, radioactive substances, and thermal pollutions are the main sources in case of water pollution. Suspended fine particles, oxide gases of carbon, nitrogen and sulfur are the pollutants in this case of air pollution. Noise pollution is observed due to special events using loud speakers, transport, industry, and construction. Noise is the unwanted sound, which depends on loudness and pitch. Sound energy flowing per unit area per unit time is the sound intensity or loudness and it is measured in a nonlinear logarithmic scale called decibel (db). Pitch depends on frequency or number of oscillation per second (Hz). The unit for modified decibel scale taking loudness and pitch is dbA. Threshold hearing is 0 dbA while normal hearing takes place at 60 dbA. At 80 – 90 dbA for 8 hours, a day will produce hearing loss. The limit of painful noise is 140 dbA and death happens at 180 dbA. Plastic, soaps, detergents, paints, chlorofluro carbon (CFC), pesticides are the sources of pollutants in case of industrial pollution.

ELECTROSTATIC FIELD AND POTENTIAL

There are two kinds of charges viz. positive and negative with unit of charge in SI system is Coulomb. Electrically neutral atoms consist of positive nucleus and rotating electrons. Any charge smaller in magnitude than that on an electron has not been detected so far. *The magnitude of all other charges is found to be integral multiple of the charge on the electron and thus charges are quantized* or charges exist in discrete packet rather than in continuous amount. Quantization of charge is a universal law of nature [David, 2009].

Electrostatic field is a vector quantity. It is created due to an electric charge in a medium or in vacuum. According to Coulomb's law in electrostatics force between two electric charges q_1 and q_2 separated by a distance vector $\vec{r}$ in a medium with permittivity ε is given by $\vec{F} = \frac{q_1 q_2 \vec{r}}{4\pi\varepsilon r^3}$ with $\varepsilon = \varepsilon_0 \varepsilon_r$.

Here the permittivity of the free space (also known as fundamental conversion factor) in SI units is $\varepsilon_0 = 8.854 \times 10^{-12} Fm^{-1}$. ε_r is the relative permittivity or dielectric constant of the medium within which the charges are situated? In vacuum or free space we have $\varepsilon_r = 1$ and for other media $\varepsilon_r > 1$. Electrostatic field at a point in space is thus defined as the force on a unit positive test charge placed at that point. We must assume that the test charge to be small so that it will not influence the behavior of the field.

Thus

$$\vec{E} = Lt_{\Delta q \to 0} \vec{F} / \Delta q \qquad (1)$$

This definition suits only macroscopic phenomena because microscopically $\Delta q \to 0$ contradicts quantization of charge. Thus in free space electrostatic field will be $\vec{E} = \frac{q\vec{r}}{4\pi\varepsilon_0 r^3}$ and $\vec{\nabla} \times \vec{E} = \frac{q}{4\pi\varepsilon_0} \vec{\nabla} \times (\frac{\vec{r}}{r^3}) = 0$ where $\vec{\nabla}$ is a differential vector operator. This implies electrostatic field is conservative in nature.

Electrostatic potential at a point may be defined as the work done by an external agency in bringing a unit positive test charge from infinity to that point. Since electrostatic field is conservative, it can be derived from a scalar function.

Thus

$$V(r) = \int_{\infty}^{r} \vec{E} \cdot d\vec{r} = \frac{q}{4\pi\varepsilon_0\varepsilon_r} \int_{\infty}^{r} \frac{dr}{r^2} = -\frac{q}{4\pi\varepsilon_0\varepsilon_r r} \quad - (2)$$

Clearly $$\vec{E} = \frac{q\vec{r}}{4\pi\varepsilon_0\varepsilon_r r^3} = -\vec{\nabla}V(r) \quad - (3)$$

Practically electrostatic field is measured is volt/meter and electrostatic potential or electric voltage is measured by a voltmeter in volts (V). We shall use the term electric voltage or simply voltage throughout here in place of electrostatic potential.

PLANT GROWTH

The origin of seed plants is a problem that remains unsolved. However, more and more data tends to place this origin in the middle Devonian. The earliest fossil seeds are around 365 million years old from the Late Devonian of West Virginia. Plant growth is unique because plants have capacity for unlimited growth throughout their life. It is most conspicuous characteristics, irreversible, permanent increase in size of an organ or its parts or even of an individual cell. The ability of growth is due to the presence of meristems at certain locations in their body [Buchanan et al., 2000], [Taiz and Zeiger, 2006]. Root apical meristem and shoot apical meristem are responsible for the primary growth of the plant and principally contribute to the elongation of plants. Period of growth is divided into three phases: meristematic, elongation and maturation. The constantly dividing cells both at the root apex and shoot apex represent meristematic phase of growth. The increased growth rate per unit time is termed as growth rate (r). The initial growth rate is slow and called lag phase (LP). It increases rapidly thereafter and called exponential growth phase (EP). Here both the progeny cells following mitotic cell division retain the ability to divide and continue to do so. However, due to limited nutrient supply the growth slows down leading to a stationary phase (SP). Thus, there are three phases LP, EP and SP. We shall get a sigmoid or S curve and if g and g_0 be the final and initial size respectively and t be the time then mathematically

$$g = g_0 e^{rt} \quad - (4)$$

The essential elements for growth are water, oxygen and nutrients. In addition optimum temperature range is best suited for its growth.

