African Journal of Biotechnology Vol. 11(88), pp. 15415-15421, 1 November, 2012
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB12.2212
ISSN 1684–5315 ©2012 Academic Journals

Full Length Research Paper

Magnetic-time model for seed germination

Tarlochan Singh Mahajan[1]* and O. P. Pandey[2]

[1]Department of Physics, GSSDGS Khalsa College, Patiala 147001, Punjab, India.
[2]School of Physics and Materials Science, Thapar University, Patiala 147004, Punjab, India.

Accepted 24 September, 2012

Germination of seed depends on several physico-chemical factors like temperature, water potential, light, nitrate content, smoke, electric field and magnetic field. In the present work, effect of static magnetic field on black-gram seeds (*Cicer arietinum* L.) was described. Seeds of *C. arietinum* L. were exposed in batches to static magnetic fields of 0 to 226 mT strength in steps of 50 mT (approximately) for 1 h. Treatment of seeds in these magnetic fields increased the speed of germination, seedling shoot and root length under laboratory germination tests. On the basis of this, a new germination model called magnetic time model is developed which was incorporated in hydrothermal model and hence nominated as hydrothermal magnetic time model which is proposed to incorporate the effect of magnetic field of different intensities on plants. Magnetic time constant θ_B is determined experimentally for different seeds population. The model is helpful in a way that it defines another constant called hydrothermal-magnetic-time constant, which is of great importance to understand the behavior of induced magnetic field on seeds and plant growth.

Key words: Magnetic-time model, hydro-thermal-magnetic-time model, *Cicer arietinum* L.

INTRODUCTION

The physiological process of germination depends on several environmental factors such as temperature, water potential, light, nutrients and smoke (Baskin and Baskin, 2004). The effects of static magnetic fields on the metabolism and growth of different plant species was reported by several authors (Harichand et al., 2002; Aladjadjiyan et al., 2003; Florez et al., 2007; Majd et al., 2009; Fischer et al., 2004). Temperature is an important factor in seed germination which affects dormancy and germination rate (Wei et al., 2009; Probert et al., 2000). Water potential also affects the seed population (Bradford, 2002). The germination and growth behavior of different seeds under the influence of different physical parameters have been explained by different models. Effect of temperature is discussed in thermal-time model (Ellis et al. 1986; Vleeshouwers and Kropff, 2000; Hardegree 2006; Guillermo et al. 2009). To account for the effects of water potential on progress toward germination, Gummerson (1986) and Bradford (2002) proposed the hydro-time model. Thermal-time and hydro-time have been combined into hydrothermal-time model that can describe seed germination patterns. These models explained very well the thermal and hydro parameters related to germination but was unable to describe the effect of magnetic field. In the present work, effect of magnetic field on germination and growth of black gram (*C. arietinum* L.) seeds were described. Based on this study, a new model called magnetic time model and hence hydrothermal magnetic time model was proposed. A combined effect of all these factors (magnetic, thermal and hydro parameters) explains the growth of seeds in a better way as compared to existing models. With the help of proposed model, one can study the germination and growth behavior of seeds over a wide range of parameters like water, temperature along with magnetic field.

Existing models

Thermal-time model

Mathematical models that describe germination patterns in response to temperature *(T) have* been developed (Bradford, 2002). This model predicts that the germination rate for a given seed fraction or percentage or the inverse of germination time (*GRg*, or $1/t_g$) is linear function of T above T_b. The minimum or base temperature T_b is the lowest temperature at which germination can occur.

*Corresponding author. E-mail: sikhsidhant@gmail.com.

The optimum temperature T_o is the temperature at which germination is most rapid. This can be written as:

$1/ t_g = K + m T$ or

$1/ t_g = m (T - T_b)$

Inverse of the slope of straight line (*1/ m*) is called thermal time constant $\theta_T(g)$.

