

# ***Effect of Electric and Magnetic Field on Seed Germination***

**A**

**Thesis**

**Submitted for the award of degree of**

**DOCTOR OF PHILOSOPHY**

**By**

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**January- 2014**

## CERTIFICATE

This is to certify that the thesis entitled “**Effect of Electric and Magnetic Field on Seed Germination**” which is being submitted by **Tarlochan Singh Mahajan** of the requirements for the award of the degree of Doctor of Philosophy in the School of Physics & Materials Science Thapar University, Patiala (Punjab), India is an exclusive record of candidate’s own research work under my supervision. The thesis in part or in full has not been submitted in any other university or institute for the award of any degree. The thesis is fit to be considered for the award of degree of Doctor of Philosophy.

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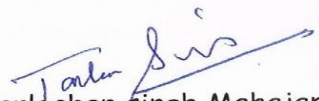
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- [2] **Mahajan T. S.**, and Pandey O. P., Magnetic-time Model at off Season Germination, *International Agrophysics*, **28**, 1, Accepted In Press doi: 10.2478, 2014.
- [3] **Mahajan T. S.**, and Pandey O. P., Magnetic-time model for seed germination, *African Journal of Biotechnology*, **11**, 88, 15415-15421, 2012.
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- [9] **Mahajan T. S.**, and Pandey O. P., Effect of Electric and Magnetic Treatments on the Germination of Bitter Gourd (*Momordica charantia*) Seed, *International Journal of Agriculture and Biology*, **Under review process** IJAB-13-1225, 2013.
- [10] **Mahajan T. S.**, and Pandey O. P., Electrical Stimulation on the Germination of *Vigna Radiata* Seed (Article Id: IJBT-301), *Indian Journal of Biotechnology*, **Under review**, 2013.

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## PREFACE

Visible light plays an important role for the survival of species in our eco-system. Light signals control the seed germination, leaf expansion, stem elongation, flower initiation and pigment synthesis. Since light being electromagnetic source affects the process of seed germination therefore, it is of special interest to find the effect of electric and magnetic fields on the seed germination process.

In view of increasing population, particularly in developing countries, it is imperious to increase the crop production. Insecticides and pesticides are used to increase the crop yield, but there are evidences which showed that over use of chemicals do pose a potential risk to humans and other life forms and unwanted side effects to the environment. So there is a need to turn toward new technological involvements to increase food production. There is a special need to determine whether an electric and magnetic field can be utilized to stimulus the seed germination process or not.

Earth's magnetic field is a natural component of the environment for living organisms and there is an electric field between clouds and the earth. All plants on the earth's surface experience electric and magnetic fields. However, the role of electric and magnetic fields and their influence on plants is insufficiently understood. Presented work deals with the studies relating to pre-sowing electric and magnetic treatment on dry seeds and finding early germination parameters. The entire work in this thesis is presented in **six chapters**.

In the **first Chapter** physical parameters for the measurement of electric and magnetic fields are given. Some statistical functions, which are used for cumulative germination along with their limitations, are described. Malthus-Verhulst function is used to find the germination rate coefficient. Its use along with its limitation is discussed in this chapter. Established models explain the thermal and hydro parameters related to seed's germination but fail to include the effect on magnetic field. Water absorption statistic is an important tool to understand basic germinating processes. Therefore, existing water models are discussed along with their limitations. The work done on different seeds has been presented in this chapter.

**Chapter 2** gives a detailed account of the literature survey in context of the effects of electric and magnetic treatment on seed germination and plant growth. It is found that no data analysis (regarding electric and magnetic treatment to seed) is available on the white gourd (*Benincasa hispida*), spinach (*Spinacia oleracea* L.), and bitter gourd (*Momordica Charantia*) seeds. Some data of magnetic-field treatment is available for chickpea (*Cicer arietinum* L.), maize (*Zea mays* L.), mung bean and okra (*Abelmoschus esculentus* L.), but the data is limited (a few

magnetic values and a few exposure times) and not sufficient to reach at any conclusion relevant to the effect of electric and magnetic field on seed germination process. Literature review showed that research work available on the effect of the electric field on seed germination is limited. Very few researchers worked on the study of water uptake by the magnetically treated seeds, but no work has been done on the effects of water uptake by electrically treated seeds. This chapter highlighted the reports of bio-electric and bio-magnetic responses on the seeds and plants. Many reports contain positive responses of seed germination and seedling growth, and moreover, some other reports contain negative responses on the germination with the application of electric and magnetic field. In this chapter, it is described that there is a need to generate more electric and magnetic germinating data for seeds, which are not being taken yet and to correlate it with the seed germination parameters.

**Chapter 3** describes about experimental procedures followed for the electric field and magnetic-field treatment of seeds. For the verification of the experimental data, three new models named ‘Magnetic-time model’, ‘Hydro-thermal-magnetic-time model’ and ‘Water uptake model’ are formulated theoretically and discussed in detailed within this chapter. Apart from these, two models ‘Malthus-Verhulst function’ and ‘Stochastic Model’ are also reformulated and presented. Magnetic-time model and Hydro-thermal-magnetic-time model incorporate the effect of applied magnetic field along with thermal and hydro parameters on growth from the seeds. Water absorption statistic is an indispensable tool to understand basic germinating processes. To understand the impact of electric and magnetic field on seed germination a new model for water uptake is formulated and presented in this chapter. A simple approach to the Stochastic model is discussed to find the number of seeds left in the sample at any time  $t$ . The experimental verification of the Malthus-Verhulst function is limited as it is very difficult to find the time when the first seed germinates. Therefore, this model is reformulated and discussed in detail.

**Chapter 4** deals with results and discussion of the electric field on seed germination. The seeds of Chickpea (*Cicer arietinum* L.), Mung bean (*Vigna Radiata*), Bitter Gourd (*Momordica Charantia*), Spinach (*Spinacia oleracea* L.), White gourd (*Benincasa hispida*), Okra (*Abelmoschus esculentus* L.) and Maize (*Zea mays* L.) are pre-treated with low-level electric field and its effect on the germination are presented. The results of electric treatment are studied by measuring water uptake by the seed and also by measuring the germination capacity. To find early germination effects, mean germination time and transition time are calculated for different type of seeds, the results of which are presented within this chapter.

To explore dielectric nature of seed, germination coefficient  $\alpha E$  and transition constant are calculated by using Re-formulated Malthus-Verhulst function and Stochastic function respectively for each seed. It is shown that these functions worked well for all the studied species.

**Chapter 5** describes the results and discussion of the magnetic field on seed germination. Different seeds used in present work are pre-treated with different intensity of magnetic field and with different time exposures. The results of magnetic treatment are studied by measuring the water uptake by the seed and also by measuring germination capacity. Magnetic time model and water uptake model are tested for different species and is presented in this chapter. Magnetic time model is used to understand the results. Magnetic time constant  $\theta_B$  is calculated, to understand the germination process. The use of mean germination time, mean germination rate, germination rate coefficient, germination magnetic constant, transition time, water uptake is discussed in this chapter to find the effects of magnetic field on germination of seeds.

**Chapter 6** describes the conclusions drawn from this work on electric and magnetic-field exposure of seeds. In this chapter electric and magnetic effects on the seed germination are summarized into a unified premise and concluded with future scope in the required direction. It is found that low electric field improves the early germination parameters. However, higher electric field gives retardation to germination yield. Magnetically treated seeds showed a change in water uptake and germination capacity. In this chapter it is discussed that in future there is scope to investigate the seed microscopically to know the seed element which resonates or stimulates at some particular field level. Apart from this, the future scope of the developed models and requirement of more work on different seeds has been given.

## Abbreviations Used

Time taken for first seed to germinate (initial time of germination)	$t_0$
Electric permittivity of the seed	$\epsilon$
Electric or electric field energy	$\rho_E$
Absolute permittivity of free space	$\epsilon_0$
Magnetic field	MF
Magnetic field energy density	$\rho_M$
Number of seeds that germinated within the time t	$N_g(t)$
Final number of germinated seeds	$N_k$
Germination rate coefficient	$\alpha$
Time required for the first seed to germinate	$t_0$
Minimum (lowest) or base temperature at which germination starts	$T_b$
The optimum temperature be the temperature at which germination is most rapid	$T_o$
Thermal time constant	$\theta_T(g)$
Base water potential that will just prevent germination of fraction g of the seed population	$\Psi_b$
Water potential at any time t	$\Psi$
Hydrothermal time constant	$\Theta_{HT}$
Geomagnetic field	GMF
High voltage electrostatic field	HVEF
Magnetic field	MF
Mean germination time of a given seed population	$t_g$
Germination rate of a given seed population	$g(r)$
Magnetic field	B
Hydrothermal-magnetic time constant	$\Theta_{HTB}$
Water uptake coefficient when seed exposed with electric field	$k_E$
Transition electric constant	$\lambda_E$
Transition magnetic constant	$\lambda_B$
Electro- magnetic field	EMF

# Chapter 1

## Introduction

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### Overview

In this chapter, the effects of electric and magnetic field on seed germination have been discussed. It is observed that both electric and magnetic field influence the early germination process. The experimental work on different seeds are being done to understand their growth factors under the influence of electric and magnetic fields which varies for different seeds. Apart from this various functions and models developed to understand the germination process and their limitations is also described in this chapter.

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## **1.1 INTRODUCTION**

In view of increasing population particularly in developing countries, it is imperious to increase the crop production. Moreover, the agricultural land is shrinking day by day because a major part of land is being used to meet infrastructural needs of increasing population. Therefore, today the major challenge is to produce enough food from the less land to cater the increasing demand. Insecticides and pesticides are used to increase the crop yield, but there are evidences which show that over use of chemicals do pose a potential risk to humans and other life forms and unwanted side effects to the environment. So there is a need to turn toward new technological involvements to increase food production. Pre-sowing electric and magnetic treatment of seeds is one of the cost effective new technological method to enhance the crop yield with no side effects to the environment. With using this technology, the use of synthetic inputs such as fertilizers, pesticides, etc. can be reduced or avoided and the crop production and quality can also be increased. Thus, the role of electric and magnetic field treatments to enhance the productivity of plant (and to improve physical parameters related to seed germination) has become essential. The seeds treated with static and variable magnetic fields before sowing has a positive effect upon the germination yield, growth speed and germination rate [1-4]. The results further show that electrically treated seeds also produce a better growth rate and stem height compared with non-exposed seeds [5, 6].

## **1.2 Electro-Culture**

Electro-culture practice of plants started in 1746, when Dr. Maimbray of Edinburg treated myrtle plants with the electric field, thereby enhancing their growth and flowering [9]. Two years later, the French abbot Jean Nolet found that overall growth of plants accelerated when cultivated under electric field. Electro-culture can stimulate the growth of plants to a greater extent (electro-culture include: static electricity, antennas, direct and alternating current, magnetism, radio frequencies, monochrome and intermittent lighting, and sound). Through electro-culture, the energies are applied to the seeds, plants, soil or water and nutrients. Electro-culture can accelerate seeds germination rate, increases the crop yields, improve crop quality and reduces the requirements for pesticides for increasing the crop yield. With electro-cultural treatment farmers can grow bigger and better crops in less time [7]. The effect of the electric field on seeds and plants is a subject of present concern and investigation. It is well known that magnetic field affects to the human body and biological tissues. However, very few researches have shown the relationship between the electric field with plant growth.

