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Effect of electric field (at different temperatures) on germination of chickpea seed

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Chickpea (*Cicer arietinum*) seeds were exposed to electric field from zero to 1300 V for 15 min at three different temperatures (13, 16 and 19°C). It was found that the exposure of chickpea seeds to the electric field caused a change in water uptake capacity (and its coefficient) as compared to control. A new theoretical model for water uptake was developed and verified experimentally. Experiments were performed at three different temperatures. It was observed that temperature nullifies the effect of the electric field on seeds.

Key words: *Cicer arietinum* L. seeds, electric-field, water-uptake model, ferroelectric effect.

INTRODUCTION

Exposure of seeds to the magnetic field has been reported as safe and affordable treatment for enhanced germination and growth of plants by many workers (Aladjadjiyan, 2002; Fischer et al., 2004; Podleoeny et al., 2005; Florez et al., 2007). These studies have been done on varieties of seeds where encouraging results of magnetic field exposure of different dozes have been optimized and studied (Rochalska and Grabowska, 2007; Mahajan and Pandey, 2011; Mahajan and Pandey, 2012). However, there exist no clear opinion concerning the impact of the electric field on germination and plant growth. Dymek et al. (2012) reported the effect of pulsed electric fields (PEF) of varying voltages (110, 160, 240, 320, 400 and 480 V) on radicle emergence without affecting the gross metabolic activity of barley seeds. The inhibitory effect of the electric field of more than 12 kV/cm for 60 s on germination of tomato seed has also been reported (Moon and Chung, 2000). Some authors (Kiatgamjorn et al., 2002a; Kiatgamjorn et al., 2002b) have shown that the electric field intensity of 25 kV/m enhances the growth of bean sprouts (shoot height and higher radicle elongation).

The effect of magnetic field treatment on chickpea seeds has been studied by many authors (Vashisth and Nagarajan, 2008; Mahajan and Pandey, 2011; Mahajan and Pandey, 2012) but so far the effect of static electric field on chickpea seeds has not been studied. The basic aim of the present study was to investigate the effect of electric field (by varying voltage) on the water absorption and germination of chickpea (*Cicer arietinum* L.) seeds. Chickpea seeds were exposed to the electric field (by varying voltage from zero to 1300 V) for 15 min at three different temperatures (13, 16 and 19°C). The present study was conducted to find the resonating electric field which might have significant effect on germination and growth of chickpea seeds. In resonating state, there is always maximum transference of energy. It is found that seeds are sensitive to some particular value of magnetic field (Vashisth and Nagarajan, 2010). In resonating state, seed show extra ordinary behaviour towards germination (either more enhanced or more retarded). Another aspect of the present study was to establish a relation between water uptake by the chickpea seed and residual electric field after treatment. Apart from this, the effect of

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temperature with varying electric field on germination and growth of these chickpea (*C. arietinum*) seeds was also studied.

MATERIALS AND METHODS

Experimental setup consists of a fully adjustable DC high-voltage supply (0-13 kV), and a test cell comprising of two circular aluminium plates of 8 cm diameter with the adjustable inter-electrode gap (which is principally a condenser). Chickpea (*C. arietinum* L.) dry seeds (single layer) were loaded in between two electrodes. To avoid direct contact of seeds with the electrodes, two transparent circular high-density polyethylene layers of the same diameter as that of the electrode are kept above and below the seeds. In order to measure any change in temperature during the electrical treatment, a hole was bored in one disc of parallel plate capacitor and a thermometer was inserted horizontally. To make good contact between the thermometer and disc, some mercury was poured into the hole. It was noted that there was no heating effect during the experiments. Four replications of Chickpea seeds comprising of 40 seeds in each set were exposed at 350, 500, 700, 900, 1150 and 1300 V for 15 min. The distance between two electrodes was kept 1.5 cm. The corresponding intensity of the electric field developed was 233.3, 333.3, 466.6, 600, 766.6 and 866.6 V/cm, respectively. The exposed seeds of each set were kept in between two thin wet layers of cotton cloth which was transferred onto a sponge bed sheet of 1.8 cm thickness kept inside transparent plastic boxes (20 × 13 × 4 cm^3) covered with a lid. Equal amount of water was poured on sponge bed sheets in each box. Using the formula $w = ((w_2 - w_1)/ w_1) \times 100$ (Nizam, 2011), water uptake was measured by weighing the seeds before and after soaking at a fixed time interval. Here, w_1 is initial weight of seed, and w_2 is weight of seed after absorbing water in a particular time *t*. Seed water content was measured by an analytical balance with1 mg accuracy.