For suboptimal temperatures (from T_b to T_o), germination timing can be described on the basis of thermal time or heat units. That is, the T in excess of T_b multiplied by the time for a given germination percentage t_g, and is a constant for that percentage (the thermal time constant, $\theta_T(g)$) which can be written as:

$$\theta_T(g) = (T - T_b) t_g \quad (1)$$

$$GR_g = 1/ t_g = (T - T_b) / \theta_T(g) \quad (2)$$

This model predicts that the germination rate for a given seed fraction or percentage (*GRg* or *1/tg*) is linear function of T above T_b. The maximum or ceiling temperature (T_c) is the highest temperature at which seeds can germinate. Similar models have been proposed to describe germination rates at supra-optimal temperatures (from T_o to T_c). In many cases, *GRg* declines linearly with an increase in T between T_o and T_c (Hardegree, 2006). To account for this variation in T_c values, Ellis et al. (1986), Covell et al. (1986) and Hardegree (2006) proposed the following model:

$$\theta_2 = (T_c (g) - T) t_g \quad (3)$$

or

$$GR_g = 1/ t_g = (T_c (g) - T) / \theta_2 \quad (4)$$

Where θ_2 is a thermal time constant at supra-optimal T and T_c (g). The above equations are verified experimentally by Alvarado and Bradford (2002).

Hydro-time model

Gummerson (1986) and Bradford (2002) proposed the hydro time concept. When a seed is dried from fully hydrated state, there must be some point at which it will no longer be able to germinate. Ψ_b is the base or threshold parameter that will just prevent germination of fraction *g* of the seed population.

Gummerson (1986) and Bradford (2002) showed that if *GRg* values were plotted as a function of Ψ, the resulting curves were essentially linear and parallel. According to hydro-time model, germination rate is linearly related to water potential. Θ_H is hydro time constant and can be written as:

$$\Theta_H = (\Psi - \Psi_b) \times t_g \quad (5)$$

From Equation 5, t_g is inversely related to the difference between the Ψ and Ψ_b value of that seed.

Hydro-thermal model

Thermal-time and hydro-time models as described above have been combined to form hydrothermal-time model that can describe seed germination patterns. Combining Equations 1 and 5, a hydrothermal time constant Θ_{HT} for sub-optimal temperature T can be defined (Bradford, 2002; Grundy et al., 2000):

$$\Theta_{HT} = (\Psi - \Psi_b) (T - T_b) t_g \quad (6)$$

This hydrothermal model has worked well to describe germination time courses (Bradford, 2002).

Limitations of existing models and solutions (magnetic-time model)

Established models explain the thermal and hydro parameters related to seeds germination but fail to include effect of magnetic field. In order to understand the effect of magnetic field on plant growth features, we proposed a new model which is magnetic-time and hydrothermal-magnetic models to incorporate the effect of applied magnetic field on growth of the seeds.

Proposed model

Magnetic-time model

When other factors like temperature, water potential, etc. are kept constant at a given place then germination rate GR_g or $1/ t_g$ is also a linear function of applied magnetic field B:

$$1/ t_g = C + m B \quad (7)$$

Where, C is intercept of $1/ t_g$. Inverse of the slope of straight line (*1/ m*) is called magnetic time constant $\theta_B(g)$. If GR_g or $1/ t_g$ is taken along X-axis and B is along Y axis, then slope of line directly gives the value of $\theta_B(g)$, then equation (7) becomes:

$$B = \theta_B(g) (1/ t_g) - H_g \quad (8)$$

or

$$B + H_g = \theta_B(g) GR_g \quad (9)$$

Where, H_g is some constant for a given fractions (percentages) of the seed population and is intercept of B.