### 1.2.1 The physical parameters of electric field

An electric field measured in V/m is said to be uniform if its intensity does not change with distance. The electric field intensity is defined as [5],

$$E = \frac{V}{d\eta} \quad \text{V/m} \quad (1.1)$$

Where  $V$  is the potential applied between the plates and measured in volt whereas  $d$  is the distance between the plates measured in meters.  $\eta$  is field utilization factor (its value depends on the geometry of the electrodes):

$$\eta = \frac{E_{av}}{E_{max}} \quad (1.2)$$

Here  $E_{av}$  and  $E_{max}$  represent to average and maximum electric field values. Let  $E_o$  be the electric field produced by an external voltage applied to the plates of a parallel plate capacitor (plate area  $A$  and plate separation  $d$ ). Seeds layer of thickness  $t$  ( $t < d$ ) is then introduced between the plates. Electric field inside the seed now gets modified (reduced) and become  $E$  [8].

$$E = E_o - P/\epsilon \quad (1.3)$$

Where  $P$  is total dipole density and  $\epsilon$  is electric permittivity of the seed. Polarisation  $P$  is directly proportional to the reduced value of the electric field [9]. The absolute electric exposure dose  $D_E$  is described as follows:

$$D_E = \rho_E t \quad (1.4)$$

Where  $\rho_E$  is electric or electric field energy density and  $t$  is time of exposure. where  $\rho_E$  is defined as:

$$\langle \rho_E \rangle = \frac{1}{2} \epsilon_0 E^2 \quad (1.5)$$

Where  $\epsilon_0$  is absolute permittivity of free space.

### 1.3 The Physical Parameters of Magnetic Field

Earth's magnetic field (MF, about 50  $\mu\text{T}$ ) is a natural component of the environment for living organisms [10]. The role of weak magnetic fields and their influence on plants is still insufficiently understood [10]. Many authors have reported the effects of static magnetic fields on the metabolism and growth of different plant species. Before going in detail in this study it is necessary to understand some basic parameters of magnetic field which relates to the study of seed germination. The absolute magnetic exposure dose  $D_M$  is described as follows[8]:

$$D_M = \rho_M t \quad (1.6)$$

Where  $\rho_M$  is magnetic field energy density and  $t$  is time of exposure. Where  $\rho_M$  is defined as:

$$\langle \rho_M \rangle = \frac{1}{2} \mu_0 H^2 \quad (1.7)$$

Where H is related to B for free space as:

$$B = \mu_0 H \quad (1.8)$$

Magnetic field is generally generated by current carrying solenoid, at a point well inside the solenoid its value is:

$$B = \mu_0 n I \quad (1.9)$$

At a point near the end of a solenoid, it is calculated as:

$$B = \frac{\mu_0 n I}{2} \quad (1.10)$$

### 1.4 Germinating Functions

In order to measure the germination time several methods and mathematical expressions have been proposed [11]. Some researchers [12] have used polynomial curves to fit their germination data whereas other authors [13-16] have used some statistical functions like Weibull function, Morgan-Mercer-Flodin function, Richards function, Mitscherlich, Gompertz function and logistic function for cumulative germination. In earlier time, Goloff

and Bazzaz [17] studied the effect of temperature on germination rate and found a linear relation between the logarithm of the number of seeds to be germinated and time. All described functions are limiting in use because many of these functions are not having any meaning from biological angle.

#### 1.4.1 Malthus-Verhulst Function

Malthus-Verhulst function [18-20] is used for seeds pretreated with electric or magnetic field. Malthus-Verhulst function is:

$$N_g(t) = N_k / (1 + (N_k - 1) \exp \{-\alpha N_k (t - t_0)\}) \quad (1.11)$$

Where  $N_g(t)$  is the number of seeds that germinated within the time  $t$ ,  $N_k$  is final number of germinated seeds,  $\alpha$  is germination rate coefficient,  $t_0$  is time required for the first seed to germinate. This function is limiting in use as it is difficult to find experimentally the time when very 1<sup>st</sup> seed germinates. So, there is a need of reformulation of this function.

### 1.5 Existing Germinating Models

#### 1.5.1 Thermal Time Model

Mathematical models that describe germination patterns in response to temperature ( $T$ ) have been developed and used by many researchers [21-23]. Thermal time model showed that the germination rate for a given seed fraction or percentage ( $GRg$ ) is a linear function of  $T$  above  $T_b$ . Where  $T_b$  is the minimum (lowest) or base temperature at which germination starts. The optimum temperature  $T_o$  be the temperature at which germination is most rapid. This can be written as:

$$1/t_g = K + m T \quad (1.12)$$

or

$$1/t_g = m (T - T_b) \quad (1.13)$$

This is the equation of a straight line ( $Y = mX$ ;  $1/t_g = m (T - T_b)$ ). Inverse of the slope of this straight line is called thermal time constant  $\theta_T(g)$ .

$$\theta_T(g) = (T - T_b) t_g \quad (1.14)$$

$$GR_g = 1/t_g = (T - T_b) / \theta_r(g) \quad (1.15)$$

This model predicts that the germination rate for a given seed fraction or percentage ( $GR_g$ , or  $1/t_g$ ) is a linear function of  $T$  above  $T_b$ . The above equations is verified experimentally by Alvarado [24].

### 1.5.2 Hydro Time Model

Gummerson [25] 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.  $\Psi_b$  is the base or threshold parameter that will just prevent germination of fraction  $g$  of the seed population. Gummerson [25] showed that if  $GR_g$  values were plotted as a function of  $\Psi$ , the resulting curves become linear and parallel (for different seed population). According to hydro-time model hydro time constant  $\Theta_H$  can be written as:

$$\Theta_H = (\Psi - \Psi_b) \times t_g \quad (1.16)$$

From equation (1.16),  $t_g$  is inversely related to the difference between the  $\Psi$  and  $\Psi_b$  value of that seed [23, 26].

### 1.5.3 Hydro Thermal Model

Thermal-time and Hydro-time models as described above have been combined into Hydrothermal-time model that can describe seed germination patterns with temperature and water potential. Combining Equations 1.22 and 1.24, a hydrothermal time constant  $\Theta_{HT}$  can be defined as [27]:

$$\Theta_{HT} = (\Psi - \Psi_b) (T - T_b) t_g \quad (1.17)$$

This hydrothermal model has worked well to describe germination time for different seeds [25, 27].

### 1.5.4 Water Uptake Model

The rate of seed swelling during hydration is analogous to the imbibition of polymers solvents [28]. The rate of seed swelling ( $dw/dt$ ) during hydration is often described by the equation  $dw/dt = k(w_{max} - w)$  [29]. 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. In this model, it is assumed that the seed coat, rather than the seed interior, limits imbibition. Another model of water uptake assumes that water absorption by the seed follows diffusion kinetics. In the diffusion model of water flow, it is assumed that seed coat does not offer a significant resistance to water uptake so water moves across homogeneous seed, made up of the cotyledons [29]. Diffusion model is based upon the assumption that water flow occurs from one differential shell layer to the other because of water potentials between shells. It is analogous to Fick's first law of diffusion [30]. It is assumed that seed weight  $w$  will increase as imbibition proceeds. Spherical seeds behave like a homogeneous material with a constant diffusivity  $D$  during swelling [31].

### **1.5.5 Limitations of existing models and solutions (Magnetic time model)**

During the evolution process, all living organisms experienced the action of the earth's magnetic field (geomagnetic, GMF), which is a natural component of the environment. The results obtained by several workers have demonstrated the influence of magnetic field on growth of plants. Established models explain the thermal and hydro parameters related to seeds germination but fail to include the effect of magnetic field. In order to understand the effect of magnetic field on plant growth features it is required to develop a new model which could incorporate the effect of applied magnetic field on growth of the seeds.

## **1.6 Seeds Investigation**

Whether seeds and plants respond to electric and magnetic field is a subject of investigation. It is found that no data analysis (regarding electric and magnetic treatment to seed) is available on the white gourd (*Benincasa hispida*), spinach (*Spinacia oleracea L.*) and bitter melon (*Momordica Charantia*) seeds. Some data of magnetic field treatment is available for chickpea (*Cicer arietinum L.*), Maize (*Zea mays L.*), mung bean (*Vigna Radiata*) and okra (*Abelmoschus esculentus L.*), which is not sufficient to reach at any conclusion relevant to the effect of electric and magnetic field on early seed germination parameters (as the data available is only for selective magnetic field values). Thus, seeds undertaken for present investigations are:

- Chickpea (*Cicer arietinum L.*)
- Mung bean (*Vigna Radiata*)

- Bitter Gourd (*Momordica Charantia*)
- Spinach (*Spinacia oleracea* L.)
- White gourd (*Benincasa hispida*)
- Okra (*Abelmoschus esculentus* L.)
- Maize (*Zea mays* L.)

### 1.6.1 Chickpea (*Cicer arietinum* L.)



The Common names of Chickpea (Species: *Cicer arietinum* L., Family: *Leguminosae*) are Bengal gram and Black gram (Indian), Chickpea (English), Garbanzo (Latin America), Lablabi (Turkey), Shimbra (Ethiopia). Chickpea (*Cicer arietinum* L.) is a nutritive seed with high-protein content, 25.3-28.9 % [32]. Chickpea seeds are green vegetables and eaten as fresh. The flour of grounded seeds can be used as soup. Split chickpea without its seed-coat is called dhal. Dhal is eaten as fried, boiled and as a snack food. In the Indian subcontinent, there is a big consumer market for chickpea flour also called besan. In flour mills, dhal is converted into flour or besan. Flour is used in preparations of various kinds of snacks (pakoras), sweets (ladoos and burfis) and driads like bhoojya [33]. Satoo is made by mixing roasted chickpea flour with roasted barley and wheat flour which is a famous drink used in summer in Punjab (India). Dhokla is very popular and consumed in different parts of India made of chickpea flour with rice [33]. Sprouted chickpea seeds are added to salads. Green young plants can be eaten like spinach. Because of their high protein-content, chickpea is also part of animal feed. A cooked chickpea-milk (4:1) mixture was thought as good for feeding children. Chickpea-based chapattis is made from chickpea flours mixed with wheat in various ratios as per the taste of the individual family, e.g. 1:1, 1:2, 1:3 and 1:4 is very much liked in Indian villages and cities [33]. Chickpeas yield 21% starch and is used for giving a light finish to silk, wool, and cotton cloths [34]. Chickpea was reported to be effective in controlling cholesterol level in rats [35]. Chickpea seed has digestible protein, which varies from 76-78%

and carbohydrate varies from 57-60%. It also contains 3% fiber, 4.8-5.5% oil, 3% ash, 0.2% calcium, and 0.3% phosphorus [32].

### 1.6.2 Mung bean (*Vigna radiate*)



Mung bean, the seed of *Vigna Radiata*, is also commonly referred 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 Indian subcontinent as a short-duration catch crop between two principal crops (wheat and rice). Mung bean contains carbohydrates, proteins and low content of fat and fibre. It is 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 used two mung beans varieties SML 832 and SML 668. Punjab Agricultural University in India released SML 832, used in the present investigation, is a new high yielding, MYMV resistant (Mung bean Yellow Mosaic Virus) spring/summer mung bean variety.

### 1.6.3 Bitter Gourd (*Momordica Charantia*)



Some traditional medicines are derived from medicinal plants, minerals and organic matter [36]. India is the biggest producer of medicinal plants all around the world [37, 38]. *Momordica charantia*, also known as bitter gourd, bitter melon and Karela, belongs to the

Cucurbitaceae family and is commonly consumed as food (bitter flavouring) in India. It has been traditionally used to treat diabetes [39]. Its leaves and stems have been used to cure diseases due to its hypoglycaemic effect [40], and they contain the following compounds: charantin, a steroidal glycoside; vicine, a glycoalkaloid and polypeptide 'p', a 166 residue insulinomimetic peptide. Its hypoglycaemic activity is based on a structural similarity to insulin and stimulation of insulin secretion by the pancreas [39]. It is also used to treat inflammation, colds, hypertension, sore throats, menstrual problems, tuberculosis, fever, anaemia, kidney stones, parasites, malaria, anorexia, liver problems, vomiting and headache [39]. To increase the *Momordica charantia* yield, pesticides are generally used, but their unwanted side effects on human health and the environment have become a major concern.