In the present study, constant temperatures of 13, 16, 17.5 and 19°C were used for incubation of seeds (both treated and control) leading to sprouting. Number of germinated seeds was counted after a certain time interval. A seed was considered to be germinated when radical has emerged out with more than 2 mm length.

Water uptake model

The rate of seed swelling (*dw/dt*) during hydration is often described by the Equation (Meyer et al., 2007):

$$dw/dt = k(w_{max} - w) \quad (1)$$

$$-kt = \ln ((w_{max} - w)/w_{max}) \quad (2)$$

Where, w_{max} is weight of seed at full hydration, *w* is the weight of a seed at time *t* and $w_{max} - w$ is the water deficit in the seed.

Another model of water uptake statistics assumes that water absorption by the seed follows diffusion kinetics. Seed weight (w) starts increasing as imbibition proceeds satisfying diffusion equation (Meyer et al., 2007):

$$\frac{w}{w_{max}} = 1 - \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp(-Dn^2\pi^2 t / r^2) \quad (3)$$

Where, *D* measures the rate of swelling of seed (in the unit of the diffusion coefficient $m^2 s^{-1}$) and *r* denotes the radius of seed (seed is assumed as spherical).

A new water uptake model

Here, a new water uptake model is formulated named as Mahajan-Pandey water uptake model (free from w_{max}) containing only one unknown parameter *k*. In this model, it is assumed that net weight of water absorbed at any instant is ($w - w_{dry}$). Where, w_{dry} is the weight of the seed before soaking and *w* is the weight of a seed at any instant *t* is: i) directly proportional to weight of the seed (before soaking); ii) directly proportional to the time interval between *t* and *t+dt* (that is *dt*) during which water is absorbed by the seed; iii) inversely proportional to time *t* elapsed starting from when hydration was started.

$$(w - w_{dry}) \propto w_{dry} \times dt/t \quad 4$$

or

$$(w - w_{dry}) / w_{dry} \propto dt/t \quad 5$$

Let water uptake by the seed in a small time *dt* is denoted by *dw*(($w - w_{dry}$) /w_{dry}= *dw*) therefore,

$$dw \propto dt/t \quad 6$$

Integrating above equation (limits: at the time t_0 relative water content absorbed by the seed is w_1 and at time *t* is w_2)

$$w_2 = k \times ln(t) - k \times ln(t_o) + w_1 \quad 7$$

Where, *k* is some constant, or

$$w = k \times ln(t) \pm k_2 \quad 8$$

Where, $k_2 = -k \times \ln(t_o) + w_1$ and $w_2 = w$

The value of *k* depends upon those parameters which affect the germination. Presently, only electric field is varied (keeping other parameters constant), so here *k* becomes a function of the electric field only; therefore, *k*is denoted as k_E.

$$w = k_E \times ln(t) \pm k_{E2} \quad 9$$

Where, k_E is called here is water uptake coefficient)

RESULTS

Water uptake by seeds treated with electric field of different strength (0 to 1150 V) was studied. Maximum effect was observed at 700 V creating an electric field of 466.6 V/cm (electric field = vage/distance between the plates of capacitor). At this treatment, there is a reduction of water absorption and the relative water uptake was also decreased. On the other hand, seeds treated at 1150 V creates an electric field of 766.6 V/cm and exhibited opposite effect to that of 700 V. At this electric field, the water absorption was higher than that of control and relative water absorption was also increased (Figure 1). Treatment of seed with 350 and 500 V has a lesser effect on water absorption as compared to 700 and 1150 V (Figure 1). Water uptake (%) by chickpea seed increases linearly with the logarithm of imbibition time (Figure 2). Straight lines satisfy equation 9 of water uptake statistics (R^2nearly equals to 1) of proposed water uptake model. Slope of these lines signifies coefficient of water uptake by the seed.