Hydro-thermal-magnetic-time model

Thermal-time, hydro-time and magnetic-time have been

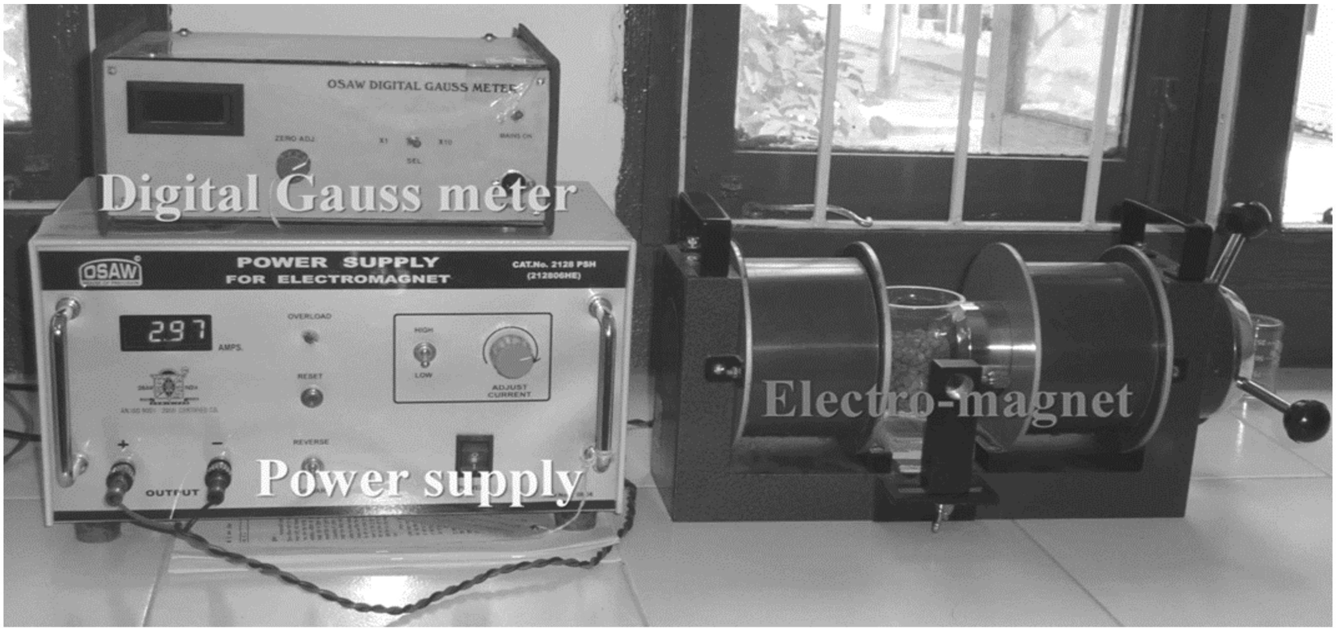

Figure 1. Photograph of magnetic field generator.

combined into hydrothermal-magnetic-time model that can describe seed germination patterns more precisely. By combining Equations 6 and 9, a hydrothermal-magnetic time constant (Θ_{HTB}) for sub-optimal conditions can be defined as:

$$\Theta_{HTB} = (\Psi - \Psi_b)\ (T - T_b)\ (B + H_g)\ t_g \quad (10)$$

The aim of the present study is to analyse the magnetic-time model for seed germination.

MATERIALS AND METHODS

A magnetic field generator was fabricated to provide variable horizontal static magnetic field (north pole to south pole) of strength up to 750 mT. The gap between pole pieces was variable (5 to 10 cm) with two way knobbed wheel screw adjusting system (Figure 1).

The flat faced pole pieces were cylindrical in shape with 7.5 cm in diameter. There was two coils, each coil was wound on non-magnetic format and had resistance of about 3 ohm. The number of turns per coil was 850. The power supply was designed to provide constant current to electromagnet. The current requirement up to 3.5 amp/coil (the total of 7 amp) was met by DC power supply (0-45V/0-7.5A) with a continuous variable output current used for the electromagnet. A digital Gauss meter monitored the field strength produced in the pole gap. The probe was made of indium arsenide crystal and encapsulated to a non-magnetic thin cylindrical sheet which could measure up to 2T.

Black-gram seeds (*C. arietinum* L.) were exposed to the magnetic field of 62 to 226 mT in steps of 50 mT for 1 h for all field strengths in a cylindrical-shaped sample holder of 42 cm^3 capacity, made of a non-magnetic thin transparent plastic sheet. Four replications for each sample comprising of 30 seeds in each set were taken in a cylindrical plastic container and kept in between the poles of the electromagnet. The magnetic field was applied for one hour. The required strength of the magnetic field was obtained by increasing the total current in step of 1.5 A in the coils of the electromagnet. From center to end of the poles, the variation in the magnetic field was 0.8% in all around outward direction. All treatments in the experiments were run simultaneously along with controls under similar conditions and the experiment was performed in natural light.