#### 1.6.4 Spinach (*Spinacia oleracea* L.)



Spinach (*Spinacia oleracea* L.) (in Hindi, it is called Palak) is a rich source of carotenoids (lutein,  $\beta$ -carotene, zeaxanthin), p-Coumaric acid, ascorbic acid, proteins, vitamins and other substances [41]. The chemical composition of Spinach is calcium-73mg/100gm, magnesium-84mg/100gm, iron-10.9%, Phosphours-1mg/100gm, pottasium-206mg/100gm and vitamins C, A, thiamin, riboflavin, lutein and zeaxanthin [41, 42]. Palak, is a medicinal plant with high nutritional value, used as, anti bacterial, anti diabetic and hepatoprotective agent [43]. *Spinacia oleracea* is an eatable flowering plant in the family of Amaranthaceae. This plant has been related with various biological activities like virus inhibitor, anthelmintic, antioxidant, hepatoprotective and reducing risk of breast cancer[43]. Important varieties of Spinach cultivated in Punjab are Pb.selection and Pb.Green. Extensive literature survey revealed that no reports were available on the effects of germination of Palak seeds by giving electric and magnetic treatments. The present study was undertaken to explore the germination effects of Palak seed in the environment of electric and magnetic fields.

### 1.6.5 White gourd (*Benincasa hispida*)



The white gourd also called, winter melon, winter gourd, or ash gourd, is eaten like a vegetable. It is the only member of the genus *Benincasa* (Botanical name: *Benincasa hispida* Family: Cucurbitaceae (Pumpkin family)). In India, it is called petha. The plant resembles that of the pumpkin [44]. Its flowers are golden-yellow, 2½ inch to 3½ inches wide, on hairy shoots. When a flower transforms into fruit, it may take oblong, oblate or globular shape and may reach 4 ft. in length and 2 ft. in diameter [44], and may get a weight of 10 to 18 kg. Its skin is light or dark-green and is coated by a layer of white, chalky wax. The plant prospers in any type of soil like sandy, loam or clay. Excessive humidity has unfavourable effects on plant health and productivity [45]. According to Srivastava and Sachan [45], the mature fruit is rich in vitamins B and C. In India, the fruit is declared as laxative, diuretic, tonic, aphrodisiac, antiperiodic, specific for hemoptysis and other hemorrhages from internal organs [46]. The fruit juice is administered insanity for epilepsy and other nervous diseases. The seeds and seed oil are taken to expel tapeworms. The seed kernels are applied to skin eruptions, and the ash of burned seeds is an extremely suitable remedy for gonorrhoea [47]. The raw flesh of this fruit is also used to relieve prickly heat (by rubbing directly on the infected area or adding to one's bath water). It is a remedy also for facial eruptions [47]. An ash made from the fruit is applied to painful wounds.

### 1.6.6 Okra (*Abelmoschus esculentus* L.)



Okra botanical name is *Abelmoschus esculentus* L. It belongs to Moench family. In India, different names have been given in different regional languages, but its popular name is lady's finger and bhindi. Okra *Abelmoschus esculentus* L. (Moench), is an important vegetable crop grown in tropical and sub-tropical parts of the world. This crop is cultivated in home gardens. It is grown commercially in various countries like Turkey, Iran, Western Africa, Yugoslavia, Bangladesh, Afghanistan, Pakistan, Burma, Japan, Malaysia, Brazil, Ghana, Ethiopian, Cyprus and the Southern United States. India rank is first in the world for producing 3.5 million tonnes (70% of the total world production) of okra produced from over 0.35 million ha land [48]. Okra is an important source of vitamins, calcium, potassium and other mineral matters which are often lacking in the diet of developing countries. Composition per 100 g of edible portion is; Moisture 89.6 g, Minerals 0.7 g, Protein 1.9 g, Carbohydrates 6.4 g, Fat 0.2 g, Calcium 66 g, Fibre 1.2 g, Iron 0.35 mg, Calories 35, Potassium 103 mg, Phosphorus 56 mg, Thiamine 0.07 mg, Sodium 6.9 mg, Nicotinic acid 0.6 mg, Sulphur 30 mg, Vitamin C 13 mg, Riboflavin 0.1 mg, Magnesium 53 mg, Oxalic acid 8 mg and Copper 0.19 mg [48]. Okra is an annual plant 3 to 6 feet in height, deep taproot, and hibiscus-like flower. It is a tropical direct sown vegetable. The popular varieties which are cultivated in Punjab are Pusa, Sawani, Punjab Padmani, Punjab-7, Punjab-8, Pb. Kranti, Pb. Varsha, Uphan A-11. The Fruits of Punjab Padmini are quick growing, dark green, hairy, and matures within 55-60 days after sowing. This variety is tolerant to Yellow Vein Mosaic Virus (YVMV).

### 1.6.7 Maize (*Zea mays* L.)



Maize is an important crop which is consumed as food. In Punjab, the delicious food of maize is popular as Makki di roti in combination with Sarson ka-sag. Baby corn is eaten as

Salad and is used for cooking vegetables, pickles, pakoras, soups, etc. Maize is one of the main fodder crop of the Punjab state. During 2009-10, an expenditure of Rs. 23,56,000 was incurred under ISOPOM scheme in Punjab to enhance maize production (like training camp, distribution of free mini kits, plant protection chemicals and publicity) as compared to Rs. 16,13,850 during 2008-09 [49]. Around 10,000 seed mini kits of varieties like, HQPM-1 (5000) & Bio 9637(5000) were distributed free of cost to the farmers during Rabi/Summer season. Presently permanent maize scheme (staff scheme) is also being implemented to enhance maize production in the state. An amount of Rs. 18.67 lac was allocated under this scheme and an expenditure of Rs. 17.81 lac is incurred to implement the scheme [49]. Maize crop is mainly sown in the districts of Hoshiarpur, Roopnagar, Shaheed Bhagat Singh Nagar, Amritsar, Gurdaspur, Jalandhar, Kapurthala, Patiala, Ludhiana, SAS Nagar and Fatehgarh Sahib in the state. Traditionally maize was grown as kharif crop, and now sowing during rabi season has also been started in some districts with new varieties. Punjab Agricultural University (PAU) has released a new disease-resistant variety of maize PMH 7. PMH 7 variety of hybrid maize is suitable for spring planting. The variety matures in 115 days has an average yield of 30 quintals per acre.

## References

- [1] Martínez E., Flórez M., Maqueda R. *et al.*, Pea (*Pisum sativum*, L.) and lentil (*Lens culinaris*, Medik) growth stimulation due to exposure to 125 and 250 mT stationary fields, *Polish Journal of Environmental Studies*, **18**, 4, 657-663, 2009.
- [2] Martinez E., Carbonell M. V., and Amaya J. M., A static magnetic field of 125 mT stimulates the initial growth stages of barley (*Hordeum vulgare* L.), *Electromagnetic Biology and Medicine*, **19**, 3, 271-277, 2000.
- [3] Martínez E., Carbonell M., Flórez M. *et al.*, Germination of tomato seeds (*Lycopersicon esculentum* L) under magnetic field, *International Agrophysics*, **23**, 1, 45-49, 2009.
- [4] Gholami A., and Sharafi S., Effect of magnetic field on seed germination of two wheat cultivars, *World Acad. Sci. Eng. Technol*, **62**, 279-282, 2010.
- [5] Kiatgamjorn P., Tarateeraseth V., Khan-ngern W. *et al.*, "The effect of electric field intensity on bean sprout growing," in Proc. Int. Conf. Electromagnetic Compatibility, October, pp. 7-11, 2002.
- [6] Kiatgamjorn P., Khan-ngern W., and Nitta S., "The Effect of Electric Field on Bean Sprout Growing," in International Conference on Electromagnetic Compatibility (ICEMC2002), Bangkok, Thailand, pp. 237-241, 2002.
- [7] Nelson R. A. "Electro-Culture " 10-13-2013, Rex Research, POB 19250, Jean, NV 89019 USA: Rex Research Civilization 2013;  
<http://www.rexresearch.com/articles/elcultur.htm#ECligh>.
- [8] Pietruszewski S., Muszynski S., and Dziwulska A., Electromagnetic fields and electromagnetic radiation as non-invasive external stimulants for seeds (selected methods and responses), *International agrophysics*, **21**, 1, 95, 2007.

- [9] Kittel C., *Introduction to Solid State Physics*, seventh ed., pp. 383-398: John Wiley & Sons, 2012.
- [10] Belyavskaya N., Biological effects due to weak magnetic field on plants, *Advances in Space Research*, **34**, 7, 1566-1574, 2004.
- [11] Ranal M. A., and Santana D. G., How and why to measure the germination process?, *Revista Brasileira de Botânica*, **29**, 1, 1-11, 2006.
- [12] Chea F. P., Chen Y., Montville T. J. *et al.*, Modeling the germination kinetics of *Clostridium botulinum* 56A spores as affected by temperature, pH, and sodium chloride, *Journal of Food Protection*®, **63**, 8, 1071-1079, 2000.
- [13] Arauz L., Neufeld K., Lloyd A. *et al.*, Quantitative models for germination and infection of *Pseudoperonospora cubensis* in response to temperature and duration of leaf wetness, *Phytopathology*, **100**, 9, 959-967, 2010.
- [14] Dias L., Describing phytotoxic effects on cumulative germination, *Journal of chemical ecology*, **27**, 2, 411-418, 2001.
- [15] Miller T., Gubler W., Geng S. *et al.*, Effects of temperature and water vapor pressure on conidial germination and lesion expansion of *Sphaerotheca macularis* f. sp. *fragariae*, *Plant disease*, **87**, 5, 484-492, 2003.
- [16] Santana D., and Ranal M., Linear correlation in experimental design models applied to seed germination, *Seed Science and Technology*, **34**, 1, 233-239, 2006.
- [17] Tseng S., and Hsu J. P., A Stochastic Analysis of Seed Germination, *Botanical Bulletin of Academia Sinica*, **30**, 201-205., 1989.
- [18] Pietruszewski S., and Kania K., Effect of magnetic field on germination and yield of wheat, *International Agrophysics*, **24**, 297-302., 2010.
- [19] Pietruszewski S., Influence of magnetic and electric fields on seeds. Germination of selected cultivated plants, *Acta Scientiarum Polonorum*, **1**, 1, 75-81, 2002.
- [20] Pietruszewski S., Modeling by logistic curve germination of wheat seeds Henika cultivar in magnetic field, *Acta Agrophysica*, **58**, 143-151, 2001.
- [21] Bierhuizen J., and Wagenvoort W., Some aspects of seed germination in vegetables. 1. The determination and application of heat sums and minimum temperature for germination, *Scientia Horticulturae*, **2**, 3, 213-219, 1974.
- [22] Ellis R., Covell S., Roberts E. *et al.*, The influence of temperature on seed germination rate in grain legumes II. Intraspecific variation in chickpea (*Cicer arietinum* L.) at constant temperatures, *Journal of Experimental Botany*, **37**, 10, 1503-1515, 1986.
- [23] Bradford K., "The hydrotime concept in seed germination and dormancy," *Basic and applied aspects of seed biology*, pp. 349-360: Springer, 1997.
- [24] Alvarado V., and Bradford K., A hydrothermal time model explains the cardinal temperatures for seed germination, *Plant, Cell & Environment*, **25**, 8, 1061-1069, 2002.
- [25] Gummerson R., The effect of constant temperatures and osmotic potentials on the germination of sugar beet, *Journal of Experimental Botany*, **37**, 6, 729-741, 1986.
- [26] Bradford K. J., A water relations analysis of seed germination rates, *Plant Physiology*, **94**, 2, 840-849, 1990.
- [27] Dahal P., and Bradford K. J., Hydrothermal time analysis of tomato seed germination at suboptimal temperature and reduced water potential, *Seed Science Research*, **4**, 71-71, 1994.
- [28] Leopold A. C., Volumetric components of seed imbibition, *Plant Physiology*, **73**, 3, 677-680, 1983.
- [29] Meyer C. J., Steudle E., and Peterson C. A., Patterns and kinetics of water uptake by soybean seeds, *J Exp Bot*, **58**, 3, 717-32, 2007.