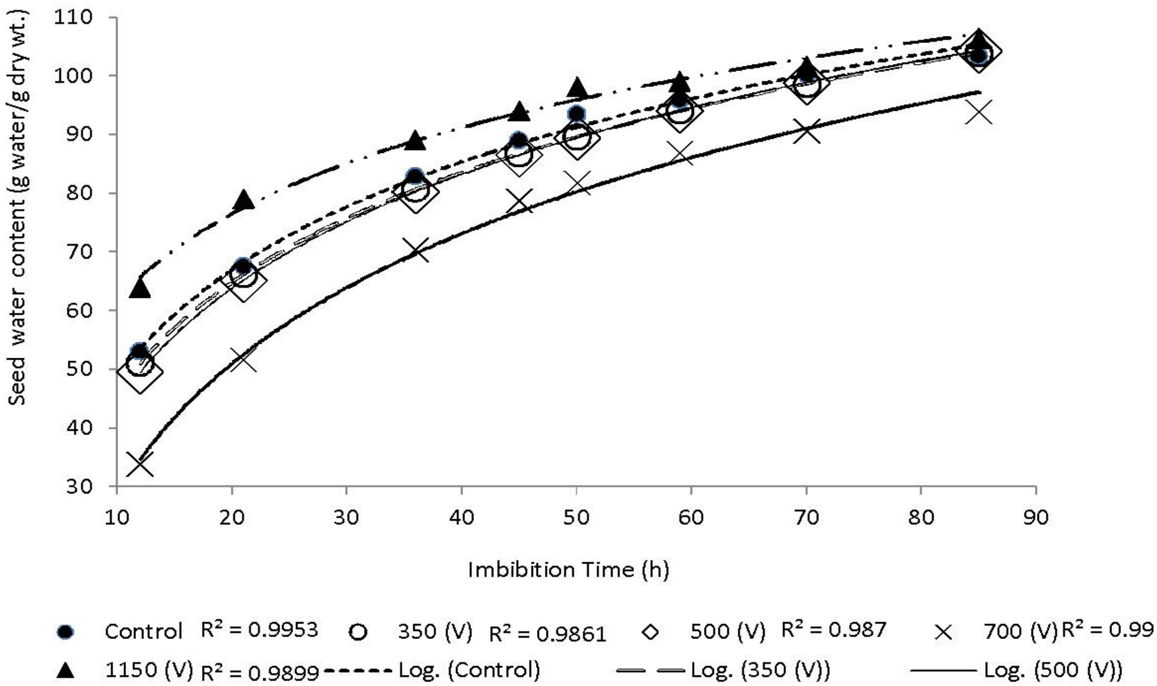

Figure 1. Logarithmic trend between water uptake (percentage) and imbibition time for different voltages at the fixed temperatures 17.5°C.