GERMINATION OF SEEDS

We shall first explain in brief about seed and its function. A seed [Buchanan et al., 2000], [Taiz and Zeiger 2006] is a small embryonic plant or an embryo with two points of growth (one of which forms the stems the other the roots) enclosed in a covering called the seed coat, usually with some stored food reserves. It is the product of the ripened ovule of gymnosperm and angiosperm plants, which occurs after fertilization and some growth within the mother plant. The formation of the seed completes the process of reproduction in seed plants, which started with the development of flowers and pollination. A typical seed includes three basic parts: (i) An embryo that is an immature plant from which a new plant will grow under proper conditions. (ii) A seed coat (or testa) develops from the tissue, the integument, originally surrounding the ovule. The seed coat helps protect the embryo from mechanical injury and from drying out. (iii) A supply of nutrients within the seed for the embryo that will grow as seedling. The form of the stored nutrition varies depending on the kind of plant.

Seeds serve several functions for the plants that produce them. Key among these functions is: (i) Embryo nourishment, (ii) Seed dispersal and (iii) Seed dormancy during unfavorable conditions. Seed dormancy is defined as a seed failing to germinate under environmental conditions optimal for germination, normally when the environment is at a suitable temperature with proper soil moisture. This true dormancy or innate dormancy is therefore caused by conditions within the seed that prevent germination. Thus, dormancy is a state of the seed, not of the environment. Induced dormancy, enforced dormancy or seed quiescence occurs when a seed fails to germinate because the external environmental conditions are inappropriate for germination, mostly in response to conditions being too dark or light, too cold or hot, or too dry. Seed dormancy has two main functions: synchronizing germination with the optimal conditions for survival of the resulting seedling and spreading germination of a batch of seeds over time so that a catastrophe after germination (e.g. late frosts, drought, herbivory) does not result in the death of all offspring of a plant. Often seed dormancy is divided into several categories: (a) Physical dormancy, (b) Chemical dormancy, (c) Morphological dormancy, (d) Morphophysiological dormancy, (e) Physiological dormancy, (f) Combinational dormancy, (g) Secondary dormancy, (h) Photodormancy and (i) Thermodormancy.

Germination of seed is a process in which a plant or fungus emerges from a seed or spore, respectively, and begins growth or it is a process by which a seed embryo develops into a seedling. It involves the reactivation of the metabolic pathways that lead to growth and the emergence of the radical or seed root and plumule or shoot. The emergence of the seedling above the soil surface is the next phase of the plant's growth and is called seedling establishment. Most seeds go through a period of quiescence where there is no active growth; during this time, the seed can be safely transported to a new location and/or survive adverse climate conditions until circumstances are favorable for growth. Quiescent seeds are ripe seeds that do not germinate because they are subject to external environmental conditions that prevent the initiation of metabolic processes and cell growth. Under favorable conditions, the seed begins to germinate and the embryonic tissues resume growth, developing towards a seedling. Three fundamental conditions must exist before germination can occur. (i) The embryo must be alive, called seed viability, which is the ability of the embryo to germinate and is affected by a number of different conditions. (ii) Any dormancy requirements that prevent germination must be overcome. (iii) The proper environmental conditions must exist for germination. Seed vigor is a measure of the quality of seed, and involves the viability of the seed, the germination percentage, germination rate and the strength of the seedlings produced. The germination percentage is simply the proportion of seeds that germinate from all seeds subject to the right conditions for growth. The germination rate is the length of time it takes for the seeds to germinate. Germination percentages and rates are affected by seed viability, dormancy and environmental effects that impact on the seed and seedling.