- [30] Steudle E., "The biophysics of plant water: compartmentation, coupling with metabolic processes, and flow of water in plant roots," *Water and life*, pp. 173-204: Springer, 1992.
- [31] Crank J., *The mathematics of diffusion*: Oxford university press, 1979.
- [32] Hulse J., "Nature, composition and utilization of grain legumes," in *Uses of tropical legumes: Proceedings of a consultants' meeting*, pp. 27-30, 1989.
- [33] Yadav S. S. S., and Chen W., *Chickpea breeding and management*: CABI, 2007.
- [34] Duke J. A., *Handbook of legumes of world economic importance*, 1981.
- [35] Geervani P., Utilization of chickpea in India and scope for novel and alternative uses, *Uses of Tropical Grain Legumes*, **27**, 47, 1989.
- [36] Grover J. K., Yadav S., and Vats V., Medicinal plants of India with anti-diabetic potential, *J Ethnopharmacol*, **81**, 1, 81-100, 2002.
- [37] Seth S. D., and Sharma B., Medicinal plants in India, *Indian J Med Res*, **120**, 1, 9-11, 2004.
- [38] Scartezzini P., and Speroni E., Review on some plants of Indian traditional medicine with antioxidant activity, *J Ethnopharmacol*, **71**, 1-2, 23-43, 2000.
- [39] Lana D. P., and Julia W. M. "Momordica Charantia: Boston Healing Landscape Project," Boston University School of Medicine, or Boston Medical Center.2012.
- [40] Fernandes N. P., Lagishetty C. V., Panda V. S. *et al.*, An experimental evaluation of the antidiabetic and antilipidemic properties of a standardized Momordica charantia fruit extract, *BMC complementary and alternative medicine*, **7**, 1, 29, 2007.
- [41] Verma R. K., Sisodia R., and Bhatia A., Role of Spinacia oleracea as antioxidant: A biochemical study on mice brain after exposure of gamma radiation, *Asian J Exp Sci*, **17**, 51-7, 2003.
- [42] Gopalan C., Sastri B. R., and Balasubramanian S., Nutritive value of Indian foods, *Hyderabad: National Institute of Nutrition*, 1971.
- [43] Dande P. R., Sharma G., Sharma R. *et al.*, Pharmacognostical Studies Of Leaves Of Spinacia Oleracea Linn, *International Journal of Pharmaceutical Sciences and Research*, **1**, 9, 41-46, 2010.
- [44] Morton J. F., *The wax gourd, a year-round Florida vegetable with unusual keeping quality*: State horticultural society, 1971.
- [45] Srivastava V., and Sachan S., Grow ashgourd the efficient way, *Indian Hort*, **14**, 13, 1969.
- [46] Chopra R. N., and Chopra I., *Indigenous drugs of India*: Academic publishers, 2006.
- [47] Stuart G. A., and Smith F. P., *Chinese materia medica: vegetable kingdom*: Gordon Press, 1977.
- [48] Government\_of\_India M. E. F., *Series of crop specific biology documents Biology of Okra*, Department of Biotechnology : Ministry of science & Technology Government of india., 2013.
- [49] Sandhu M. S. "The Department of Agriculture Punjab : Cash Crops(Maize)," 16-08-2013, Department of Agriculture, Punjab S.C.O. 85-88, Sector 34-A Chandigarh. : The Director (DAP); <http://agripb.gov.in/home.php?page=maize>.

#### Overview

Prior to sowing the seeds some chemical treatment of soil is frequently done by the farmers. However, these chemicals lead to unwanted side effects on human health and the environment which have become a major concern. Agricultural scientists are trying to explore the technique, which must be proficient, eco-friendly, clean and affordable. The Application of electro-magnetic field stimulation may be a good tool for improving the yield and plant growth for agricultural production. Thus, studying such techniques like pre-sowing electric and magnetic field treatments to seeds to enhance the productivity has become important. The germination, growth, yield and quality of crops are determined by the type of seed species, and can be improved by selecting any appropriate pre-sowing physical treatment such as the electric field or magnetic field. This chapter summarises the reported research in the area of the effects of electric and magnetic field on seed germination and plant growth. Based on the literature work the present research is planned to cover the gaps which are highlighted at the end of this chapter.

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## 2.1 Effect of the Electric Field on Seeds and Plants

It is well known that electric, magnetic and electromagnetic fields lead to biochemical, physical and physiologic changes in cell structures [1, 2]. A survey of the plant life suggests that near high-voltage transmission lines electro-magnetic fields caused an influence on plant growth [3]. The physical pre-sowing seed treatment by ionizing radiation, lasers, electrical field, ultraviolet, and magnetic field had an acceleratory effect on plant characteristics. These methods are affordable, clean, and safe. Researches are working in laboratory condition 'to study plant life' in the environment of high magnetic field [4], very low magnetic field [5], and moderate electric and magnetic fields [6]. Biological, chemical and physical pre-sowing seed treatments are being used for better seed germination and growth, but the agricultural scientists are trying to explore the technique, which is proficient, eco-friendly, clean and affordable. Application of electro-magnetic field stimulation may be a good tool for improving the yield and plant growth for agricultural production. Electromagnetic fields and electromagnetic radiation may have a positive, but mostly temporary and impermanent effect on the percentage of germination, growth speed and germination rate. Literature available on the effect of the electric field on seed germination is limited. Moreover, there is no clear picture about the interaction of electrostatic field with seeds. **Murr** [7, 8] used 30-80 kV/m electrostatic field to stimulate grain sorghum seedlings and reported positive results. **Murr** [9] reported a mechanism of plant-cell damage in an electrostatic field. Some authors showed that plant growth is limited and depends on the sign of the electrostatic field [10, 11]. Seeds and plants investigated by the researchers so far under the effect of electric field are: corn and bean [8], grain sorghum [9], cucumber [12], soy [13], rice [14], flax [15], pine [16], tomato [17], bean [18].

**Jian et al.** [14] studied the biological effects of high voltage electrostatic field (HVEF) on aged rice seeds (including dry seeds and wet seeds soaked in sterile deionized water for 24 hours). The results showed that with the application of high voltage electric field seed vigour and seedling growth of the aged wet rice seeds were significantly improved. With electric intensity less than  $450 \text{ kVm}^{-1}$  compared to control, the vigour index of aged wet rice seeds was increased 31.96%. No significant effects of high voltage electric field on dry aged rice seeds were found.

**Pozeliene** [15] showed that the diseases of the seeds processed by the electric field was less than the diseases of the seeds treated with fungicide and concluded at the confidence of 0.95, that the impact of the electric field has the considerable influence to minimize the seed diseases. Electric field stimulated the germination of the seed. The maximum germination was given by the strength of 3-3.5 kV/cm electric field.

**Gui et al.** [16] studied pine seed (*Pinus tabulaeformis* Carr.), by treating them in electrostatic fields and found enhancement in germination percentage. Results indicate that the effects of treatment depend on value of dosage, process and index of early stage of seeds. The optimal dosage for improvement of both germination and root development was found with 500 kV/m electric field for 10 minutes treatment of dry or wet seeds (during initial germination and middle and later stages of seedling development).

**Moon and Chung** [17] showed that germination of tomato seeds that are affected when treated with electric or magnetic field before sowing. When seeds were treated with electric field then germination rates of treated tomato seeds were 1.1-2.8 times higher compared to the untreated seed. However, an inhibitory effect on germination was shown for electric fields of more than  $12 \text{ V cm}^{-1}$  with exposure times of 60 s.

**Kiatgamjorn et al.** [18] studied the effect of the electric field intensity on the growth of the bean sprouting, stem height and the root length. The bean was exposed under the electric field at 10 kV/m and 25 kV/m, respectively. The experimental results showed that the bean sprouts under high electric field intensity have a better growth in comparison with the low electric field intensity.

## 2.2 Effect of Magnetic Field on Seeds and Plants

The effect of magnetic fields has exhibited many uses in ancient and modern society [19]. The effect of magnetic treatment on biological systems, particularly in the plant has been studied by various researchers since 19th century [19]. Pre-sowing seed treatments with magnetic fields have been reported to enhance the performance of crop plants [20, 21]. Exposure of seeds to magnetic fields is one of the safe and affordable potential to enhance post germination plant development. Various researchers have studied and reported that wheat, barley, sunflower, beans, tomato, corn, maize, etc. treated with magnetic field showed positive enhancement in terms of plant growth, height, yield, seed mass per spike as well as shoot and root length and total fresh and dry masses [22, 23]. Very few researchers worked upon the study of water uptake by the magnetically treated seeds. Most of the research which

have been done so far, relates the effect of few value of magnetic field and few value of exposure time on seeds germination and plant growth as is clear from the table 2.1.

**Table 2.1** Summary of previous researches with only few values of magnetic field and exposure time involving static magnetic fields.

Seed	Electric or Magnetic field Strength and Period	Effect of exposure	Ref. Year
Tomato	100 mT for 10 min	Significant increase in leaf area, leaf dry weight, and specific leaf area (SLA) per plant.	[21] 2006
Wheat	50 Hz, 30 mT, 15 min	Increase in the length of sprouts and an increase in the germinating capacity	[24] 2001
Broad bean seeds	B=85mT& 30 mT 15s	Positive effect of the magnetic treatment on the germination and the emergence	[25] 2004
Soybean	150 and 200 mT for 1h	Enhanced production of ROS mediated by cell wall peroxidase while ascorbic acid content, superoxide dismutase and ascorbate peroxidase activity decreased in the hypocotyl of germinating seeds.	[26] 2012

Seeds and plants investigated so far under the effect of magnetic field are: cumin [19], rice [27], tobacco [28], rose coco beans [29], barley [30], chilli [31], sugar beet [32], lentil [33-36], radish [37], pea [38], ocimum [39], dodder [40], corn [41], wheat [24, 42-45], broad bean [25], tomatoes [46, 47], soybean [26, 48], maize [49-54], okra [55], cotton [56], chickpea [57], mung [58], common bean [59].

**Florez et al. [27]** reported enhancement in germination in rice when exposed to 125/250 mT magnetic field for specific time intervals. Experiment indicates that the better results are found for appropriate combination of magnetic field strength and exposure time.

**Aladjjiyan et al. [28]** studied the influence of a stationary magnetic field with 0.15 T magnetic induction at expositions 10 min, 20 min and 30 min, on tobacco seeds (*Nicotiana tabacum* L.) and found that the magnetic field stimulates the germination and leads to increasing the germination energy.

**Odhiambo et al.** [29] studied the germination of Rose coco beans (*Phaseolus vulgaris* L.), The seeds were exposed to static electromagnetic fields generated by Helmholtz coil (5 mT, 10 mT, 30 mT and 60 mT) under laboratory conditions. The exposure period was fixed at 3, 4.5 and 6 h. Maximum seed germination occurred when exposed to South Pole field inducing germination of approximately 73% compared to 52% of control at a field strength of 30 mT at exposure period of 4.5 h.

**Martinez et al.** [30] studied barley plant in the environment of stationary magnetic field and found a stimulating effect on the first stage of growth of barley seeds for all exposure times studied. They found that when barley seeds were subjected to a magnetic field of 125 mT for different times (1, 10, 20, and 60 min, 24 h, and chronic exposure), an increase in length and weight were observed. Maximum increase in the measured parameters were obtained when the time of exposure to the magnetic field was long (24 h and chronic); however, the exposure for a short time (1 min) had a similar effect on early growth.

**Nimmi et al.** [31] investigated the effect of a weak permanent magnetic field 62 mT on germination, growth and development of chilli (*Capsicum annum*. L.) seeds. Four pre-sowing treatments (4, 8, 12, and 24h exposure) of chilli seeds were carried out in the experiment to compare with the untreated control. Permanent magnetic field had a stimulating effect on the first stage of growth of chilli seeds for all exposure times studied.

**Rochalska et al.** [32] investigated pre-sowing treatment using a low frequency magnetic field (16 Hz, 5mT) and its impact on the yield and quality of sugar beet plants. Magnetic treatments increased the emergence of seeds, especially for low vigour seeds. The chlorophyll content also increased significantly. As a result, the yield of plant roots was increased. The magnetic field also influenced the content of sugar in the root of the beet.