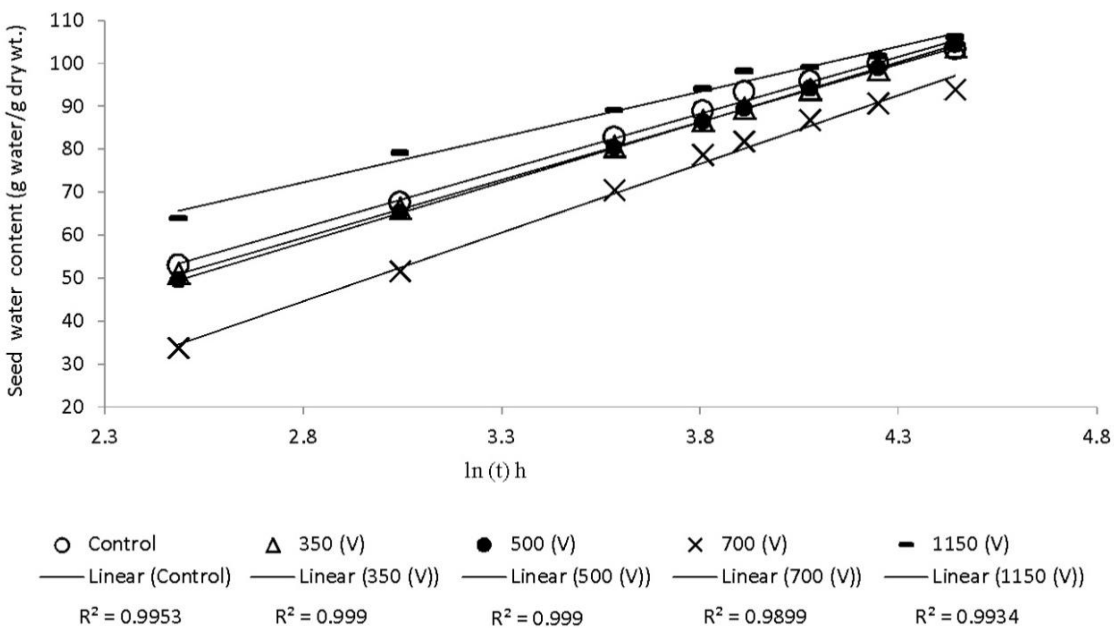

Figure 2. Linear increase between water uptake (%) and logarithm of time (h) for different voltages at the fixed temperatures 17.5°C.

Germination capacity (G) varies with time (at 17.5°C) that follows logarithm trend (Figure 3). ($G_{control}$ = 179.35 ln(t) - 645.38, $G_{350\ (V)}$ = 149.35ln(t) - 531.52, $G_{500(V)}$ = 151.94ln(t) - 544.74, $G_{700\ (V)}$ = 120.58ln(t) - 463.35, $G_{1150\ (V)}$ = 160.47ln(t) - 560.22). Experimental data of germination capacity fitted well in log curves ($R^2_{control}$ = 0.9835, $R^2_{350(V)}$ = 0.9988, $R^2_{500(V)}$ = 0.9846, $R^2_{700(V)}$ = 0.9997, $R^2_{1150(V)}$ = 0.9972). Germination capacity of