Each sample of 30 seeds was divided into two halves, fifteen seeds were taken in five transparent plastic boxes with lid of dimension 20 × 13 × 4 cm^3 and a sponge sheet of thickness 2 cm. The rest of fifteen were sowed in an earthen pot. It was ensured that all the pots are having same type of soil and same amount of moisture content. Sponge sheets in each box were damped with equal amount of water. All the seeds were planted on same day, ensuring that all the external variables are same for each class of seed during experiment. Average room temperature and average relative humidity was 26°C and 80%, respectively during observations. Equal amount of water was added to the sponge of all samples when necessary. When germination started then, number of germinated seeds was counted after certain time interval and the shoot length of every germinated seed was also measured using thread. This was done to minimize 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 radical came out with more than 2 mm length (Kaveh et al., 2011; Al-Harbi et al., 2008). Root length and shoot length of 8-day-old seedling (in earlier stage of growth) in the pots was measured. Mean germination time of seeds contained in sponged plastic boxes was calculated using:

$$\bar{t} = \sum_{i=1}^{k} n_i \times t_i \Big/ \sum_{i=1}^{k} n_i.$$

RESULTS AND DISCUSSION

Our laboratory data showed that exposure of different magnetic fields enhances the germination of black gram

Figure 2. Photograph showing enhancement of root and shoot length of 8 day old black gram (*C. arietinum* L.) seedlings.

Table 1. Root length and shoot length in 8 days seedlings in cm with statistical parameters.

Statistical parameter	Root length in 8 days seedlings (cm)					Shoot length in 8 days seedlings (cm)				
	control	0.06T	0.116T	0.168T	0.226T	control	0.06T	0.116T	0.168T	0.226T
Mean	9.5	17.3	17.6	11.8	13.3	6.68	12	10.5	10.7	8.91
Standard error	0.72	1.1	0.94	0.44	0.68	0.26	0.49	0.54	0.42	0.39
Standard deviation	2.39	3.66	3.12	1.47	2.25	0.87	1.63	1.8	1.4	1.3
Minimum	6	12	15	10	10	5	9	7.5	9	7
Maximum	14	22.5	26	15	16.5	8.5	15	13	13	11.5

(*C. arietinum* L.) seeds (Figure 2). There is excellent improvement in germination related characters such as mean germination time, germination rate, root length and shoot length of seeds contained in sponged condition (lag phase of plant growth) and also for sown 8 day old seeds (exponential phase of plant growth) under the applied static magnetic field. The role of local magnetic field is negligible in germination as its value is too small (0.000032T) and its variation is negligible from place to place as compared to applied magnetic field which is 50 to 226 mT. Enhancement of various crop seeds exposed to magnetic fields has also been reported by many workers (Aladjadjiyan, 2002; Fischer et al., 2004; Florez et al., 2007; Vashisth et al., 2007, 2008, 2010a, 2010b). From experimental data (Table 1) it is found that shoot length of 8 day old seedling increased from 33 to 80% (Figures 2 and 3) and root length is increased from 25 to 85% (Figures 2 and 4) with applied magnetic field (62 to 226 mT). Increase in root length is comparatively higher than shoot length. The yield (root length plus shoot length) is maximum between 62 and 116 mT for one hour treatment of magnetic field for black gram (*C. arietinum* L.) seeds as shown in Figure 5. Shabrangi and Majd (2009) reported the data on lentil seeds with varying magnetic field of 0.06 to 0.36 T and showed root length as linear function of applied magnetic field and found optimal field near around 0.3 T where the root length was maximum. Vashisth et al. (2007, 2010a, 2010b) in their study have shown that at certain combinations of magnetic field and exposure time, the germination rate is enhanced. Their observation indicates that the internal energy of the seed responds positively when there is an appropriate combination of magnetic field and exposure time. In their recent publication, Vashisth and Nagarajan (2010a) have shown enormous improvement over untreated control sunflower (*Helianthus annuus*) of 10 day old seedlings, which was 6 to 41% for shoot length, 16 to 80% for root length and 12to 57% for total seedling length. Florez et al. (2007) noted that germination of maize seeds becomes fast when they are exposed to

