

## Magnetic-time model at off-season germination

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**Abstract.** Effect of static magnetic field on germination of mung beans is described. Seeds of mung beans, were exposed in batches to static magnetic fields of 87 to 226 mT intensity for 100 min. Magnetic time constant – 60.743 Th (Tesla hour) was determined experimentally. High value of magnetic time constant signifies lower effect of magnetic field on germination rate as this germination was carried out at off-season (13°C). Using decay function, germination magnetic constant was calculated. There was a linear increase in germination magnetic constant with increasing intensity of magnetic field. Calculated values of mean germination time, mean germination rate, germination rate coefficient, germination magnetic constant, transition time, water uptake, indicate that the impact of applied static magnetic field improves the germination of mung beans seeds even in off-season.

**Key words:** decay function, magnetic-time model, Malthus-Verhulst functions, mung beans seeds

### INTRODUCTION

Germination of seeds depends on many factors like temperature, water potential, light, soil, electric field, magnetic field and electromagnetic radiation, *etc.* In the present study mung beans are used to find the effect of magnetic field on sprouting and germination in off-season. Mung bean (*Vigna radiata*) which is also commonly referred to as green bean, munggo or monggo, green gram, golden gram, green soy, mung, moong, or mash bean. Mung bean is a pulse crop widely grown in the Indian subcontinent as a short-duration catch crop between two principal crops (wheat and rice). Mung bean contains carbohydrates, proteins and has a low content of fat and fibre. It is a low input, short duration, high-value crop containing easily digestible protein. Mung bean fixes nitrogen in the soil and helps to maintain soil fertility. In Punjab (India), farmers often use two mung beans varieties – SML 832 and SML 668. Punjab Agricultural

University in India released SML 832, used in the present investigation, as a new high yielding, MYMV resistant (Mung bean Yellow Mosaic Virus) spring/summer mung bean variety. To increase Mung production farmers, use chemical fertilizers, insecticides and pesticides. Reckless application of chemical fertilizers, insecticides and pesticides pollutes the soil. Researchers are trying to find other techniques which must be proficient, clean and affordable, and free from insecticides and pesticides. One of those techniques is treating the seeds with magnetic field before sowing. With this method, the use of synthetic inputs such as fertilizers, pesticides, *etc.* can be avoided, and the crop production and its quality can also be increased. The effect of magnetic field (MF) on plants has been studied by various researchers (Mahajan and Pandey, 2011; Marks *et al.*, 2010; Matwijczuk *et al.*, 2012; Ratushnyak *et al.*, 2008; Rochalska *et al.*, 2007) for increasing germination rate, enhancing seedling vigour, improving germination time, and growth at later development stages of plant. Many researchers worked on different type of seeds like maize, wheat, sunflower, barley, corn, beans, tomato, fruit seeds, *etc.*, and found an increase in plant growth (height, yield, seed mass per spike, shoot and root length and total fresh and dry masses) for seeds treated with magnetic field (Dominguez *et al.*, 2010; Martinez *et al.*, 2009; Pietruszewski and Kania, 2010; Zepeda-Bautista *et al.*, 2010). The magnetic-field strength and exposure time duration both modulate the crop yield. Mahajan and Pandey (2012) worked on pre-treating black gram (*Cicer arietinum* L.) seeds in batches to static magnetic fields (0 to 226 mT) for 1h and found that treatment of seeds with those magnetic fields increased the speed of germination, seedling root and shoot length under laboratory germination tests.

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Temperature and water potential affect the germination rate if other parameters are kept constant (Bradford, 2002; Wei *et al.*, 2009). Many authors used the thermal-time model and the hydro-time model to study the effects of temperature and water potential on germination (Bradford, 2002; Hardegree, 2006; Chantre *et al.*, 2009). The thermal-time model has been combined with the hydro-time model that can describe seed germination patterns in a better way. These models explained very well the hydro and thermal parameters related to germination, but could not explain the effect of magnetic field. In the present work, the effect of magnetic field on germination and growth of mung bean (*Vigna radiata*) seeds has been described by using the magnetic-time model (Mahajan and Pandey, 2012). The magnetic-time model was tested at off-season germination.