**Shabrangi et al.** [33] studied lentil (*Lens culinaris* L.) seeds which contains  $Fe^{2+}$  as a ferromagnetic element and concluded that magnetic field has significant effects on function and growth of plants. The seeds were pre-treated by different magnetic field intensities from 0.06 to 0.36 tesla (T) by using Zeeman system for different periods of time 5, 10 and 20 minutes. Seedlings growth data were measured in greenhouse condition with natural light cycle 14-h light/10-h darkness and  $25\pm 3^{\circ}C$  daily and night temperature. Activity that changes like assay of Ascorbate peroxidase (APX) and Superoxide Dismutase (SOD) were carried out by spectrophotometer in 15 days seedlings. The greatest growth and biomass was observed in 0.18 T (magnetic induction). Root had more growth than shoot under the effect of magnetic fields. Leaf size and stem thickness were increased too. These seedlings were more resistant

to drought stress. APX activity increased linearly in both root and shoot by increasing magnetic field intensities.

**Aladjajjiyan *et al.*** [34] studied the effects of magnetic treatment on the development of lentil seeds and concluded that magnetic treatment improves the growth of plants. They found the value of best treatment with magnetic-field induction as 150 mT at exposure time 6 and 9 min.

**Ahmad *et al.*** [35] used magnetically pre-treated lentil (*Lens culinaris L.*) seeds (exposed with 0.06 to 0.36 T for 5, 10, 20 minutes) for the study of seed germination rate and seedling excretion rate. They showed that the range of higher increase of germination was obtained from 0.18T to 0.24 T in 10, 20 minutes treatments.

**Martínez *et al.*** [36] exposed pea and lentil seeds to 125, 250 mT magnetic field and measured total weight, stem weight, stem length after 7 and 14 days of exposure. Martínez found that growth parameters of these seeds were increased.

**Haq *et al.*** [37] conducted an experiment with which radish seeds (*Raphanus sativus*, Mino variety) were exposed to full-wave rectified sinusoidal magnetic fields (MF) of strengths 40 mT, 80 mT, and 110 mT for 2.5, 5, and 10 min each, and its effects have been investigated on germination, seedling growth, and yield. Seeds were sown following the MF treatment according to the protocol of the International Seed Testing Association (ISTA) under controlled laboratory and field conditions. Plant height, root length, root mass, root girth, and yield increased up to 118.64%, 119.5%, 76.43%, 61.74%, and 76.41% respectively as compared to control.

**Iqbal *et al.*** [38] conducted an experiment in which the pea seeds were exposed to full-wave rectified sinusoidal magnetic fields. The effects of electromagnetic treatment on seedling growth and chlorophyll contents have been investigated. Seeds were sown after magnetic field treatment according to ISTA under controlled laboratory conditions. The magnetic field treatment of seeds increased the growth significantly ( $P < 0.05$ ) while the increment in contents of chlorophyll was found non-significant. The shoot length, root length, root dry mass, shoot dry mass, fresh root mass and fresh shoot mass increased up to 140.5, 218.2, 104, 263.6, 74.5 and 91.3%, respectively. The result suggested that the magnetic field could be used to enhance the growth in pea plant. The enzymes which are necessary for seed germination at particular stages of germination were found higher in magnetically treated seeds during seed germination.

**Soltani et al.** [39] studied the effect of magnetic forces on *Ocimum basilicum* seed germination and seedling growth. The earth magnetic field influences the movement and absorption of elements. The experiment included four treatments, two concentrations of potassium nitrate and the use of a static magnetic field. Results showed that *ocimum* seeds germinated more rapidly when subjected to a magnetic field. The number of germinated seeds, the length of radicle and primary stem were significantly higher than without a magnetic field.

**Balouchi et al.** [40] studied differences in seed germination characteristics of three annual medic species and dodder after treating with different intensities of electromagnetic field and exposure times. There were significant effects among treatments for germination percentage, shoot length and mass, seedling dry mass and seedling vigour index in dodder seeds. Seedling vigour index and dry mass decreased in *Cuscuta monogyna* seeds under different treatment of electromagnetic intensity. Enhanced electromagnetic intensity leads to higher germination rate along with increased shoot length in annual medic species. The highest germination rate and percentage was observed at 128  $\mu$ T electromagnetic intensity with 10 minute of exposure.

**Muraji et al.** [41] germinated corn seeds with relatively straight roots when placed in hermetically sealed experimental box between the magnetic poles of an electromagnet. The germinated seeds were exposed to the magnetic field of 0.005 T at frequencies 40, 80, 120, 160, 200, 280, and 320 Hz. When compared to control in the fields of 40, 80, 120, and 160 Hz the growth were enhanced, but in the fields of 240, 280, and 320 Hz the growth was reduced. The relatively low frequencies were constructive for primary growth of root while compared to high frequencies.

**Muszyński et al.** [42] investigated the effects of low frequency magnetic field ( $f = 50$  Hz,  $B = 15$  mT) for a short (15 and 30 s) exposure on durum wheat (*Triticum durum*) seedling growth under controlled laboratory conditions. Germination rate, fresh weight of seedlings, seedlings height and chlorophyll content was measured on 4<sup>th</sup> and 8<sup>th</sup> day after sowing. Magnetic field did not influence the seed germination process. Fresh weight was affected by applied treatments in the first four days. The chlorophyll levels in seedlings were significantly modified, on both the 4<sup>th</sup> and 8<sup>th</sup> days. However, the chlorophyll *a* and *b* ratios remained unchanged after MF treatments. The results show that MF may have, mostly temporary, negative and positive effect on early growth, which is strongly dependent on the applied exposure time.

**Pietruszewski et al.** [43] presented the effect of magnetic field on germination and yield of spring wheat. In the performed experiment two magnetic doses:  $D_{11}=D_{13}= 12.9$  and  $D_{21}=D_{23}=17.9 \text{ kJm}^{-3}\text{s}$  were applied. It is shown that the germination kinetic and yield of wheat were dependent on both magnetic field exposure doses. In both cases, the better germination of seeds was observed with respect to control. The yield of wheat for the exposure doses  $D_{11}=D_{13}$  was 12.5% higher and for doses  $D_{21}=D_{23}$  was 14.5% higher than the control.

**Pietruszewski** [44] worked on germination kinetic modelling by using logistic curve for germination of wheat seeds using permanent and alternating magnetic field where magnetic induction of permanent magnetic fields were 100 mT and 185 mT and of alternating magnetic field were 35 mT and 50 mT. Logistic parameters were found using the germination speed curves of wheat seeds.

**Rochalska et al.** [45] studied the influence of a low frequency magnetic field treatment on the germination of spring wheat, soybean, maize, triticale and sugar beet. Magnetic field treatment did not influence germination and growth of seedlings at 20 °C. However, It improved the germination at 10°C for seeds of the stenothermal plants soybean and maize but did not improve germination at 5°C for wheat and triticale.

**Martínez et al.** [46] studied the effects of a stationary magnetic field on the germination and initial growth stages of tomato seeds (*Lycopersicon esculentum* L.). The seeds were exposed to magnetic field strength (125 or 250 mT) for different time as different treatments (doses D1 to D12). To evaluate germination number of germinated seeds (G), mean germination time (MGT), and the time required for 1 to 90% of the seeds to germinate (T1, T10, T25, T50, T75, and T90) were determined. Parameter T10, which is closely related to the early germination was reduced when seeds were exposed to a magnetic field. The MGT was also reduced compared to control when seeds were exposed to the magnetic field.

**Poinapen et al.** [47] assessed tomato (*Solanum lycopersicum* L.) seed variety MST/32 to different magnetic flux density. Treatments not employing magnetic field exposure were used as controls. Results indicate that electrolyte leakage rate was reduced by a factor of 1.62 times during seed imbibition when non-uniform SMFs were employed. Higher germination (~11.0%) was observed in magnetically-exposed seeds than in non-exposed ones, although seedlings emerging from SMF treatments did not show a consistent increase in biomass accumulation.

**Shine et al.** [48] reported the beneficial effect of pre-sowing magnetic treatment for improving germination parameters and biomass accumulation in soybean. Soybean seeds were treated with static magnetic fields of 150 and 200 mT for 1 h and evaluated for reactive oxygen species (ROS) and activity of antioxidant enzymes. Superoxide and hydroxyl radicals were measured in embryos and hypocotyls of germinating seeds by electron paramagnetic resonance spectroscopy and kinetics of superoxide production; hydrogen peroxide and antioxidant activities were estimated spectro-photo-metrically. Magnetic field treatment resulted in enhanced production of ROS mediated by cell wall peroxidase while ascorbic acid content, superoxide dismutase and ascorbate peroxidase activity decreased in the hypocotyl of germinating seeds. An increase in the cytosolic peroxidase activity indicated that this antioxidant enzyme had a vital role in scavenging the increased H<sub>2</sub>O<sub>2</sub> produced in seedlings from the magnetically treated seeds.

**Vashisth et al.** [50] found the positive effects (germination characteristics, field emergence, leachate conductivity) of the exposure of specific static magnetic fields on fresh seeds of maize (*Zea mays* L).

**Vashisth et al.** [51] used magnetic field treatment to improve the seed quality. Temperature and relative humidity in combination cause decline in seed quality during storage. A number of physical and chemical treatments are used to maintain the seed quality (in storage). An experiment was conducted to investigate the improvement in the storability of seeds (ageing conditions and the deterioration). Seed lots of maize (cv. Ganga Safed-1) were exposed to 100 mT for 2 h and 200 mT for 1 h respectively. Results showed that seed viability and vigour with days of artificial ageing was partially ameliorated in magnetically exposed seeds. Magnetically treated seeds showed lower leachate conductivity than in unexposed control seeds during ageing. Ageing reduced the activities of antioxidant enzymes (viz., Superoxide dismutase, catalase and peroxidase and level of soluble protein).

**Anand et al.** [52] studied the effect of magnetic field treatments of maize (*Zea mays* L seeds). The seeds were exposed to static magnetic field (MF) of 100 and 200 mT for 2 and 1 h, respectively. Results suggested that MF treatment (100 mT for 2 h and 200 for 1 h) of maize seeds enhanced the seedling growth, leaf water status, photosynthesis rate and lowered the antioxidant defence system of seedlings under soil water stress.

**Aladjajiyan** [53] studied the effect of the static magnetic field of 0.15 T induction on the maize seeds and found that the magnetic field stimulated the shoot development and led to increase in the germinating energy, germination rate, fresh weight and shoot length.

**Răuciu *et al.*** [54] studied *Zea mays* with treatment of static magnetic field in order to observe several biochemical changes and stimulation effect on plant growth. Magnetic treatment ranging between 50 mT and 250 mT, for 14 days was selected. In order to investigate the biochemical changes of chlorophylls, total carotenoids and nucleic acids, spectro-photo-metrical measurements had been carried out. Low magnetic exposure (50 mT) revealed significant enhancement of the fresh tissue mass, assimilatory pigments level, chlorophyll ratio, average nucleic acids level and increase in the average plants length.

**Afshan *et al.*** [55] investigated the effect of pre-sowing magnetic treatments on germination, growth and yield of okra. The dry okra seeds were exposed to sinusoidal magnetic field induced by an electromagnet. The average magnetic field exposure was 99 mT for 3 and 11 min and seeds with no magnetic field treatment were considered as control. Both treated and non-treated seeds were sown in experimental plots (120 m<sup>2</sup>) under similar conditions. Number of flowers per plant, leaf area (cm<sup>2</sup>), plant height (cm) at maturity, number of fruits per plant were measured and found that 99 mT for 11 min exposure showed better results as compared to control.