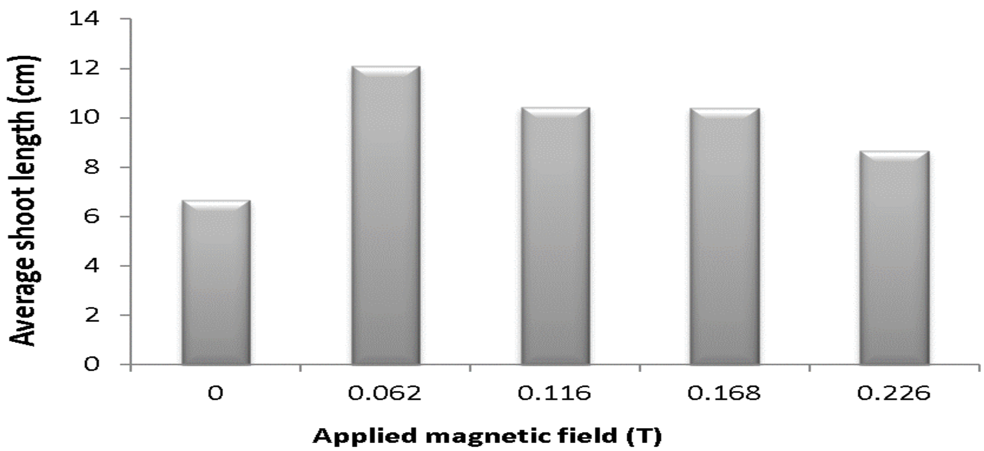

Figure 3. Variation of average shoot length (8 day old) with applied magnetic field.

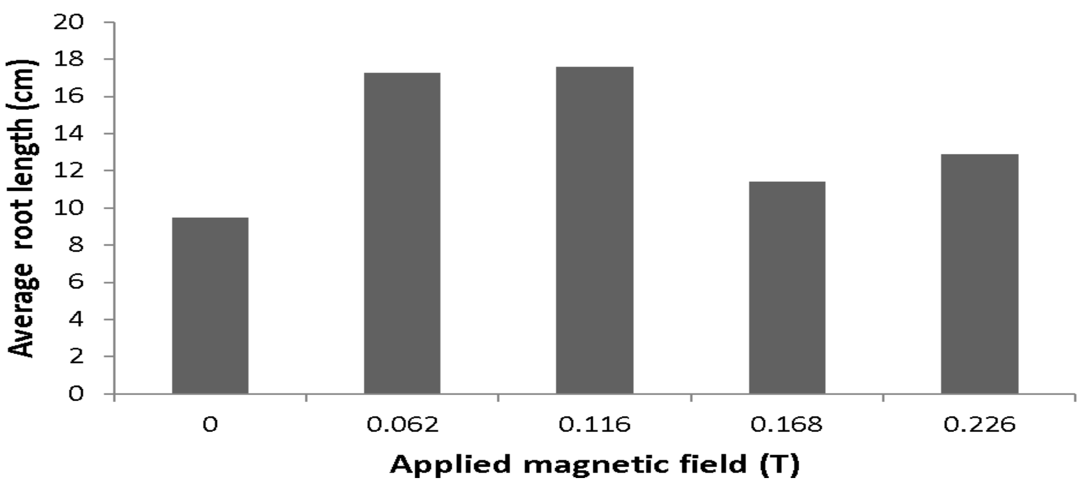

Figure 4. Effect of applied magnetic field on average root length (8 day old).