When other factors like temperature, water potential, *etc.* are considered constant for a given place, then germination rate  $g(r)$  or  $1/t_g$  is also a linear function of applied magnetic field  $B$  (Mahajan and Pandey, 2012).

$$1/t_g = C + mB, \quad (1)$$

where:  $g(r)$  is germination rate and  $t_g$  is mean germination time of a given seed population  $g$ . In the Eq. (1),  $C$  is an intercept of  $1/t_g$ . Inverse of the slope of the straight line ( $1/m$ ) is denoted as  $\theta_B(g)$  and it is called the magnetic time constant for a given seed population  $g$ .

If  $g(r)$  or  $1/t_g$  is taken along X-axis and  $B$  along Y-axis, then the slope of line directly gives the value of  $\theta_B(g)$ . Then the Eq. (1) becomes:

$$B = \theta_B(g)(1/t_g) - H_g, \quad (2)$$

or

$$B + H_g = \theta_B(g)g(r), \quad (3)$$

where:  $H_g$  is constant ( $H_g = C/m$ ) for a given seed population and is an intercept of  $B$ .

The aim of present study was to propose a statistical function (decay function) which could be used to find the number of un-germinated seeds at any instant in a given sample, and also to find some statistical constant (function of magnetic field) which could be used to find the transient time between un-germinated and germinated states of a seed sample. Summation based mean germination time is a well-known physical parameter which is commonly used by a botanist to find the average time when seedling emerges from a seed. Finding mean germination time in this way has limitations as it varies with the number of seeds in the seed sample. The proposed transition time is analogous to mean germination time and it is independent of the number of seeds in a sample (transition time depends only on the shape of the curve of decaying seeds of given sample). Mung pulses are an excellent source of dietary proteins as well as cheap and high-quality food and can play an important role

in fulfilling the requirements of developing countries where the population is increasing rapidly. In spite of the best efforts made by many researchers (Delić *et al.*, 2011) for improving the mung bean germination and growth, the yield of this crop could not be increased much. As the demand of sprouted mung beans remains throughout the year, so there is a need to develop some technique to get sufficient sprouting at all seasons. Magnetic field treatment is a safe and affordable potential method to enhance beans sprouting even at off-seasons.

## MATERIALS AND METHODS

In order to get constant horizontal static magnetic field (North Pole to South Pole) of known strength (0 to 750 mT), a magnetic-field generator having flat faced 3.0 inches diameter cylindrical pole pieces was used. The pole pieces were wound with copper coils on nonmagnetic format and had resistance of about 3  $\Omega$ . The number of turns per coil was 850. The gap between the pole pieces was adjustable up to 4 inches with the help of two-way knobbed wheel screw adjusting system. Constant current up to 3.5 A coil<sup>-1</sup> (total of 7 A) was given to the electromagnet with DC power supply (0-45V/0-7.5A) to get variable magnetic field. From DC power supply, continuous variable output current can be used for the electromagnet. A digital Gauss meter was used to monitor the field intensity produced in between the pole pieces. The probe of the digital Gauss meter was made of indium arsenide crystal and encapsulated in non-magnetic thin cylindrical sheet, and the range of measurement was up to 2T. Mung beans (*Vigna radiata*) were exposed to horizontal magnetic field of 87 to 226 mT for 100 min, in a cylindrical-shaped non-magnetic and thin transparent plastic sheet sample holder of 42 cm<sup>3</sup> capacity. Four replications of mung seeds comprising of 40 seeds in each set were taken in a cylindrical shaped plastic holder and kept between the two-pole pieces of the electromagnet. The magnetic field was applied for 100 min. The required intensity of the magnetic field was obtained by changing the total current in the coils of the electromagnet. The variation in the intensity of magnetic field from the centre to the end of the poles was negligible (0.8%). All the exposed seeds of each set were kept in between two moist thin cotton cloth layers and transferred onto a bed of sponge sheet of 2 cm thickness, kept inside transparent plastic boxes of dimensions 20×13×4 cm with a lid. Sponge sheets in each box were damped with an equal amount of tap water. All the seeds were soaked on the same day, ensuring that all the external variables were same for each set of seeds during the experiment. In case of necessity, on subsequent days an equal amount of water was added to the sponge of all sets of samples. All necessary precautions were taken ensuring that all the external variables were the same for each class of seed during the experiment. Before the experiment, all mung seeds were