**Leelapriya *et al.*** [56] have studied the effects of sinusoidal magnetic fields on percentage germination, growth, and yield of cotton (*Gossypium* species). The essential variable parameters employed were the intensity of magnetic field, frequencies and the different variety of cotton seeds of different germination capacities. The seeds were subjected to magnetic fields with nine different frequencies and intensities. In Type 3 cotton seeds exposed to 10 Hz, 100 nT fields, the yield was 75.3% higher than that of control, and in Type 2 cotton seeds exposed to 100 Hz, 1500 nT fields, the yield was 85.2% higher than that of control. The results showed that the pre sowing cotton seeds when exposed to extremely low frequency catalyze the type 2 cotton to yield more as compared to non-exposed controls. The yield observed was also frequency dependent. Only the seeds exposed to a particular frequency yields better.

**Table 2.2** Summary of previous researches involving static electric and magnetic fields with those seeds which are also undertaken in present investigation.

Seed	Electric or Magnetic field Strength and Period	Effect of exposure	Ref. Year
Maize	100 mT for 2 h and 200 mT for 1 h exposure	Quicker germination	[49] 2010
Maize	100 mT for 2 h and 200 mT for 1 h	Positive effects (germination characteristics, field emergence, leachate conductivity)	[50] 2009
Maize	100 mT for 2 h and 200 mT for 1 h	Improvement in the storability of seeds	[51] 2009
Maize	100 mT for 2 h and 200 for 1 h	Enhanced the seedling growth, leaf water status, photosynthesis rate	[52] 2012
Maize	0.15 T (10 to 30 min)	Increase of the germinating energy, germination rate, fresh weight and shoot length	[53] 2002
Maize	50 mT and 250 mT, for 14 days	Enhancement of the fresh tissue mass, assimilatory pigments level, chlorophyll ratio, average nucleic acids level	[54] 2008
Okra	99 mT for 3 and 11 min	99 mT for 11 min exposure showed better results	[55] 2012
Chickpea	100 mT for 1 h.	Enzymes related to germination process such as dehydrogenase and protease were higher	[57] 2012
Mung	Sinusoidal pulsed width modulation (SPWM) voltage (10, 20, 30, 40, 50, and 60 Hz)	20 or 60 Hz SPWM voltage has an enhancing effect on the early growth	[58] 2008

### **2.3 Inference Drawn, Gaps in Study and Scope of Work**

Seeds germinate in the soil where natural magnetic fields exist where as electrostatic fields are present in the atmosphere (presence of charged ions and atoms). Therefore, all forms of life live in the natural environment of electric and magnetic field. However, intensity of different field forces on the surface of the earth are weak to influence the seed germination and plant growth. Electric and magnetic field are an inescapable factor for plants on the Earth; however their impact on plant growth is not well understood. The reason of this effect can be searched in paramagnetic properties in chloroplasts which can cause acceleration of seeds metabolism by magnetic treatment [53]. Magnetic and electromagnetic treatments are being used in agriculture as a non-invasive technique. The review of literature has shown that the environmentally friendly MF seed treatment could be used practically to enhance the germination and yield of various crops. The enhancement of growth under specific electric and magnetic conditions has been reported by many scientists. The possible hypotheses for observed positive effect of magnetic treatment could be found in paramagnetic properties of some atoms in plant cells [34]. Magnetic moments of these atoms turn align themselves in the direction of the external field. It is magnetic property of the seed molecule of any particular plant to determine their ability to absorb and transform the energy of external magnetic field in other kind of energy and to transfer this energy later to other structures in plant cells, thus activating them for enhanced germination [34].

It is also possible that the magnetic field may influence the structures of cell membranes and in this way increases their permeability and ion transport through the ion channels [60], which then affects various metabolic pathway activities [61]. The enzymes which are necessary for seed germination at particular stages of germination were found higher in magnetically treated seeds during seed germination [38]. The magnetic field affects the biological objects by spins, free radicals, liquids crystals or mobile electron charges [38]. Chemically these free radicals are very active species, which take part in fast reactions and cause changes in the biochemical and physiological processes during seed germination leading to an increase in water uptake rate due to the magnetic field treatment which may be responsible for increasing seed germination rate as well as seedling growth.

There is considerable controversy over the validity of any explanation of the influence of a magnetic field on a biological system. No satisfactory picture of how a magnetic field affects the seeds under germination and plant growth has been given. Several models have been proposed to explain the possible mechanisms to predict the magnetic exposure

conditions that might produce biological effects. However, the effects that have been reported in the literature review do not satisfy a single hypothesis. Moreover, many researchers used one or two values of magnetic field intensity and a single exposure time (Table 2.1), so it is not possible to reach at any satisfactory explanation about the cause of magnetic effect on seed germination.

Seed germination is considered as a complex bioprocess which passes through a series of bio-reactions. Stochastic model is best approach to study the stage wise germination process. Seed germination time-course is very beneficial for physiologists, seed technologists and also for ecologists. With proper modelling, it is possible to predict the degree of success in a species based on the capacity of their harvest. It is unfortunate that previous efforts in this area remain focused only on experimental study due to lack of theoretical background. No attempt has been made to carry forward Stochastic model to understand transient states during seed germination process.

When there are a large number of seeds in favorable conditions for germination for a given lot of sample, then there is a definite probability that some particular proportion of germination will occur in a given time interval. The number of seeds that should germinate in one second is the chance of one seed germination multiplied by the number of seeds in a sample. But no efforts have been done to develop some germinating model based upon this statistics to predict that the rate of germination is proportional to the number or seeds present at that instant.

Two familiar models in seed germination course are: Thermal time model and hydro time model (discussed in first chapter). Thermal time model models describes germination patterns in response to temperature ( $T$ ) and Hydro time model showed that if  $GR_g$  values were plotted as a function of  $\Psi$ , the resulting curves become linear and parallel. These two established models explain the thermal and hydro parameters related to seeds germination but fail to include the effect of magnetic field. In order to understand the effect of magnetic field on plant growth features it is necessary to develop a new model which could incorporate the effect of applied magnetic field on growth of the seeds.

On the basis of literature review, it is found that no data analysis (regarding electric and magnetic treatment to seed) is available on the white gourd (*Benincasa hispida*), spinach (*Spinacia oleracea* L.), and bitter melon (*Momordica Charantia*) seeds. Some data of magnetic field treatment is available for chickpea (*Cicer arietinum* L.), maize (*Zea mays* L.), mung bean and okra (*Abelmoschus esculentus* L.) (Table 2.2), but the data is limited (a few

magnetic values and a few exposure time) and not sufficient to reach at any conclusion relevant to the effect of electric and magnetic field on seed germination process.

The literature review revealed that in order to measure the germination time-course there are several methods and mathematical expressions like Weibull function, Morgan-Mercer-Flodin function, Richards function, Mitscherlich, Gompertz function, logistic function and Malthus-Verhulst function for cumulative germination (discussed in chapter 1). All described functions are limiting in use because many of these functions are not having any meaning from biological angle. So there is a need of reformulation of these functions in order to get precise information of germination processes from biological point of view.

Literature available on the effect of the electric field on seed germination is limited. Very few researchers worked upon the study of water uptake by the magnetically treated seeds (discussed in chapter 1) but no work has been done on the effects of water uptake by electrically treated seeds. Meyer [62] discussed the water uptake model by using an equation ( $\ln ((w_{max} - w) / w_{max})$ ). Using this model water uptake at any instant can be calculated by letting two unknown parameters ( $w_{max}$  and  $k$ ). Finding the value of  $w_{max}$  practically is very difficult task. So there is a need to develop a new water uptake model with a minimum number of unknown parameters and without using  $w_{max}$ .

Many farmers are interested to know the physical methods for plant stimulation because of convenience for biological farming. The aim of the present work is to show the possibilities for using stationary magnet with enough space between poles for pre-sowing seed treatment.

## References

- [1] Wadas R. S., *Biomagnetism*: Polish Scientific Publishers. Warsaw, 1991.
- [2] Bilalis D. J., Katsenios N., Efthimiadou A. *et al.*, Pulsed electromagnetic field: an organic compatible method to promote plant growth and yield in two corn types, *Electromagn Biol Med*, **31**, 4, 333-43, 2012.
- [3] Hart F. X., and Marino A. A., Energy flux along high voltage transmission lines, *Biomedical Engineering, IEEE Transactions on*, **5**, 493-495, 1977.
- [4] Morgan N., Watson B., Maloney J. *et al.*, "Transgenic plant stress response in strong magnetic fields and in magnetic levitation (low gravity) environments," in Materials Research Society Conf. Applied Magnetic Field Effects on Materials Behavior, pp., 2000.
- [5] Negishi Y., Hashimoto A., Tsushima M. *et al.*, Growth of pea epicotyl in low magnetic field implication for space research, *Advances in Space Research*, **23**, 12, 2029-2032, 1999.
- [6] Pietruszewski S., Muszynski S., and Dziwulska A., Electromagnetic fields and electromagnetic radiation as non-invasive external stimulants for seeds (selected methods and responses), *International agrophysics*, **21**, 1, 95, 2007.
- [7] Murr L., Plant growth response in a simulated electric field-environment, *Nature* **200**, 490-491, 1963.
- [8] Murr L., The biophysics of plant growth in a reversed electrostatic field: A comparison with conventional electrostatic and electrokinetic field growth responses, *International Journal of Biometeorology*, **10**, 2, 135-146, 1966.
- [9] Murr L., Mechanism Of Plant-Cell Damage In An Electrostatic Field, *Nature*, **201**, 1305, 1964.
- [10] Piras A., Gui Z., Qiao L. *et al.*, Effect of Negative Electrostatic Field Treatment on Germination of Seeds Soaked GA3, *International Journal of Soft Computing and Engineering (IJSCE)*, **3**, 3, 2231-2307, 2013.
- [11] Sidaway G., Influence of electrostatic fields on seed germination, *Nature* **211**, 303, 1966.
- [12] Huang R., Sukprakarn S., Phavaphutanon L. *et al.*, A Comparison of Electric Field Treatments to Hydropriming on Cucumber Seed Germination Enhancement, *Kasetsart J.(Nat. Sci.)*, **40**, 559-565, 2006.
- [13] Costanzo E., The influence of an electric field on the growth of soy seedlings, *Journal of Electrostatics*, **66**, 7-8, 417-420, 2008.
- [14] Jian L., Ruijin L., Guixue W. *et al.*, Influence of High Voltage Electrostatic Field (HVEF) on Vigour of Aged Rice (*Oryza sativa* L.) Seeds, *Journal of Phytology*, **1**, 6, 2009.
- [15] Pozeliene A., Influence of Electric Field on the Quality of Flaxseed, *International Commission of Agricultural Engineering*, **3**, 1-6, 2001.
- [16] Gui Z., Piras A., Qiao L. *et al.*, Improving Germination of Seeds Soaked GA3 by Electrostatic Field Treatment, *International Journal of Recent Technology and Engineering (IJRTE)*, **2**, 1, 2277-3878, 2013.
- [17] Moon J.-D., and Chung H.-S., Acceleration of germination of tomato seed by applying AC electric and magnetic fields, *Journal of Electrostatics*, **48**, 2, 103-114, 2000.
- [18] Kiatgamjorn P., Tarateeraseth V., Khan-ngern W. *et al.*, "The effect of electric field intensity on bean sprout growing," in Proc. Int. Conf. Electromagnetic Compatibility, October, pp. 7-11, 2002.