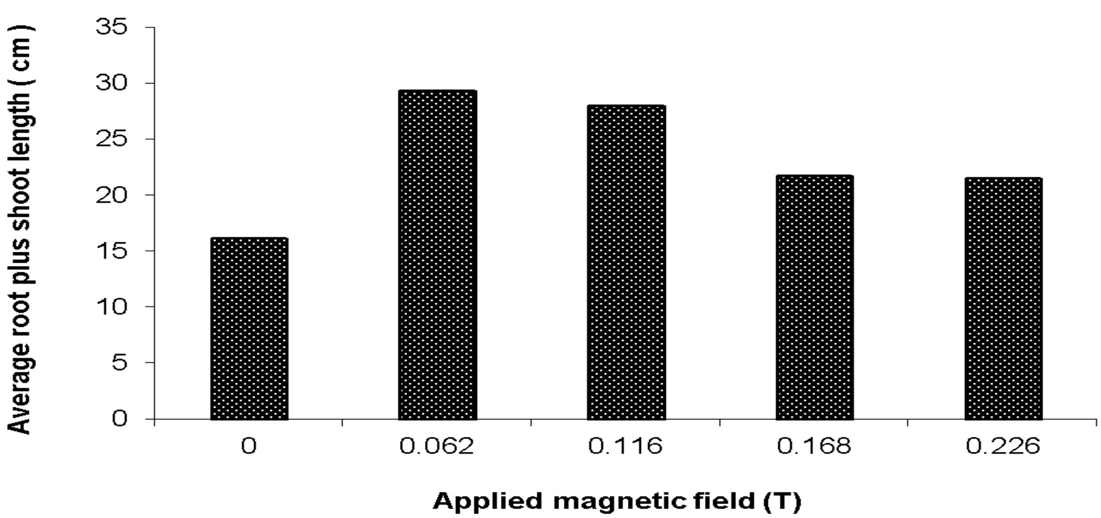

Figure 5. Effect of applied magnetic field on average root length plus shoot length (8 day old).

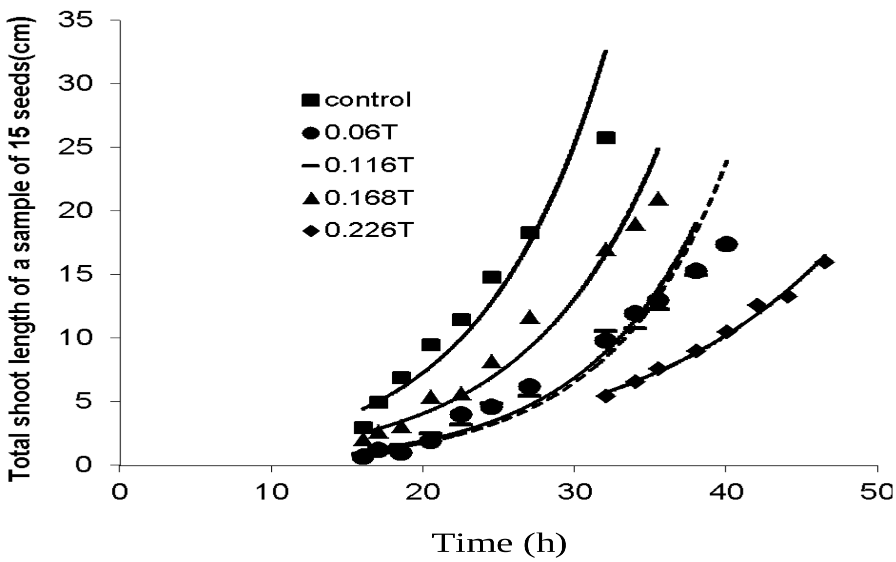

Figure 6. Exponential variation of total shoot length of a sample of 15 seeds with time.

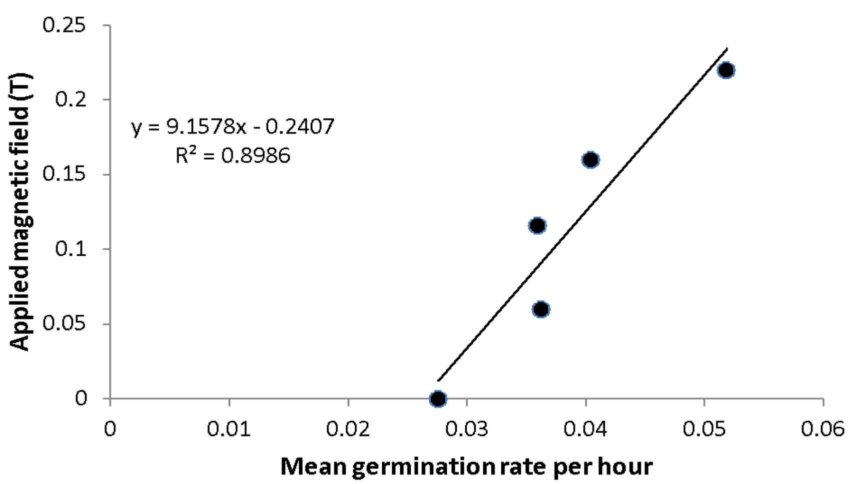

Figure 7. Variation of germination rate GR_g or $1/t_g$ as a linear function of applied magnetic field B.