washed in water, and then floating or broken beans, if any, were removed. Then the beans were soaked in water at room-temperature for softening the hard seed coat. The soaking process allows water to penetrate and stimulates germination. Water uptake was measured by weighing the seeds before and after the soaking, at fixed intervals of time. Mung beans can be sprouted in all the seasons, but best in the temperature range between 20 to 30°C. In the present study a slightly different but constant temperature of 13°C was used for sprouting. This was done to study the effect of static magnetic field at off-season sprouting. The experiment was performed in India at Patiala (Pb) (Khalsa College, Physics laboratory), between 1st and 4th of December, 2012. Sprouting is the first stage when seedling emerges from the bean after germination. When germination started, the number of germinated seeds was counted after certain time interval, and the shoot length of every germinated seed was also measured. During germination, the radicals of different seeds acquire different irregular shapes. In order to measure their length, a flexible thread is placed along the radical which also acquires the same shape as that of shoot. Finally, that length of the thread is measured with a scale. This was done to minimise the error in measurement of shoot length. Shoot length of individual seed was added to get total shoot length. A seed was considered to be germinated when the radical came out with more than 2 mm length.

In this study, a new function is proposed to find out the number of un-germinated seed  $N$  at any instant of time  $t$  in each set of samples. Let  $N_k$  be the total seeds in a sample.  $N_i$  is the number of seed germinated at  $t = t_0$ , then  $N$  can be calculated as:

$$N = (N_k - N_i) \exp(-\lambda_B(t - t_0)). \quad (4)$$

Substituting  $(t - t_0) = 1/\lambda_B$  in Eq. (4) we get  $N = 0.368(N_k - N_i)$ . The constant  $\lambda_B$  is reciprocal of time  $(t - t_0)$  at which the number of seeds left in un-germinated state reduces to 0.368 time the number of seeds in the sample at time  $t_0$ . Transition time of germination  $t$  (between un-germinated and germinated state) can be defined from the decay Eq. (4), as follows:

$$t = (1/\lambda_B) + t_0. \quad (5)$$

Nested iterative procedures and least squares regressions were applied to estimate the germination magnetic constant ( $\lambda_B$ ).

The number of seeds germinated at any instant  $t$  can be found using reformulated Malthus-Verhulst equation (Mahajan and Pandey, 2011; Pietruszewski, 2001, 2002; Pietruszewski and Kania, 2010):

$$N_g(t) = N_k N_i / [N_i + (N_k - N_i) \exp(-\alpha N_k(t - t_0))], \quad (6)$$

where  $\alpha$  is germination rate coefficient. Water uptake by seed is calculated using the formula (Nizam, 2011):