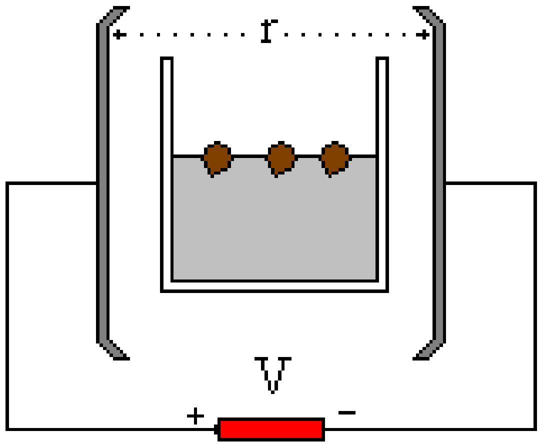

Figure 1. Schematic diagram of the experimental set up.

Three distinct phases of germination of seed occur: water imbibitions, lag phase and radical emergence. In order for the seed coat to split, the embryo must imbibe (soak up water), which causes it to swell, splitting the seed coat. However, the nature of the seed coat determines how rapidly water can penetrate and subsequently initiate germination. The rate of imbibitions is dependent on the permeability of the seed coat, amount of water in the environment and the area of contact the seed has to the source of water. Germination of seed depends on both internal and external environmental conditions. The most important external factors include temperature, water, oxygen and sometimes light or darkness. Mature seeds are often extremely dry and need to take in significant amounts of water, relative to the dry weight of the seed, before cellular metabolism and growth can resume. Most seeds need enough water to moisten the seeds but not enough to soak them. The uptake of water by seeds is called imbibations, which leads to the swelling and the breaking of the seed coat. When seeds are formed, most plants store a food reserve with the seed, such as starch, proteins, or oils. This food reserve provides nourishment to the growing embryo. When the seed imbibes water, hydrolytic enzymes are activated which break down these stored food resources into metabolically useful chemicals. After the seedling emerges from the seed coat and starts growing roots and leaves, the seedling's food reserves are typically exhausted; at this point photosynthesis provides the energy needed for continued growth and the seedling now requires a continuous supply of water, nutrients, and light. Oxygen is used in aerobic respiration, the main source of the seedling's energy until it grows leaves. Oxygen is an atmospheric gas that is found in soil pore spaces; if a seed is buried too deeply within the soil or the soil is water logged, the seed can be oxygen starved. Seeds from different species and even seeds from the same plant germinate over a wide range of temperatures. Seeds often have a temperature range within which they will germinate, and they will not do so above or below this range. Light or darkness can be an environmental trigger for germination and is a type of physiological dormancy. Most seeds are not affected by light or darkness, but many seeds, including species found in forest settings, will not germinate until an opening in the canopy allows sufficient light for growth of the seedling. Seed dormancy can originate in different parts of the seed, for example, within the embryo; in other cases, the seed coat is involved. Dormancy breaking often involves changes in membranes, initiated by dormancy-breaking signals. This generally occurs only within hydrated seeds. Factors affecting seed dormancy include the presence of certain plant hormones.

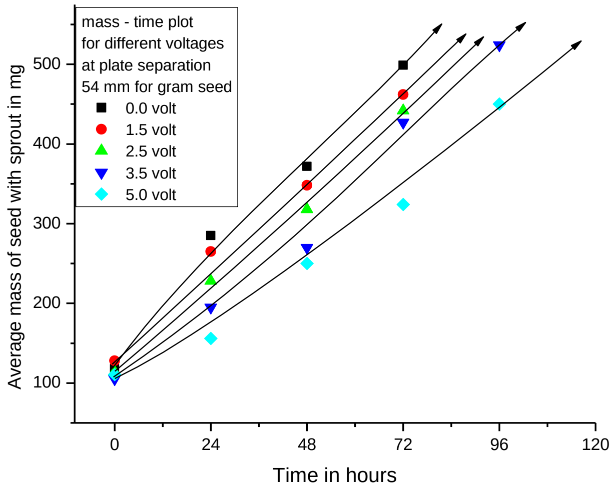

Figure 2. Variation of mass of seed with time for different voltages and electrostatic fields at fixed plate separation 54 mm for gram seeds.

Scarification mimics natural processes that weaken the seed coat before germination. Scarification, which allows water and gases to penetrate into the seed, include methods that physically break the hard seed coats or soften them by chemicals. Sometimes fruits are harvested while the seeds are still immature and the seed coat is not fully developed and sown right away before the seed coat become impermeable. Under natural conditions seed coats are worn down by rodents chewing on the seed, the seeds rubbing against rocks (seeds are moved by the wind or water currents), by undergoing freezing and thawing of surface water, or passing through an animal's digestive tract. In the latter case, the seed coat protects the seed from digestion, while often weakening the seed coat such that the embryo is ready to sprout when it gets deposited (along with a bit of fertilizer) far from the parent plant. Microorganisms are often effective in breaking down hard seed coats. Stratification also called moist-chilling is a method to break down physiological dormancy and involves the addition of moisture to the seeds so they imbibe water and then the seeds are subject to a period of moist chilling to after-ripen the embryo. Leaching or the soaking in water removes chemical inhibitors in some seeds that prevent germination. Rain and melting snow naturally accomplish this task. Other methods used to assist in the germination of seeds that have dormancy include prechilling, predrying, daily alternation of temperature, light exposure, potassium nitrate, and the use of plant growth regulators like gibberellins, cytokinins, ethylene, thiourea, sodium hypochlorite plus others.