magnetic field of 125 or 250 mT for varying periods of time. Florez et al. (2007) have reported that early growth and faster germination upon stimulation with magnetic field was shown when maize seeds were exposed to stationary magnetic fields of 125 or 250 mT for varying periods of time. Total length and fresh weight of 10-day-old seedlings were highest when their seed-lot was exposed to 125 or 250 mT. Vashisth and Nagarajan (2010b) found that for 7 days old seedling of maize (*Zea mays* L.) when subjected to different magnetic fields for different duration, had an increase in germination, speed of germination, seedling length and seedling dry weight of 9, 20, 57 and 35%, respectively as compared to control.

In the present study, the number of germinated black gram (*C. arietinum* L.) seeds was seen after some fixed time interval and the shoot length of every germinated seed was also measured using thread. Data obtained was plotted as total shoot length of entire seeds sample versus time. The trend of graph found is exponential in nature as shown in Figure 6. For a given time, the curves become steeper for higher values of field. This implies that magnetic field enhances just the germinating growth of black gram (*C. arietinum* L.) seeds. There is also excellent improvement in germination rate with the treatment of magnetic field as shown in Figure 7, which is in good agreement with results obtained by Mahajan and Pandey (2011).

Figure 7 shows that mean germination rate for a given seed population is a linear function of applied magnetic field above H_g. The slopes of line (Figure 7) give the magnetic times to germination (θ_B). Magnetic time equations for 100% of the seed population in Figure 6 is $B + 0.2407 = 9.1578\ GR_g$. From this equation, magnetic time constant $\theta_B(100)$ is calculated as 9.1578 Th (Tesla hour). The constant value H_g in Equation (9) can also be calculated from Figure 7, which is 0.2407 T (Tesla). In the absence of applied magnetic field, this constant H_g determines the germination time or germination rate. The constant H_g is analogues with T_b (in thermal time model) and with Ψ_b (in hydro-time model). T_b *and* Ψ_b are the minimum values below which germination of seeds is not possible (Bradford, 2002), likewise in magnetic time model H_g is based on threshold value in the units of magnetic field where germination rate attains some minimum value (but not zero). This is what is expected. In the absence of applied magnetic field, there are geographic and other electromagnetic fields which interact with germination processes. Bathnagar and Deb (1977) also showed that the coefficient of velocity of germination and percentage germination with respect to magnetic field are the linear function of magnetic fields. The magnetic-time model which is based on the enhancement of mean germination rate with applied magnetic field is in agreement with our laboratory data as well as the data obtained by different authors in context with stimulation of seeds with magnetic field of different intensities.

Conclusions

The present study evaluated the effect of magnetic field on germination rate of the seed population and the effect of static magnetic field on root and shoot length of black gram (*C. arietinum* L.) seedlings. Results obtained indicated that the impact of applied static magnetic field improves the germination time and enhances the germination rate of black gram (*C. arietinum* L.) seeds. Based on this study, a magnetic model for germination of seeds has been proposed. This model explains well the entire findings.

REFERENCES

Aladjadjiyan A (2002). Study of the influence of magnetic field on some biological characteristics of *Zea mays*. J. Cen. Euro. Agric. 3(2):89–94.

Aladjadjiyan A, Ylieva T (2003). Influence of stationary magnetic field on the early stages of the development of tobacco seeds (*Nicotiana tabacum* L.). J. Cen. Euro. Agric. 4(2):131-137.

Al-Harbi AR, Wahb-Allah MA, Abu-Muriefah SS (2008). 'Salinity and Nitrogen Level Affects Germination, Emergence, and Seedling Growth of Tomato'. Int. J. Veg. Sci. 14(4):380-392.

Alvarado V, Bradford KJ (2002). A hydrothermal time model explains the cardinal temperature for seed germination. Plant cell and Environ. 25: 1061-1069.

Baskin JM, Baskin CC (2004). A classification system for seed dormancy. Seed Sci. Res.14:1–16.

Bathnagar D, and Deb AR (1977). Some aspects of pre-germination exposure of wheat seeds to magnetic field: Germination and early growth. Seed Res. 5: 129-137.