$$\text{Water uptake (\%)} = ((W_2 - W_1) / W_1) 100, \quad (7)$$

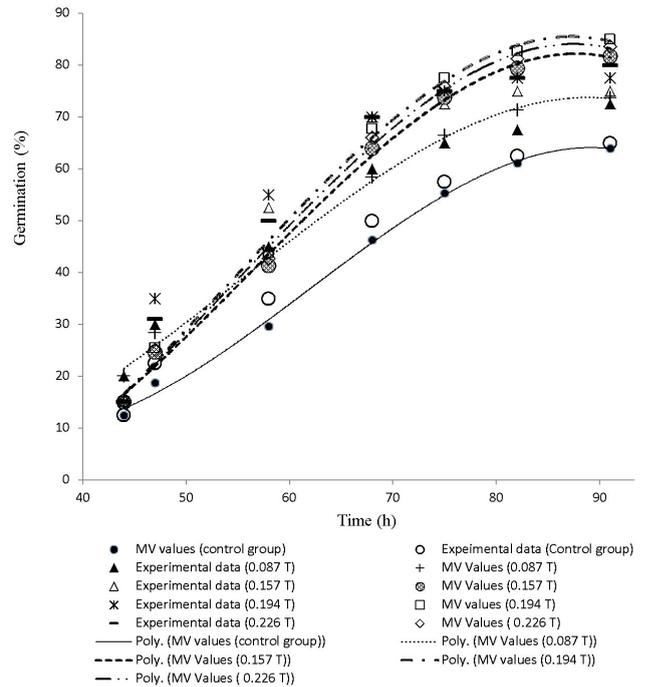
where:  $W_1$  = initial weight of seed and  $W_2$  = weight of seed after absorbing water in a particular time. For finding mean germination time many scientists (Balouchi *et al.*, 2009; Matthews *et al.*, 2006; Salehzade *et al.*, 2009; Sikder *et al.*, 2009) have used the formula:

$$\bar{t} = \frac{\sum_{i=1}^k n_i t_i}{\sum_{i=1}^k n_i}. \quad (8)$$

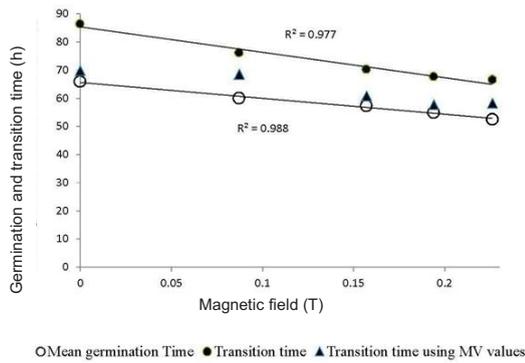
In Eq. (8)  $t_i$  signifies the time from the start of the experiment to the  $i$ th observation (in days or hours),  $n_i$  signifies number of seeds germinated for  $i$ th observation, and  $t_k$  signifies the last time of germination for  $k$ th observation.

## RESULTS

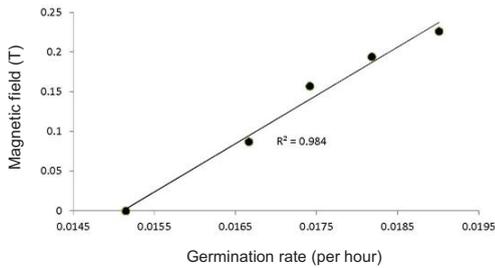
The experimental data of *Vigna radiata* seeds (for different values of intensity of magnetic field – 0.087, 0.157, 0.194, 0.226 T and control) at constant time duration of 100 min fitted well in re-formulated Malthus-Verhulst (MV) Eq. (6). The trend obtained is shown in Fig. 1. Germination kinetic curves of different seed samples show the increase in germination capacity with increasing intensity of magnetic field. Figure 2 shows that the value of transition time decreases with increasing exposure to magnetic field. Both the transition time and mean germination time values for various exposures of magnetic field are linearly magnetic