EXPERIMENT FOR GRAM SEED

Two plane circular aluminum plates of 0.1 m in diameter and 0.2 mm in thickness are kept vertical and parallel as shown in figure 1 [Ghorai, 2012], [Alok et al., 2008].

A uniform electrostatic field is created in the air medium of these two circular parallel plates by applying a voltage. The periphery of these plates is slightly bended inwards to maintain the uniformity of the electrostatic field. The outer surfaces of the plates are soldered with connecting copper wires and they are connected to a dry cell or a battery to establish a potential difference or voltage V in between. The distance between the plates (r) is kept constant to make the electrostatic field E within the plates constant and uniform. The magnitude of the electrostatic field E is can be obtained using equation (3) as

$$E = |\vec{E}| = |-\vec{\nabla} V| = |-\partial V / \partial r| = V / r \qquad - (5)$$

Electrostatic field (E) varies with the variation of V or r. We may use two methods: (i) fixed distance r and different voltage values V or (ii) fixed voltage V and different distance r.

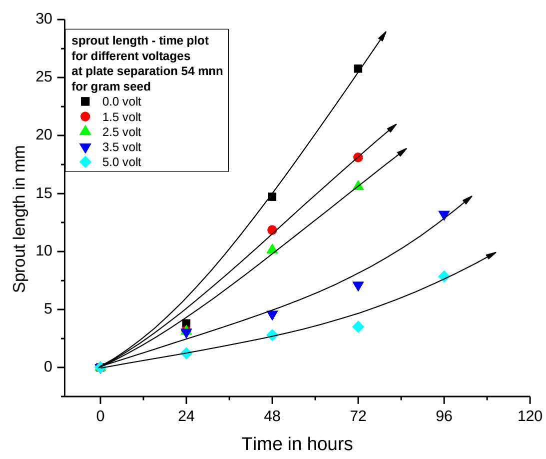

Figure 3 (a) Variation of sprout length with time for different voltages and electrostatic fields at fixed plate separation 54 mm for gram seeds.

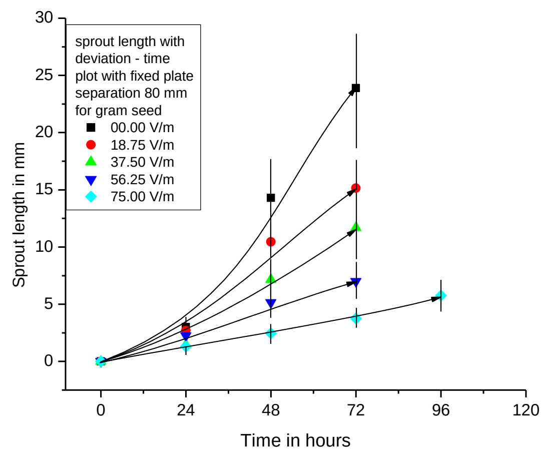

Figure 3 (b) Variation of sprout lengths with time for different voltages and electrostatic fields at fixed plate separation 80 mm with deviations for gram seeds.

Plastic tea pots readily available in the market are taken. First, ten gram seeds [leguninosae family member (subfamily: papilionaceae), viz. gram (*Cicer arietinum*)] are placed in a small plastic teapot over wet sand and soil mixture. Five such teapots are prepared and one is kept at normal conditions. Four other teapots are placed within the circular parallel plates producing different low electrostatic fields and the distance between the plates is kept fixed. Different electrostatic fields are generated by different series combination of alkali cell or dry cell or battery. There are five variables, viz. electrostatic voltage (V), distance between the parallel plates (r), electrostatic field (E), sprout length (l) and time duration of growth of sprout length (t). $l-t$ Graphs can be plotted for different E in two ways, either keeping r constant or V constant. Thus, experiment was performed in three different set up conditions: (i) For the first set up, plate separation r is kept fixed to a particular value and the voltage V is varied with alkali cells. (ii) For the second set up, plate separation r is kept fixed to another value and the voltage V is varied using dry cells. (iii) Finally for the third set up, voltage V between the parallel plates is kept fixed and the distance r is varied using dry cells.