- [19] Samani M. A., Latifeh P., and Azimi N., Magnetic field effects on seed germination and activities of some enzymes in cumin, *Life Science Journal*, **10**, 1, 323-328, 2013.
- [20] De Souza A., García D., Sueiro L. *et al.*, Pre-sowing magnetic treatment of tomato seeds: effects on the growth and yield of plants cultivated late in the season, *Spanish Journal of Agricultural Research*, **3**, 1, 113-122, 2005.
- [21] De Souza A., García D., Sueiro L. *et al.*, Pre- sowing magnetic treatments of tomato seeds increase the growth and yield of plants, *Bioelectromagnetics*, **27**, 4, 247-257, 2006.
- [22] Flórez M., Carbonell M. V., and Martínez E., Exposure of maize seeds to stationary magnetic fields: Effects on germination and early growth, *Environmental and Experimental Botany*, **59**, 1, 68-75, 2007.
- [23] Fischer G., Tausz M., Köck M. *et al.*, Effect of weak 16 2/3 HZ magnetic fields on growth parameters of young sun flower and wheat seedlings. , *Bioelectromagnetics*, **25**, 8, 638–41., 2004.
- [24] Aksenov S. I., Grunina T., and Goriachev S. N., [Characteristics of low frequency magnetic field effect on swelling of wheat seeds at various stages], *Biofizika*, **46**, 6, 1127-32, 2001.
- [25] Podlečný J., Pietruszewski S., and Podlečna A., Efficiency of the magnetic treatment of broad bean seeds cultivated under experimental plot conditions, *Int. Agrophysics*, **18**, 65-71, 2004.
- [26] Shine M. B., Guruprasad K. N., and Anand A., Effect of stationary magnetic field strengths of 150 and 200 mT on reactive oxygen species production in soybean, *Bioelectromagnetics*, **33**, 5, 428-37, 2012.
- [27] Flórez M., Carbonell M., and Martínez E., Early sprouting and first stages of growth of rice seeds exposed to a magnetic field, *Electromagnetic Biology and Medicine*, **23**, 2, 157-166, 2004.
- [28] Aladjadjian A., and Ylieva T., Influence of stationary magnetic field on the early stages of the development of tobacco seeds (*Nicotiana Tabacum L.*). *Journal of Central European Agriculture*, **4**, 2, 131–137, 2003.
- [29] Odhiambo J. O., Ndiritu F. G., and Wagara I. N., Effects Of Static Electromagnetic Fields At 24 Hours Incubation On The Germination Of Rose Coco Beans (*Phaseolus Vulgaris*), *Romanian j. Biophys*, **19**, 2, 2009.
- [30] Martinez E., Carbonell M. V., and Amaya J. M., A static magnetic field of 125 mT stimulates the initial growth stages of barley (*Hordeum vulgare L.*), *Electromagnetic Biology and Medicine*, **19**, 3, 271-277, 2000.
- [31] Nimmi V., and Madhu G., Effect of pre-sowing treatment with permanent magnetic field on germination and growth of chilli (*Capsicum annum. L.*), *Int. Agrophysics*, **23**, 195-198, 2009.
- [32] Rochalska M., Grabowska K., and Ziarnik A., Impact of low frequency magnetic fields on yield and quality of sugar beet, *International Agrophysics*, **23**, 163-174, 2008.
- [33] Shabrangi A., and Majd A., “Effect of magnetic fields on growth and antioxidant systems in agricultural plants,” in *Progress in Electromagnetics Res. Symp. Beijing, China*, pp. 1142-1147, 2009.
- [34] Aladjadjian A., Influence of stationary magnetic field on lentil seeds, *Int. Agrophys*, **24**, 321-324, 2010.
- [35] Majd A., and Shabrangi A., Effect of Seed Pretreatment by Magnetic Fields on Seed Germination and Ontogeny Growth of Agricultural Plants, *Session 3A8 Progress In Electromagnetics Research Symposium, Beijing, China, March 23-27, 2009*, 511.

- [36] Martínez E., Flórez M., Maqueda R. *et al.*, Pea (*Pisum sativum*, L.) and lentil (*Lens culinaris*, Medik) growth stimulation due to exposure to 125 and 250 mT stationary fields, *Polish Journal of Environmental Studies*, **18**, 4, 657-663, 2009.
- [37] ul Haq Z., Jamil Y., Irum S. *et al.*, Enhancement in the germination, seedling growth and yield of radish (*Raphanus sativus*) using seed pre-sowing magnetic field treatment, *Polish, J. Environ. Stud*, **21**, 2, 369-374, 2012.
- [38] Iqbal M., Haq Z., Jamil Y. *et al.*, Effect of presowing magnetic treatment on properties of pea, *International Agrophysics*, **26**, 1, 25-31, 2012.
- [39] Soltani F., Kashi A., and Arghavani M., Effect of magnetic field on *Asparagus officinalis* L. seed germination and seedling growth, *Seed Science and technology*, **34**, 2, 349-353, 2006.
- [40] Balouchi H., and Sanavy S., Electromagnetic field impact on annual medics and dodder seed germination, *Int. Agrophysics*, **23**, 111-115, 2009.
- [41] Muraji M., Nishimura M., Tatebe W. *et al.*, Effect of alternating magnetic field on the growth of the primary root of corn, *Magnetics, IEEE Transactions on*, **28**, 4, 1996-2000, 1992.
- [42] Muszyński S., Gagoś M., and Pietruszewski S., Short-term pre-germination exposure to ELF magnetic field does not influence seedling growth in durum wheat (*Triticum durum*), *Polish J. Environ. Study*, **18**, 6, 1065-1072, 2009.
- [43] Pietruszewski S., and Kania K., Effect of magnetic field on germination and yield of wheat, *Int. Agrophys*, **24**, 297-302, 2010.
- [44] Pietruszewski S., Modeling by logistic curve germination of wheat seeds Henika cultivar in magnetic field, *Acta Agrophysica*, **58**, 143-151, 2001.
- [45] Rochalska M., and Orzeszko-Rywka A., Magnetic field treatment improves seed performance, *Seed Science and Technology*, **33**, 3, 669-674, 2005.
- [46] Martínez E., Carbonell M., Flórez M. *et al.*, Germination of tomato seeds (*Lycopersicon esculentum* L) under magnetic field, *International Agrophysics*, **23**, 1, 45-49, 2009.
- [47] Poinapen D., Brown D. C., and Beeharry G. K., Seed orientation and magnetic field strength have more influence on tomato seed performance than relative humidity and duration of exposure to non-uniform static magnetic fields, *J Plant Physiol*, **170**, 14, 1251-1258, 2013.
- [48] Shine M. B., Guruprasad K. N., and Anand A., Enhancement of germination, growth, and photosynthesis in soybean by pre-treatment of seeds with magnetic field, *Bioelectromagnetics*, **32**, 6, 474-84, 2011.
- [49] Vashisth A., and Nagarajan S., Characterization of water distribution and activities of enzymes during germination in magnetically-exposed maize (*Zea mays* L) seeds, *Indian J Biochem Biophys*, **47**, 5, 311-8, 2010.
- [50] Vashisth A., and Nagarajan S., Effect of pre-sowing exposure to static magnetic field of maize (*Zea mays* L.) seeds on germination and early growth characteristics, *Pusa Agricultural Science*, **30**, 48-55, 2007.
- [51] Vashisth A., and Nagarajan S., Germination characteristics of seeds of maize (*Zea mays* L.) exposed to magnetic field under accelerated ageing condition, *Journal of Agricultural Physics*, **9**, 50-58, 2009.
- [52] Anand A., Nagarajan S., Verma A. P. *et al.*, Pre-treatment of seeds with static magnetic field ameliorates soil water stress in seedlings of maize (*Zea mays* L.), *Indian J Biochem Biophys*, **49**, 1, 63-70, 2012.
- [53] Aladjadjiyan A., Study of the influence of magnetic field on some biological characteristics of *Zea mays*, *Journal of Central European Agriculture*, **3**, 2, 89-94, 2002.

- [54] Racuciu M., Creanga D., and Horga I., Plant growth under static magnetic field influence, *Rom. J. Phys*, **53**, 353-359, 2008.
- [55] Naz A., Jamil Y., Iqbal M. *et al.*, Enhancement in the germination, growth and yield of Okra (*Abelmoschus esculentus*) using pre-sowing magnetic treatment of seeds, *Indian Journal of Biochemistry & Biophysics*, **49**, 211-214, 2012.
- [56] Leelapriya T., Dhilip K., and Sanker Narayan P., Effect of weak sinusoidal magnetic field on germination and yield of cotton (*Gossypium spp.*), *Electromagnetic Biology and Medicine*, **22**, 2-3, 117-125, 2003.
- [57] Vashisth A., Joshi D. K., and Singh R., Characterization of water uptake and distribution in chickpea (*Cicer arietinum L.*) seeds during germination by NMR spectroscopy, *African Journal of Biotechnology*, **11**, 59, 12286-12297., 2012.
- [58] Huang H. H., and Wang S. R., The effects of inverter magnetic fields on early seed germination of mung beans, *Bioelectromagnetics*, **29**, 8, 649-657, 2008.
- [59] Jared O. O., Francis N. G., and Isabel W. N., The influence of AC electromagnetic fields on the initial radicle growth rate of *Phaseolus vulgaris L.*, *Journal of Applied Biosciences*, **22**, 1350-1358, 2009.
- [60] Aksyonov S., Bulychev A., Grunina T. Y. *et al.*, Effects of ELF-EMF treatment on wheat seeds at different stages of germination and possible mechanisms of their origin, *Electromagnetic Biology and Medicine*, **20**, 2, 231-253, 2001.
- [61] Labes M., A possible explanation for the effect of magnetic fields on biological systems, *Nature*, **211**, 968, 1966.
- [62] Meyer C. J., Steudle E., and Peterson C. A., Patterns and kinetics of water uptake by soybean seeds, *J Exp Bot*, **58**, 3, 717-32, 2007.

## Chapter 3

# Experimentation and Modelling

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### Overview

In this chapter the details of experimental procedures followed for the electric field and magnetic field treatment of seeds is described. In order to obtain the required electric and magnetic fields two different types of generators were designed and fabricated. For the measurement of magnetic field, digital gauss meter and magnetic probe were used. For the verification of the experimental data three new models named 'Magnetic-time model', 'Hydro-thermal-magnetic-time model' and 'Water uptake model' were formulated. Apart from these, two models 'Malthus-Verhulst function' and 'Stochastic Model' were also reformulated. Magnetic-time model and Hydro-thermal-magnetic-time model incorporates the effect of applied magnetic field on growth of the seeds. Water absorption statistics is an indispensable tool to understand basic germinating processes. To understand the impact of electric and magnetic field on seed germination a new model for water uptake is formulated.

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### 3. MATERIALS AND MEHODS

#### 3.1 Magnetic Field Generator

In order to expose the seeds in the magnetic field, a magnetic field generator was fabricated where variable horizontal static magnetic field (north pole to south pole) of strength up to 750 mT could be obtained. The gap between the pole pieces was variable (5 to 10 cm) with two way knobbed wheel screw adjusting system as shown in Figure 3.1. The flat faced pole pieces were cylindrical in shape with 7.5 cm in diameter. There were two coils and each coil was wound on the non-magnetic format having 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 A) was met by DC power supply (0-45V/0-7.5A) with a continuously variable output current used for the electromagnet. Magnetic field is generated by current carrying solenoid. At the centre well inside the solenoid its value is (discussed in chapter 1)  $B = \mu_0 n I$ . At a point near the end of

a solenoid, it is calculated as  $B = \frac{\mu_0 n I}{2}$ .



**Figure 3.1:** Magnetic field generator.

A digital Gauss meter was used to monitor the field strength produced in the pole gap (Figure 3.2). The probe was made of indium arsenide crystal and encapsulated to a non- magnetic thin cylindrical sheet which could measure up to 2T. The absolute magnetic exposure dose  $D_M$  is described as  $D_M = \rho_M t$ . Where  $\rho_M$  is the magnetic field energy density (discussed in

chapter 1). In the measurement of magnetic dose, the role of  $B$  is more important as compared to  $t$  because it appears as its square value in the formula ( $\langle \rho_M \rangle = \frac{1}{2} \mu_0 H^2$ ). In the present research  $t$  is kept constant and the value of  $B$  is varied. The variation of  $B$  signifies the variation in the value of magnetic dose. Four replications of seed sample comprising of 40 seeds (for all experiments) were taken in the plastic container of 42 cm<sup>3</sup> capacity made of a non-magnetic thin transparent plastic sheet. These samples were kept in between the pole pieces of the electromagnet. From the center to end of the poles, the variation in the magnetic field was 0.8% in all along outward direction.