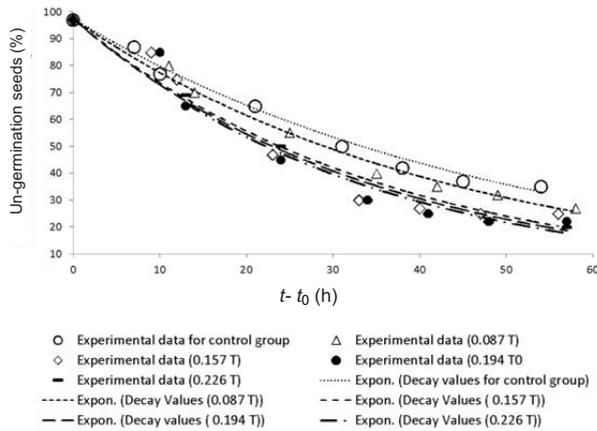
**Fig. 1.** The effect of magnetic field on germination of *Vigna radiata* seeds.



**Fig. 2.** Transition and mean germination time as a function of magnetic field intensity.

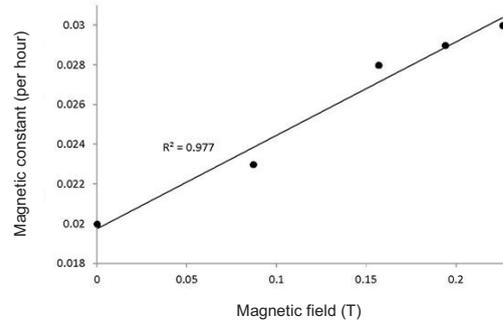


**Fig. 3.** Effect of magnetic field on germination rate.

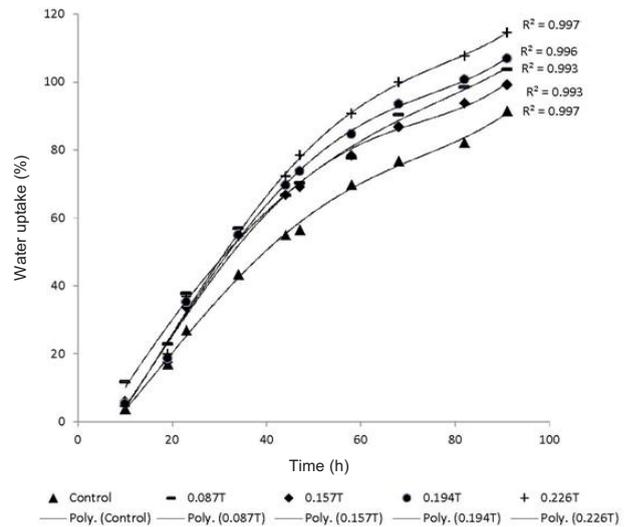


**Fig. 4.** Effect magnetic field on percent of *Vigna radiata* un-germinated seeds.

field dependent (Fig. 2). Mean germination rate increases linearly with exposure to magnetic field  $B$  on *Vigna radiata* seeds, following the equation  $B = 60.743g(r) - 0.9172$  (Fig. 3). Experimental data of un-germinated *Vigna radiata* seeds versus time are plotted along with the theoretically calculated values using the decay Eq. (4) for different values