In the first set up the distance of separation r is kept fixed to a value $r =$ 54 mm and the voltage V is established by applying different series combination of alkali cells with values 0 V, 1.5 V, 2.5 V, 3.5 V and 5.0 V. Thus the electrostatic fields will be obtained from equation (5) as 0 V/m, 27.78 V/m, 46.30 V/m, 64.81 V/m and 92.59 V/m. Highest and lowest room temperatures are recorded every day by a sensitive thermometer during the course of the experiment and average of it is noted to be 30°C and 20°C. Voltage is measured everyday by a voltmeter to ensure the constancy of it during the experiment. Germination will start in due course of time and sprout will grow. During electrostatic field treatment the seeds are taken away from electrostatic field for a short while for the measurement of sprout length and then kept inside as it was before. After one day's exposure to electrostatic field and voltage, the sprout lengths of the seeds were measured accurately with the help of pointers and the mean is taken. The process is repeated for three to four more days till the budding of green leaves. Total mass of these ten seeds as well as average mass is also measured every day. We first plot the results of variation of mean mass of a gram seed (in mg) with the time duration in hours of growth of sprout length (called germination time) along horizontal axis for different applied voltages and the fixed plate separation 54mm as shown in figure 2. Intake of water is much slower and decreases almost linearly with electrostatic field or voltage.

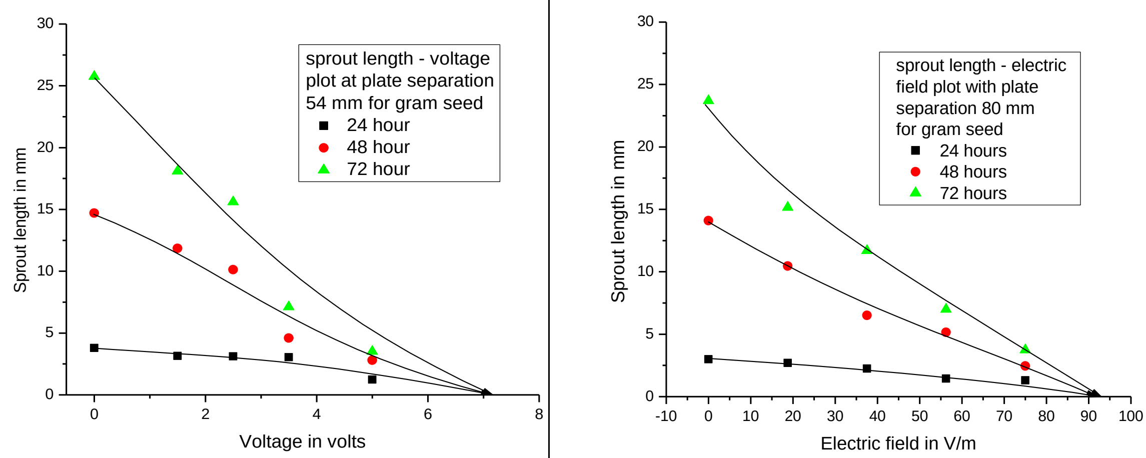

Figure 4 (a) Variation of sprout length with voltage for different time of exposure to electrostatic field and voltage for germination at fixed plate separation 54 mm for gram seeds.

Figure 4 (b) Variation of sprout length with electrostatic field for different time of exposure to electrostatic fields for germination at fixed plate separation 80 mm for gram seeds.

Another graph is plotted in this first set up with the mean or average of ten sprout lengths at a particular time of growth of sprout length from gram seeds along vertical axis and time duration of growth of sprout length (called germination time) along horizontal axis for different applied voltages (V) with values 0 V, 1.5 V, 2.5 V, 3.5 V and 5.0 V; electrostatic fields (E) 0 V/m, 27.78 V/m, 46.30 V/m, 64.81 V/m and 92.59 V/m; and the fixed plate separation 54 mm. The nature of these graphs is shown in figure 3(a) for gram seeds. With the increase in voltage they are almost straight lines and more parallel or less bend towards horizontal axis of germination time. A third graph is plotted in this first set up with applied voltages along horizontal axis and corresponding sprout length along vertical axis at different times of exposure to electrostatic field and voltage for germination and the fixed distance of separation between the plates. This is shown in figure 4(a) for gram seeds. The sprout length decays with increase in voltage V. The natural decay laws are in general exponential in nature (viz. radioactive decay) and the graph almost resembles the same nature. The graphs when extrapolated, meet the horizontal axis at a point and the corresponding voltage is called cut-off or threshold voltage. Thus it is the voltage at which germination stops or in other words, sprout does not grow. Cut-off voltage at which germination stops has been determined from the extrapolation of the graph as 7.14 volts for gram seed with the fixed distance of separation 54 mm between the plates producing electrostatic field as 132.22 V/m.