Bradford KJ (2002). Applications of hydrothermal time to quantifying and modeling seed germination and dormancy, Weed Sci. 50:248–260.

Covell S, Ellis RH, Roberts EH, Summerfield RJ (1986). The influence of temperature on seed germination rate in grain legumes. I. A comparison of chickpea, lentil, soybean, and cowpea at constant temperatures. J. Exp. Bot. 37: 705–715.

Ellis RH, Covell S, Roberts EH, Summerfield RJ (1986). The influence of temperature on seed germination rate in grain legumes. II. Intraspecific variation in chickpea (Cicer arietinum L.) at constant temperatures. J. Exp. Bot. 37:1503-1515.

Fischer G, Tausz M, Kock M, Grill D (2004). Effect of weak 162/3 HZ magnetic fieldson growth parameters of young sun flower and wheat seedlings. Bioelectromag- netics. 25(8):638–41.

Florez M, Carbonell MV, Martinez E (2007). Exposure of maize seeds to stationary magnetic fields: effects on germination and early growth. Environ. Exp. Bot. 59:68–75.

Grundy AC, Phelps K, Reader RJ, Burston S (2000). Modelling the germination of Stellaria media using the concept of hydrothermal time. New Phytol. 148:433–444.

Gummerson RJ (1986). The effect of constant temperatures and osmotic potential on the germination of sugar beet. J. Exp. Bot. 37:729–741.

Guillermo RC, Diego B, Mario RS, Gustavo O (2009). Germination parameterization and development of an after-ripening thermal-time model for primary dormancy release of *Lithospermum arvense* seeds. Annals Bot.103:1291–1301.

Hardegree SP (2006). Predicting germination response to temperature. I. Cardinal-temperature models and sub-population specific regression. Annals Bot. 97:1115–1125.

Harichand KS, Narula V, Raj D, Singh G (2002). Effect of magnetic fields on germination, vigour and seed yield of wheat. Seed Res. 30(2):289–293.

Kaveh H, Nemati H, Farsi M, Jartoodeh SV (2011). How Salinity Affect Germination and Emergence of Tomato Lines. J. Biol. Environ. Sci. 5(15):159-163.

Mahajan TS, Pandey OP (2011). Re-formulation of Malthus-Verhulst Equation for Black Gram (*Cicer Arietinum* L.) Seeds Pre-treated with Magnetic Field. Int. Agrophys. 25(4):355-359.

Majd A, Shabrangi A, Bahar M, Abdi S (2009). Effect of AC and DC Magnetic Fields on Seed Germination and Early Vegetative Growth in *Brassica napus* L, (pp. 699). Moscow-Russia: Progress In Electromagnetics Research Symposium Proceedings.

Probert RJ (2000). The role of temperature in the regulation of seed dormancy and germination. In: Fenner, M. (ed.) Seeds: The ecology of regeneration in plant communities, 2nd edition. Wallingford, UK: CAB International. pp. 261-292.

Shabrangi A, Majd A (2009). Effect of Magnetic Fields on Growth and Antioxidant Systems in Agricultural Plants (pp. 27). China: PIERS Proceedings.

Vashisth A, Nagarajan S (2007). Effect of pre-sowing exposure to static magnetic field of maize (*Zea mays* L.) seeds on germination and early growth characteristics. Pusa Agric Sci. 30: 48–55.

Vashisth A, Nagarajan S (2008). Exposure of seeds to static magnetic field enhances germination and early growth characteristics in chickpea (*Cicer arietinum* L.). Bioelectromagnetics. 29(7):571–578.

Vashisth A, Nagarajan S (2010a). Effect on germination and early growth characteristics in sun flower (*Helianthus annuus*) seeds exposed to static magnetic field.J. Plant Physiol. 167:149–156.

Vashisth A, Nagarajan S (2010b). Characterization of water distribution and activities of enzymes during germination in magnetically-exposed maize seeds. Indian J. Biochem. Biophys. 47:311-318.

Vleeshouwers LM, Kropff MJ (2000). Modelling field emergence patterns in arable weeds. New Phytol. 148:445–457.

Wei Y, Bai Y, Henderson DC (2009). Critical conditions for successful regeneration of an endangered annual plant *Cryptantha minima*: A modeling approach. J. Arid. Environ. 73:872-875.