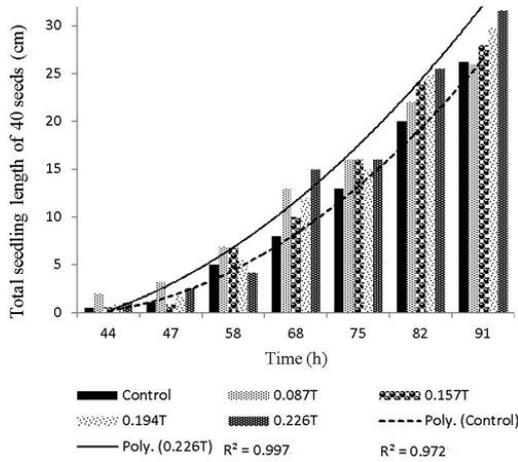


**Fig. 5.** Relation between magnetic constant and intensity of magnetic field.



**Fig. 6.** Water uptake (percentage) during germination of *Vigna radiata* seeds.

of magnetic field intensities for samples exposed for 100 min. For each data field, a decaying exponential curve is obtained and shown in Fig. 4. There is a good match between experimental and theoretical values. Figure 5 shows that there is a linear increase in germination magnetic constant  $\lambda_B$  with increasing intensity of magnetic field. Water absorption of treated and untreated seeds for all exposures to magnetic field plotted against the fixed interval of time for all the seed samples is shown in Fig. 6. Water absorption slope is more rapid for all the samples at the start (or before the seedling emerges). As seedling emerges out, the slope of the water absorption curve decreases. Total seedling length of seed sample (40 seeds) can be described with polynomial function (total seedling length of 40 seeds:  $l = at^2 + bt - c$ , where  $a, b, c$  are some constants for a particular seed sample and are a function of temperature, water potential, magnetic field and other parameters which affect the germination (Fig. 7).



**Fig. 7.** Increase of total seedling length of 40 seeds with time for all exposure intensities of magnetic field.

## DISCUSSION

The experimental data of magnetic-field intensities at values 0.087, 0.157, 0.194 and 0.226T for 100 min of exposure and also for control fitted well in the re-formulated Malthus-Verhulst equation (Fig. 1). Using the re-formulated Malthus-Verhulst equation the germination rate coefficient was determined ( $\alpha$ -values:  $\alpha_c=0.003h^{-1}$ ,  $\alpha_{0.087T}=0.0028h^{-1}$ ,  $\alpha_{0.157T}=0.0038h^{-1}$ ,  $\alpha_{0.194T}=0.0041h^{-1}$ ,  $\alpha_{0.226T}=0.004h^{-1}$ ) by minimising the residual sum of squares and executing the best possible fit for the growth model to the data. Data shows that values of  $\alpha_{0.157T}$ ,  $\alpha_{0.194T}$ ,  $\alpha_{0.226T}$  are slightly improved over the control, except  $\alpha_{0.087T}$ . However, kinetic curve (Fig. 1) shows the higher yield for higher fields and also at 0.087T. Apparently, the  $\alpha$  values do not signify definite result, but these values become important upon taking its reciprocal  $(K/\alpha) + t_0$ , where K is some fractional constant. When K is considered 0.1 then  $(K/\alpha) + t_0$  values approximately matches with mean germination time and signifies that upon increasing magnetic field there is a linear decrease in mean germination time (Fig. 2). Pietruszewski and Kania (2010) obtained the data ( $\alpha_c = 5.155 \cdot 10^{-3}$ ,  $\alpha_{D11} = 7.625 \cdot 10^{-3}$ ,  $\alpha_{D13} = 7.625 \cdot 10^{-3}$ ,  $\alpha_{D21} = 7.085 \cdot 10^{-3}$ ,  $\alpha_{D23} = 5.855 \cdot 10^{-3}$ ) for wheat seeds by exposing seeds to magnetic field of 45mT and 30 mT for different time intervals and at the different time (for magnetic doses: D11=D13=12.9 and D21=D23=17.9 kJ m<sup>-3</sup>). They concluded that the yield of wheat for the exposure doses D11=D13 was 12.5% higher and for doses D21=D23 and 14.5% higher than control.

Both the transition time values (calculated using the formula  $(1/\lambda_B) + t_0$ ) and mean germination time values (calculated using Eq. (8)) are parallel for different exposures to magnetic field and are linearly dependent on the magnetic field as shown in Fig. 2. The mean germination time obtained is summation based. It tells the average time when

seedling emerges from a seed. Calculation of mean germination time using summation equation has limitations as it varies with the number of seeds in the given seed sample. Transition time depends only on the shape of a curve of decaying seeds for a given sample and is independent of the number of seeds in a sample, so it gives more precise value as compared to mean germination time.