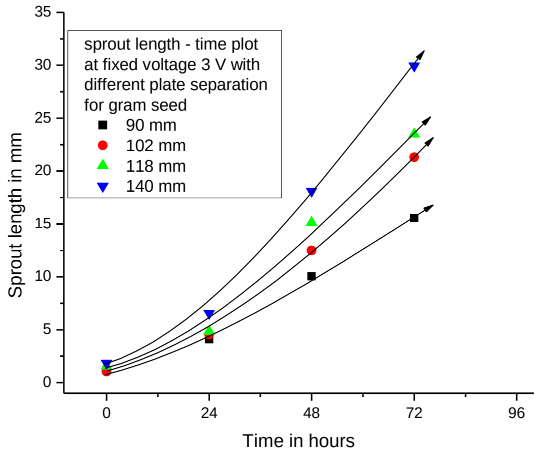

Figure 5 (a) Variation of sprout length with time for different electrostatic fields at fixed voltage 3 V for gram seeds.

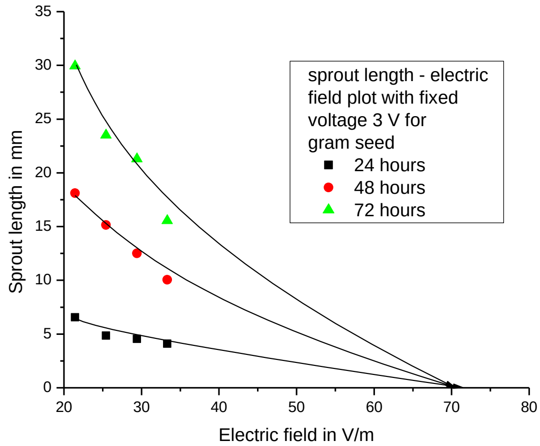

Figure 5 (b) Variation of sprout lengths with electrostatic field for different time of germination at fixed voltage 3 V for gram seeds.

It has been found that the voltage of the different series combination of alkali cells remains same throughout the duration of the experiment in the first set up and so alkali cells are replaced by the simple dry cells of AA size readily available in the market for the second set up. The distance of separation r here is kept fixed to a new value of $r = 80$ mm and the voltage V is established by applying different series combination of dry cells with values 0 V, 1.5 V, 3.0 V, 4.5 V and 6.0 V. Highest and lowest room temperatures are noted every day by a sensitive thermometer and the average of it is found out to be 23°^{o}C and 13°C. Voltage is measured everyday by a sensitive voltmeter to ensure its constancy as in the previous case. A graph is plotted with the mean or average of ten sprout lengths for gram seeds at a particular time of growth of sprout length from seeds along vertical axis and time duration of growth of sprout length (called germination time) along horizontal axis for different applied electrostatic fields according to equation (5) as $(E=)$ 0 V/m, 18.75 V/m, 37.50 V/m, 56.25 V/m and 75.00 V/m with the fixed plate separation 80 mm. The natures of these graphs are shown in figure 3(b) along with deviations for gram seeds. With the increase in voltage they are almost straight lines and more parallel or less bend towards horizontal axis of germination time and they resemble the graphs of figure 3(a).

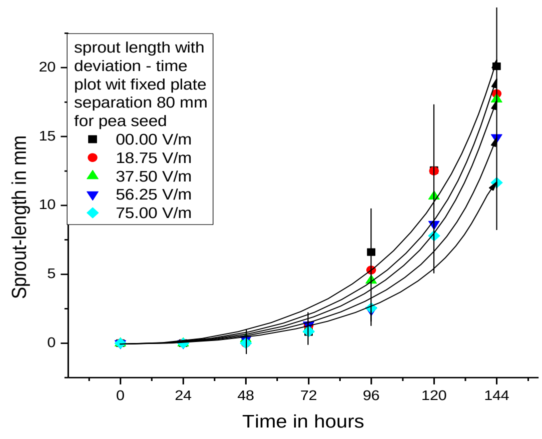

Figure 6 (a) Variation of sprout length with time for different electrostatic fields at fixed plate separation 80 mm for pea seeds with deviations.