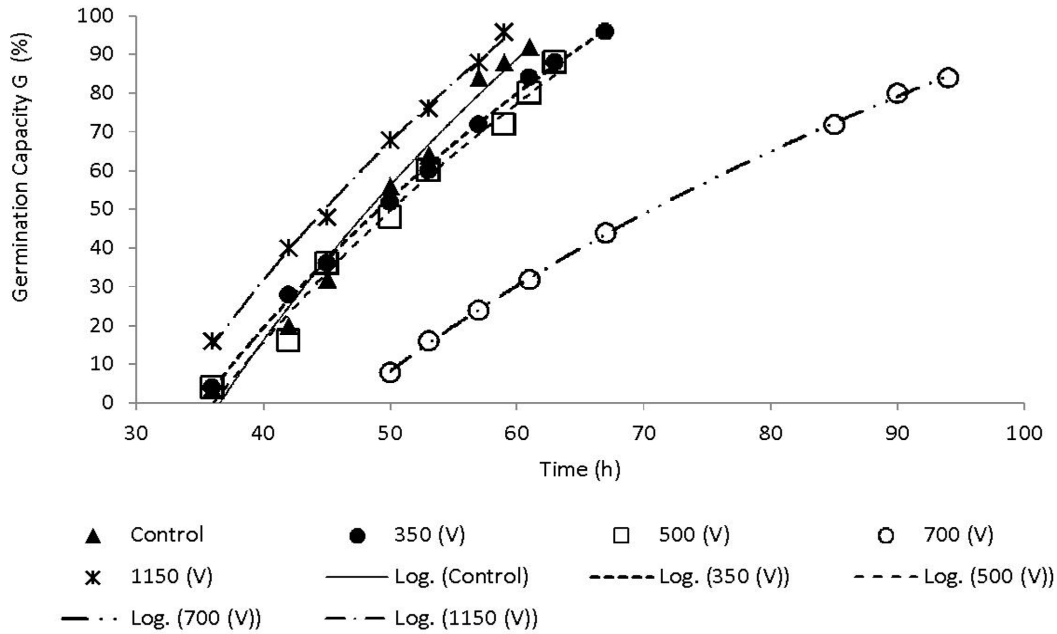

Figure 3. Variation of germination capacity (%) with time at the fixed temperatures 17.5°C.

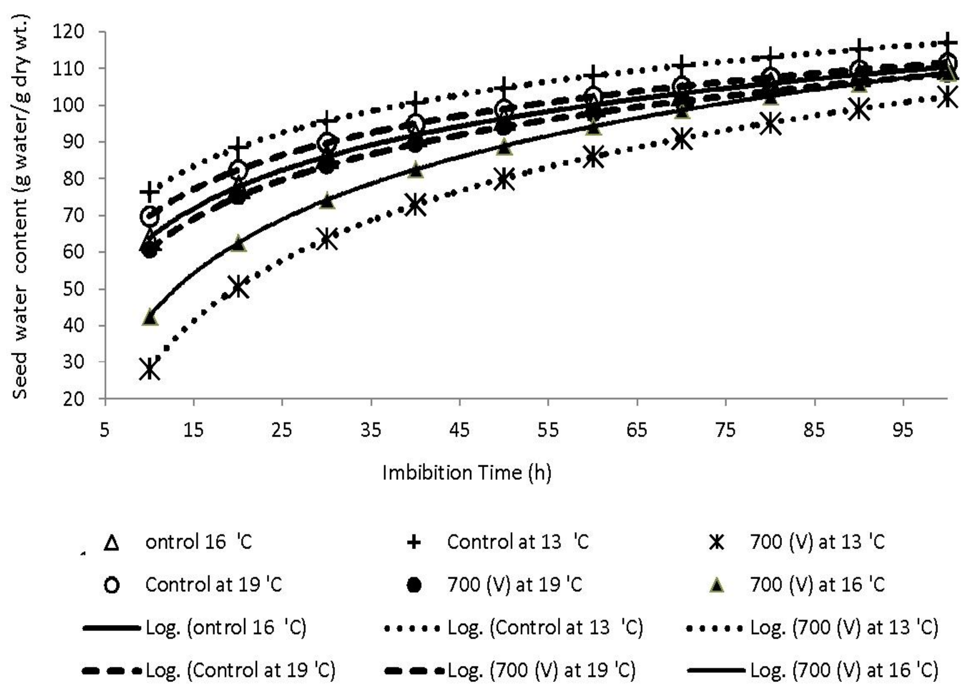

Figure 4. Variation in water uptake (percentage) as a function of temperatures at fixed voltage.

treated seeds at 350 and 500 V (at 17.5°C) was close to that of the control. However, it is significantly lower at 700 V, and is higher than control in case of seeds treated at 1150 V.

Seed water content at constant vage (700 V) with respect to control at different temperature also showed logarithm trend with time and is shown in Figure 4. It shows that the difference of water uptake in treated seeds as compared to untreated seeds (control) decreases with increasing temperature. This reduction