Figure 3 shows that mean germination rate for a given seed population is a linear function of applied magnetic field above  $H_g$ . The slope of the line gives the magnetic time to germination ( $\theta_B$ ). Magnetic time equation obtained from Fig. 3 is  $B + 0.9172 = 60.743 g(r)$ . From this equation, magnetic time constant  $\theta_B$  is calculated by comparing it with Eq. (3) which is 60.743Th (Tesla hour). The constant value  $H_g$  in Eq. (3) can also be calculated from Fig. 3, which is 0.9172 T (Tesla). Mahajan and Pandey (2012) calculated  $\theta_B$  equal to 9.1578 Th for black-gram seeds (*Cicer arietinum* L.) by exposing it in batches to static magnetic fields of 0 to 226 mT strength in steps of 50 mT (approximately) for 1 h. In the present study the value of magnetic time constant  $\theta_B$  is high, which signifies lower effect of magnetic field on germination rate, as was expected because this germination was carried out at off-season of germination of *Vigna radiata* seeds. Aladjadjian (2003) showed that magnetic field excites the process of germination and there is a linear function between germination G and exposure time of magnetic field with equation  $G = 0.088t + 0.215$  and  $G = 0.0745t + 0.3$  for non-soaked and preliminary soaked tobacco seeds (*Nicotiana tabacum* L.).

The experimental data of un-germinated *Vigna radiata* seeds versus time fitted in the theoretically calculated decay Eq. (4) for different values of magnetic-field intensities (Fig. 4). The advantage of the decay function is that one can find the number of un-germinated seeds at any time in a given seed sample. Another application of the decay function is to find the transition time (using Eq. (5)) from un-germinated state to germinated state with the help of germination magnetic constant  $\lambda_B$  ( $\lambda_{B(\text{control})} = 0.02h^{-1}$ ,  $\lambda_{B(0.087T)} = 0.023h^{-1}$ ,  $\lambda_{B(0.157T)} = 0.028h^{-1}$ ,  $\lambda_{B(0.194T)} = 0.029h^{-1}$ ,  $\lambda_{B(0.226T)} = 0.03h^{-1}$ ). The data show that there is a linear increase in germination magnetic constant with increasing intensity of magnetic field, as shown in Fig. 5. Increasing germination magnetic constant implies the decrease in transition time, hence magnetic field improves the germination time even at off-season. Bar graph (Fig. 6) of water uptake (percentage) shows that water absorption increases for treated seeds for all exposures to magnetic field, and it is the highest for 0.226T and the lowest for the control. The same information can be retrieved from total seedling length of 40 seeds (Fig. 7). It is clear from Fig. 7 that seedling length of 40 seeds grows satisfying the polynomial equation ( $l_{0.226T} = 0.5048t^2 + 1.2976t - 1.5857$  and  $l_{\text{control}} = 0.5655t^2 - 0.1345t - 0.2286$ ) which is the highest at 0.226T exposure and the lowest at control. The graph shows that even at

off-season the application of magnetic field gives better yield, that is good sprouting with increasing intensity of magnetic field. Early germination data (mean germination time, mean germination rate, germination rate coefficient, germination magnetic constant, transition time, water uptake) and total seedling length data show the positive impact of magnetic field on *Vigna radiata* seeds.

#### CONCLUSIONS

1. Mean germination time, mean germination rate, germination rate coefficient, germination magnetic constant, transition time and water uptake indicate that the impact of applied static magnetic field improves the germination of *Vigna radiata* seeds even at off-season.

2. There is a decrease in transition germination time and mean germination time with increasing exposure of magnetic field to *Vigna radiata* seeds.

3. The proposed new germinating function (decay function) fitted well to the experimental data. By using this function one can find the number of un-germinated seeds at any instant in the sample under observation.

4. The germination magnetic constant may be described by a straight line with increase in intensity of magnetic field.

5. Magnetic time model worked well for germination of *Vigna radiata* seeds. High value of magnetic time constant signifies low effects of magnetic field on germination rate, as was expected because this germination was carried at off-season.

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