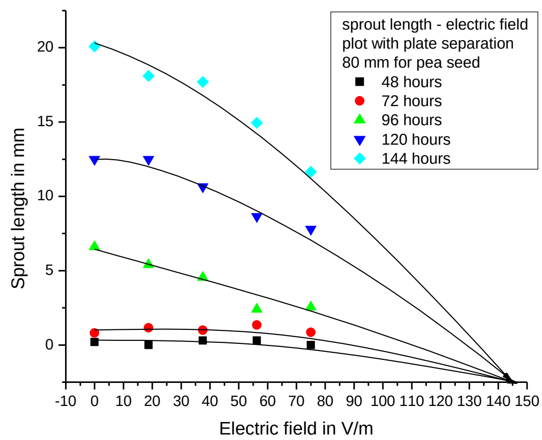

Figure 6 (b) Variation of sprout length with electrostatic field for different time of germination at fixed plate separation 80 mm for pea seeds.

Another graph is plotted for this second set up with applied electrostatic field (E) for different voltages along horizontal axis and corresponding sprout length along vertical axis at different times of exposure to electrostatic field for germination and the fixed distance of separation between the plates. This is shown in figure 4(b) for gram seeds which resembles figure 4(a). The sprout length decays with increase in electrostatic field E almost like natural decay processes, which are in general exponential in nature (viz. radioactive decay), and the graph resembles the same nature. The graphs when extrapolated meet the horizontal axis approximately at a point and the corresponding voltage and electrostatic field are called cut-off or threshold values, which are 7.402 volts and 92.52 volt/meter for gram seed with the fixed distance of separation 80 mm between the plates producing electrostatic field.

In the third experimental set up the distance of separation (r) between the plates is varied to values 90 mm, 102 mm, 118 mm and 140 mm and the voltage applied between the plates is kept fixed to a value of 3 volt. Thus the values of electrostatic fields are 33.33 V/m, 29.41 V/m, 26.42 V/m and 21.43 V/m. A graph for gram seeds for this third set up can be plotted for germination time along horizontal axis and corresponding sprout length along vertical axis with different electrostatic fields, which is shown in figure 5(a). Figure 5(b) indicates the sprout length variation of seeds with electrostatic field at different time of exposure to electrostatic field for germination. The cut-off or threshold value of electrostatic field at which germination stops or in other words, sprouts do not grow has been found out by extrapolation to be about 70.24 volt/meter for gram seeds and corresponding plate separation will be 42.71 mm for 3V. The nature shows they are not straight lines but exponential decay. Thus $l-t$ and $l-E$ graphs yield same nature of plots in all the three set ups.

EXPERIMENT FOR PEA SEED

As in the previous section for gram seed here physical understanding of the variation of growth of sprout length of a leguninosae family member (subfamily: papilionaceae), viz. pea (*Pisum sativum*) seeds with applied voltage and electrostatic field will be dealt with. Here graphs can be plotted for different E in two ways, keeping either V constant or r constant. The experimental arrangement is same as described in figure 1. We keep r fixed to a value $r = 80$ mm. The voltage V is established by applying different series combination of dry cell with values 0 V, 1.5 V, 3.0 V, 4.5 V and 6.0 V. Germination will start in due course of time. Due to germination, sprout will grow and after one day's exposure to electrostatic field, the teapots are taken outside the electrostatic fields to measure accurately the sprout lengths of the seeds. The process is repeated for four to five more days till the budding of green leaves. Highest and lowest room temperatures are noted every day by a sensitive thermometer and average of it lies within 23°C – 13°C. Voltage is measured everyday by a voltmeter to ensure the potential difference between the plates of the capacitor constant.

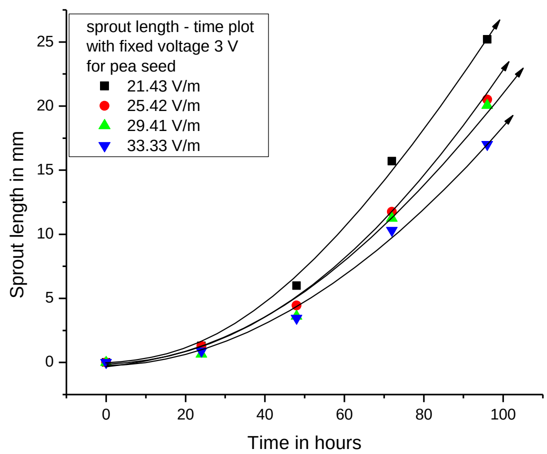

Figure 7 (a) Variation of sprout length with germination time for different electrostatic fields at fixed voltage 3 V for pea seeds.