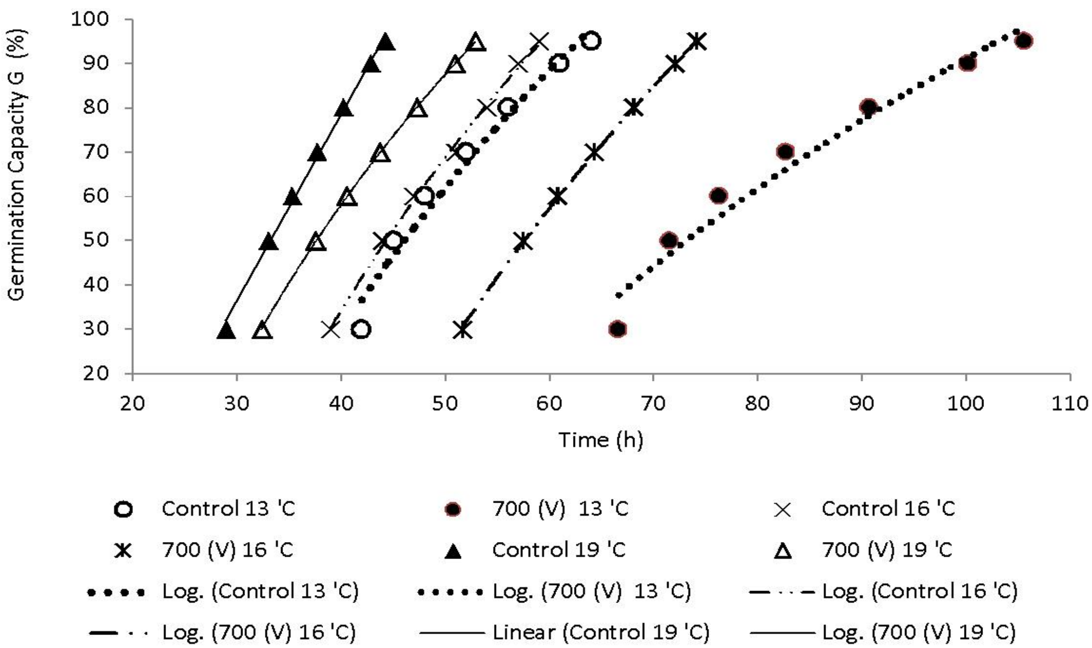

Figure 5. Variation in germination capacity (percentage) as a function of temperatures at fixed voltage.

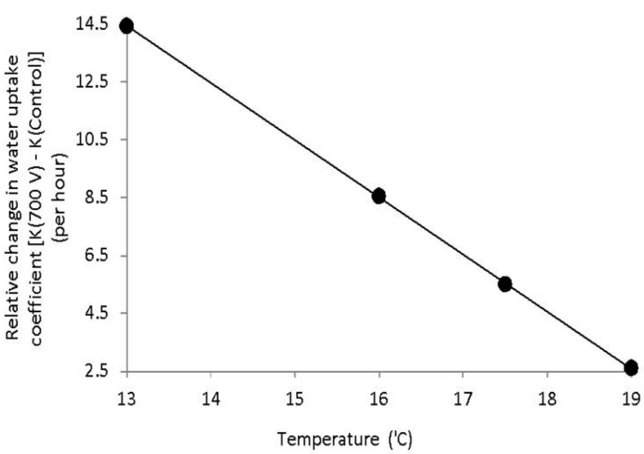

Figure 6. Negative constant slope between the relative change in water uptake coefficient (K700V - Kcontrol) and temperatures.

was further observed to increase with an increase in imbibition time. Maximum difference in water absorption between treated and untreated seeds was recorded at 13°C.It was found to decrease further with increasing temperature and is lowest at 19°C.Germination capacity follows the logarithmic trend with time (at 700 V) with respect to control for various temperature treatments (Figure 5). Maximum effect on G for treated seeds is observed at 13°C and minimum at 19°C. There is a moderate effect on germination capacity of electrically treated chickpea seeds at 16°C. The relative change in the water uptake coefficient (k_{700V} - $k_{control}$) at 13, 16, 17.5, 19°C were 14.44, 8.55, 5.5, 2.6 h^{-1}, respectively (Figure 6). It decreased linearly with temperature. Relative change in the water uptake coefficient follows the equation (k_{700V} - $k_{control}$) = -1.9773×T + 40.151 with R^2 = 0.9999 (T is in °C).