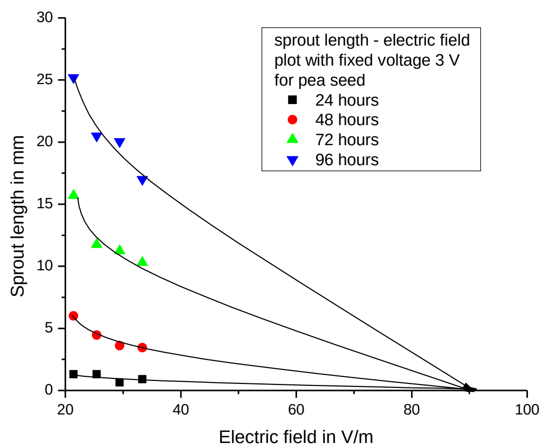

Figure 7 (b) Variation of sprout lengths with electrostatic field for different time of germination at fixed voltage 3 V for pea seeds.

Five graphs are plotted with the mean or average of ten sprout lengths at a particular time of growth of sprout length from seeds together with their standard deviations along vertical axis and time duration of growth of sprout length along horizontal axis for different applied voltages and the fixed distance between the plates of the parallel plate capacitor $r = 80$ mm with corresponding electrostatic fields $(E =)$ 0 V/m, 18.75 V/m, 37.50 V/m, 56.25 V/m and 75.00 V/m. The natures of these graphs are shown in figure 6(a) along with deviations for pea seeds. With the increase in voltage they are almost straight lines and more parallel or less bend towards horizontal axis of germination time. The sprout length decays with increase in electrostatic field E. Another graph is plotted for different electrostatic fields along horizontal axis and corresponding sprout length along vertical axis at different times of exposure to germination and the fixed plate separation of 80 mm. This is shown in figure 6(b) for pea seeds. The sprout length decays with increase in electrostatic field E as in previous case. The graphs when extrapolated meet the horizontal axis at a point and the corresponding electrostatic field is 145 volt/meter for pea seed with the fixed distance of separation 80 mm between the plates of the parallel plate capacitor. The corresponding cut-off or threshold voltage has been determined from the extrapolation of the graph as 11.6 volts.

In the next set up varying the distance of separation (r) between the plates of the parallel plate capacitor to values 90 mm, 102 mm, 118 mm and 140 mm and keeping the dry cell emf to a fixed value of 3 volt, we get the values of electrostatic fields as 33.33 V/m, 29.41 V/m, 26.42 V/m and 21.43 V/m. A graph for pea seeds can be plotted for germination time along horizontal axis and corresponding sprout length along vertical axis with different electrostatic fields, which is shown in figure 7 (a). With the increase in electrostatic field they are almost straight lines and more parallel or less bend towards horizontal axis of time duration of growth of sprout length. Figure 7 (b) indicates the sprout length variation of seeds with electrostatic field at different time of germination and the cut-off or threshold value of electrostatic field at which germination stops or in other words, sprouts do not grow has been found out by extrapolation to be about 91 volt/meter and the corresponding plate separation will be 32.97 mm for 3 V.

Table 1. Cut-off or threshold values for gram and pea seeds.

Seed	Case	Plate separation r in mm	Voltage V in volt	Electric field E in V/m
Gram	First set	54	7.14	132.22
	Second set	80	7.904	98.8
	Third set	42.71	3	70.24
Pea	First set	80	11.6	145
	Second set	32.97	3	91

DISCUSSIONS AND CONCLUSIONS

It is clear that sprout length variation of seeds depends on the magnitude of applied voltage or electrostatic field and the plate separation. Thus application of an electrostatic field can control the process of germination of gram and pea seeds. The threshold or cut-off values of voltage and electrostatic field (shown in table 1) were determined by extrapolation from experimental graph and not by direct determination experimentally. This is why there is a variation of 0.764 V in the threshold voltage, 33.42 V/m in the threshold electrostatic field in case of gram seeds in the first two sets. For the third set with fixed voltage the projected electrostatic field value is smaller with corresponding plate separation 42.71 mm. Similar wide variation of 54 V/m in electrostatic field is observed in case of pea seed. In this sense the extrapolation method for the calculation of cut-off values seems not adequate and enough useful. We do not have any idea about the exact nature of relationship between electrostatic field and the growth of the sprout length. Therefore, it is difficult to propose any fitted equation of these non-linear plots. In addition, there exists a variety of fitting. In any case, we can conclude that the decrease in the growth of sprout length results in due to slower rate of cell division. The biological reason for this may be due to lesser diffusion through the cell wall or weakening of the activity of the other cell components. The proposed lines in the figures show the continuity in the process of germination and post-germination while scatter plots will show discontinuity. This justifies the drawing of lines joining scatter points. The natures of these graphs show distinctly that growth in sprout length and its growth rate diminish with increase in electrostatic field E or voltage V .

The nature of these graphs shows distinctly that the growth in sprout length and its growth rate diminish with increase in electrostatic field *E*. This might have been utilized as a potential factor in agriculture sector, specifically, in the process of preservation of seeds in cold storages.

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