DISCUSSION

Meyer discussed the variation of water uptake (*ln ((*w_{max} *- w)/* w_{max}*))* with time (Meyer et al., 2007). Using this model (Equation 2) water uptake at any instant can be calculated by letting two unknown parameters (w_{max} and *k*). Diffusion model (Meyer et al., 2007) (Equation 3) has also been used to find water uptake at any given instant by the seed. However, use of the above functions is limited because both contain two unknown parameters (w_{max} and *k*). Therefore, in this study, a new water uptake statistical model was proposed (Equation 9), and it showed a linear relation between the logarithm of time and water uptake ((w - w_{dry})/w_{dry}), without using unknown parameter such as w_{max}., which has also been confirmed experimentally (Figure 2).

Many materials (including living organisms and most of the agricultural products) are dielectrics in nature. The electrical nature of material (seeds) has been described by their dielectric properties (Nelson, 2010). Thus, this dielectric effect of the electric field on the seeds can be used to explain the basic processes which are responsible for water uptake and seed germination. Let E_o be the electric field between the parallel plate capacitor

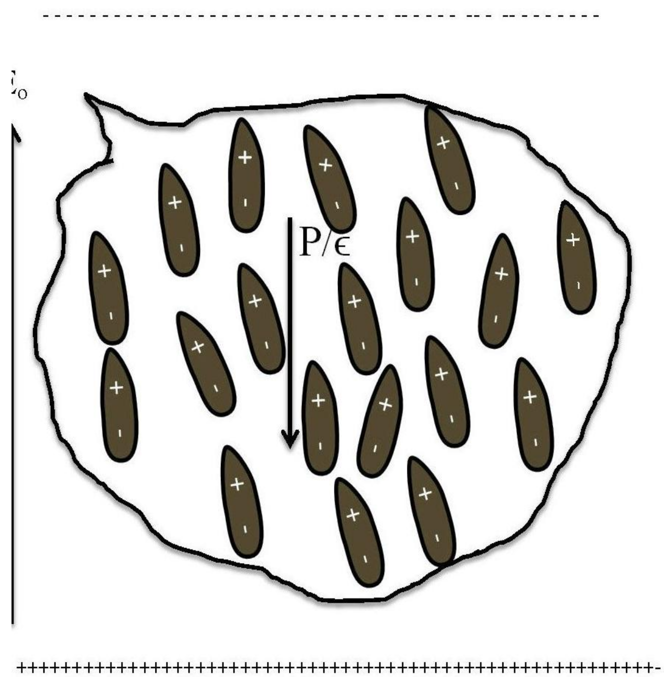

Figure 7. Schematic diagram: Tiny dipoles produced inside the seed with the application of external electric field.

(plate area *A* and plate separation *d*) without seeds and E ($E= Eo - P/\epsilon$; $E < E_o$) the electric field when a layer of seed is inserted between the plates. *P* denotes total dipole density and ϵ is electric permittivity of the seed. Ferroelectric crystals (Like KDP type, KH_2PO_4) exhibit residual electric dipole moment upon removal of external electric field (Kittel, 2012). Moreover, *C. arietinum* also contain ions like ^{32}P- and ^{42}K- (Das and Sen, 1981). It may be considered here that in resonating state, seeds may also exhibit ferroelectric properties. There may be a number of small electric dipoles inside the seed.These dipoles align in the presence of the electric field. Upon removal of the electric field, induced dipoles may not vanish completely. Small dipole moments called residual dipole moments are left inside the seed. Water is also a polar molecule, when it comes in contact with the seed with such created dipoles, may have dipole-dipole interaction (interaction between water dipole and residual or electrically formed stressed dipole inside the seed). When positive face of a water dipole comes near to positive face of a dipole inside the electrically exposed seed, it is repelled back and will create hindrance in water absorption by the seeds. When negative face of a water dipole comes close to positive face of an electrically exposed seed, it is attracted causing an increase in water absorption. This could be happening in seeds treated at 700 and 1150 V (Figures 1 and 2). Schematic diagram of this mechanism is also shown in Figures 7 and 8. Due to delay in water absorption, the observed germination capacity was lower at 700 V (or at 466.6 V/cm electric field) as compared to control (Figure 3). Vashisth and Nagarajan (2010) had shown that internal energy of the seed responds positively when there is an appropriate combination of magnetic field and exposure time. In electrically treated seeds from zero to 1300V, there is a critical exposure around 700 V for 15-min exposure, which stimulates chickpea seeds much more as shown in Figures 1 and 3. To study the effect of temperature on induced dipole moment (developed inside the seed), the entire experiment was repeated at three different temperature, that is, 13, 16 and 19°C keeping the voltage constant (700 V is chosen here; as at this voltage there is the maximum stimulating effect of the electric field on the seed). Figure 4 shows that, with increasing temperature, the gap between exposed-seed-water-uptake-curve and control-seed-water-uptake-curve decreased. It implies that voltage-effect on the seed germination is reduced upon increasing temperature. When seeds were placed in an electric field, they got polarized and acquired induced electric dipole moments in the direction of the field, and they retained this dipole moment even upon removal of the electric field. With increasing temperature, seed losses the residual polarization. It is shown in Figure 5 that with increasing voltage, the separation between exposed-seed-germination-curve and control-seed-germination-curve was decreased. It implies that effect of voltages on the seed germination reduced with increasing temperature. Experimental data (Figure 5) of germination capacity at different temperatures keeping voltage constant (stimu-

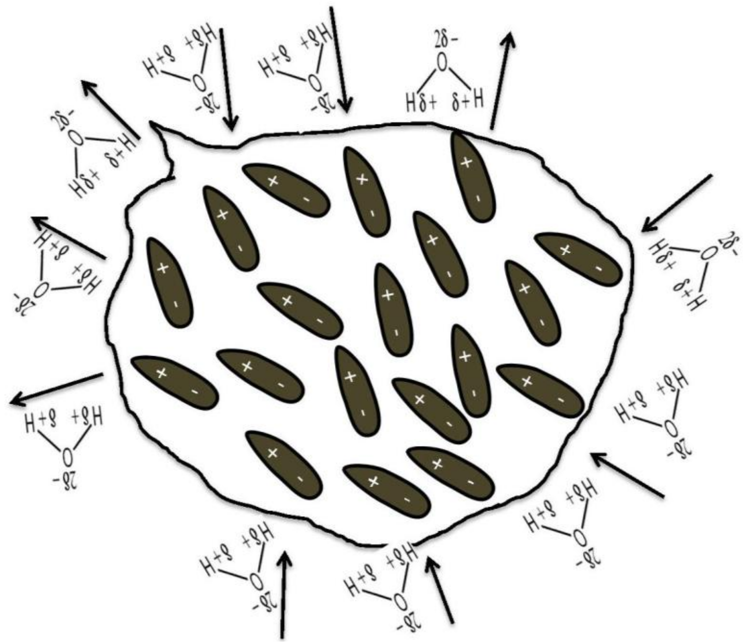

Figure 8. Schematic diagram: Dipole-dipole interactions (between the seed dipoles and water dipoles).

lating voltage, which is 700 V) shows that the electric susceptibility (χ_e) of the seed (caused by retaining the dipole moment upon removal of the electric field) is inversely proportional to the temperature (T), that is $\chi_e \propto 1/T$. Electrically treated seed follows the law $\chi_e \propto 1/T$, which is further supported by experimentally observed data as shown in Figure 6. Figure 6 shows that the relative change in the water uptake coefficient [k(700 V) - k(Control)] is inversely proportional to the temperature.

Conclusions

The exposure of chickpea seed under varying electric field from zero to 1300 V indicate that there is a critical (resonating) effect which is around 700 V (or at 466.6 V/cm) for 15 min exposure causing more stimulation in chickpea seeds as compared to treatments done at other applied voltage. Seeds exhibited ferroelectric properties. Dipole-dipole interactions are responsible for delay or acceleration in water absorption. Ferroelectric effect of the seeds decreased linearly with an increase in temperature.

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