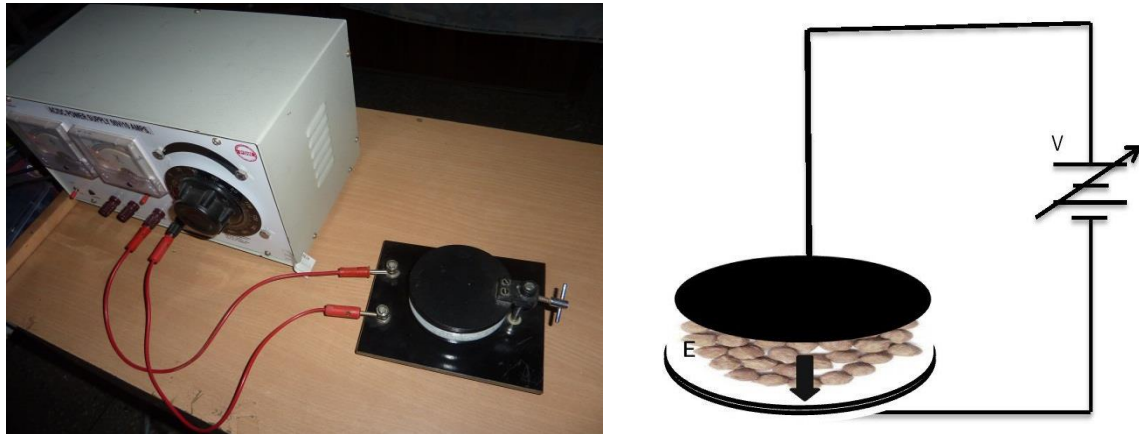


**Figure 3.2:** Digital Gauss meter.

### 3.2. Electric Field Generator

In order to expose the seeds in the electric field, an electric field generator was fabricated. Experimental setup consists of a fully adjustable DC high-voltage supply (0-13 kV), a test cell comprising of two circular aluminum plates of 8 cm diameter with the adjustable inter-electrode gap which principally act as a condenser (Figure 3.3). Dry seeds of selected spices (discussed in chapter 1) of a 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 were 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 (Figure 3.4).



**Figure 3.3:** Electric Field generator



**Figure 3.4:** Temperature measurement during electric exposure.

It was noted that there was no heating effect during the experiments. An electric field measured in V/m using the formula  $E = \frac{V}{d\eta}$  Where  $V$  is the potential applied between the plates and measured in volt, whereas  $d$  is the distance between the plates measured in meters.  $\eta$  is field utilization factor (its value depends on the geometry of the electrodes). Field utilization factor is measured as  $\eta = \frac{E_{av}}{E_{max}}$  where  $E_{av}$  and  $E_{max}$  represent to average and maximum electric field values. Present electrode geometry used for the research was such that  $E_{av} \cong E_{max}$ . Therefore, the value of  $\eta$  is taken as 1. The absolute electric exposure dose  $D_E$  is measured as  $D_E = \rho_E t$ . Where  $\rho_E$  is electric or electric field energy density and  $t$  is

time of exposure. In the measurement of electric dose, the role of  $E$  is more important as compared to  $t$  because it appears as its square value in the formula  $\langle \rho_E \rangle = \frac{1}{2} \epsilon_0 E^2$ . In the present research  $t$  is kept constant and the value of  $E$  is varied by varying the potential difference  $V$  between the electrodes of electric generator. The variation of the value of  $V$  signifies the variation in the value of electric dose. After electrical treatment, all the seeds were taken between the thin moist cotton cloth layer over the sponge bed in the box on the same day. For germination, plastic boxes were used with the lid of dimension  $20 \times 13 \times 4 \text{ cm}^3$  having sponge sheet of 2 cm thickness. Sponge sheets in each box were damped with an equal amount of tap water whenever necessary. All necessary precautions were taken to ensure that all the external variables were same for each class of seed during the experiment. Number of germinated seeds was counted after a 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.

### 3.3 Plant growth chamber

Constant temperature for seed germination is maintained by using plant growth chamber (manufactured by Optikindia, Ambala, India). Temperature of incubator can be varied in between  $+5 \text{ }^\circ\text{C}$  to  $45 \text{ }^\circ\text{C}$  with  $\pm 1 \text{ }^\circ\text{C}$  accuracy. Similarly, relative humidity can be varied in between 40% to 95 % RH, depending upon the requirement (Figure 3.5).



**Figure 3.5:** Plant growth chamber.

### 3.4 Modeling

To describe the germination parameters which are influenced by the electric and magnetic field, new models have been formulated. However, in some cases existing models have also been reformulated to explain the results.

#### Reformulation of Malthus-Verhulst function

Pierre-François Verhulst in 1838 modified the model given by Thomas Malthus, which describes the self-limiting growth of a biological population. The germination kinetics of seeds stimulated with a magnetic or electric field before sowing is most often described using the Malthus-Verhulst equation [1-3]. The use of Malthus-Verhulst function is limited as it is based upon the assumption that at  $t = t_0$ , very first seed germinates. Experimentally it is very difficult to find the time when very first seed germinates.

Malthus-Verhulst equation is:

$$N_g(t) = N_k [1 + (N_k - 1) \exp\{-\alpha N_k (t - t_0)\}]^{-1} \quad (3.1)$$

Where:  $N_g(t)$  is the number of seeds that has germinated within time  $t$ ,  $N_k$  is the final number of germinated seeds,  $\alpha$  is germination rate coefficient,  $t_0$  is time required for the first seed to germinate.

#### Derivation of germination rate using Malthus-Verhulst equation

For germination rate, differentiating Eq. (3.1) with respect to time we get

$$\begin{aligned} dN_g(t)/dt &= - N_k [1 + (N_k - 1) \exp\{-\alpha N_k (t - t_0)\}]^{-2} d/dt[(N_k - 1) \exp\{-\alpha N_k (t - t_0)\}] \\ &= - N_k [1 + (N_k - 1) \exp\{-\alpha N_k (t - t_0)\}]^{-2} [(N_k - 1) \exp\{-\alpha N_k (t - t_0)\}] (-\alpha N_k) \\ &= \alpha (N_k)^2 [1 + (N_k - 1) \exp\{-\alpha N_k (t - t_0)\}]^{-2} [(N_k - 1) \exp\{-\alpha N_k (t - t_0)\}] \\ &= \alpha (N_k \times N_k) [1 + (N_k - 1) \exp\{-\alpha N_k (t - t_0)\}]^{-2} [(N_k - 1) \exp\{-\alpha N_k (t - t_0)\}] \end{aligned}$$

$$\text{Because } N_k = N_g(t) [1 + (N_k - 1) \exp\{-\alpha N_k (t - t_0)\}]$$

Substituting above

$$dN_g(t)/dt = \alpha N_k N_g(t) [1 + (N_k - 1) \exp\{-\alpha N_k (t - t_0)\}] [1 + (N_k - 1) \exp\{-\alpha N_k (t - t_0)\}]^{-2} \times$$

$$\begin{aligned}
& [(N_k - 1)\exp\{-\alpha N_k (t-t_0)\}] \\
&= \alpha N_k N_g (t) [1+(N_k - 1)\exp\{-\alpha N_k (t-t_0)\}]^{-1} [(N_k - 1)\exp\{-\alpha N_k (t-t_0)\}] \\
&= \alpha N_k N_g (t) [(N_k - 1)\exp\{-\alpha N_k (t-t_0)\}] [1+(N_k - 1)\exp\{-\alpha N_k (t-t_0)\}]^{-1}
\end{aligned}$$

Adding and subtracting  $\alpha N_k N_g$

$$= [\alpha N_k N_g (t) [(N_k - 1)\exp\{-\alpha N_k (t-t_0)\} + 1] - \alpha N_k N_g (t)] / [1+(N_k - 1)\exp\{-\alpha N_k (t-t_0)\}]$$

Because  $[(N_k - 1)\exp\{-\alpha N_k (t-t_0)\} + 1] = N_k/N_g$

Therefore  $dN_g(t)/dt = (\alpha N_k N_g (t) \times N_k/N_g - \alpha N_k N_g (t)) / (N_k/N_g)$

$$dN_g(t)/dt = (N_k - N_g (t)) \alpha N_g \quad (3.2)$$

Again differentiating with respect to time t

$$\begin{aligned}
(d/dt)(dN_g(t)/dt) &= (d/dt)(\alpha N_g N_k - \alpha N_g N_g (t)) \\
&= \alpha N_k (d/dt)(N_g) - (d/dt)(N_g^2 \alpha) \\
&= \alpha N_k (d/dt)(N_g) - 2 \times (d/dt)(N_g \alpha)
\end{aligned}$$

Because  $dN_g(t)/dt = (N_k - N_g (t)) \alpha N_g$

$$(d/dt)(dN_g(t)/dt) = \alpha N_k (N_k - N_g (t)) \alpha N_g - 2 \alpha (N_k - N_g (t)) \alpha N_g$$

$$(d/dt)(dN_g(t)/dt) = \alpha^2 N_k N_g (N_k - N_g (t)) - 2 \alpha^2 (N_k - N_g (t)) N_g$$

$$(d/dt)(dN_g(t)/dt) = \alpha^2 N_g (N_k - N_g (t)) [N_k - 2 N_g]$$

Pietruszewski [2] and Pietruszewski and Kania [3] derived germination rate as:

$$(d/dt)(dN_g(t)/dt) = \alpha N_g (N_k - N_g (t)) [N_k - 2 N_g]$$

In the present derivation, it is found that germination coefficient should appear with its square value so corrected equation is

$$d^2 (N_g)/ dt^2 = (d/dt)(dN_g(t)/dt) = \alpha^2 N_g (N_k - N_g (t))(N_k - 2 N_g) \quad (3.3)$$

### **Finding $t_{max}$ :**

To find  $t_{max}$  double derivative of  $N_g$  must be zero:  $d^2 (N_g)/ dt^2 = 0$

Therefore  $\alpha^2 N_g (N_k - N_g(t))(N_k - 2N_g) = 0$

It implies either  $N_k - N_g(t) = 0$  that is  $N_k = N_g(t)$

Or

$(N_k - 2N_g) = 0$  that is  $N_k = 2N_g$

For  $N_k = N_g(t)$  implies using equation 3.1 that either  $N_k = 1$  or  $t$  tends to infinity therefore this possibility is discarded (impossible situation)

Now second possibility is considered, that is  $N_k = 2N_g$

Substituting this value in equation 3.1

$$N_k / 2 = N_k [1 + (N_k - 1) \exp\{-\alpha N_k (t_{\max} - t_0)\}]^{-1}$$

$$1 + (N_k - 1) \exp\{-\alpha N_k (t_{\max} - t_0)\} = 2$$

$$(N_k - 1) \exp\{-\alpha N_k (t_{\max} - t_0)\} = 1$$

$$\exp \alpha N_k (t_{\max} - t_0) = (N_k - 1)$$

$$\alpha N_k (t_{\max} - t_0) = \ln (N_k - 1)$$

$$(t_{\max} - t_0) = [\ln (N_k - 1)] / \alpha N_k$$

$$t_{\max} = [\{\ln (N_k - 1)\} / \alpha N_k] + t_0 \quad (3.4)$$

The use of Malthus-Verhulst function is limited as experimentally it is very difficult to find the time when very first seed germinates. Otherwise, we can easily find the starting time  $t_0$  when a few number of seeds  $N_i$  germinate. So Malthus-Verhulst equation is reformulated as:

$$N_g(t) = N_k N_i / [N_i + (N_k - N_i) \exp\{-\alpha N_k (t - t_0)\}] \quad (3.5)$$

### Derivation of germination rate using reformulated Malthus-Verhulst equation

For germination rate, differentiating Eq. (3.5) with respect to time we get:

$$\begin{aligned} dN_g(t)/dt &= - N_k N_i [N_i + (N_k - N_i) \exp\{-\alpha N_k (t - t_0)\}]^{-2} d/dt[(N_k - N_i) \exp\{-\alpha N_k (t - t_0)\}] \\ &= - N_k N_i [N_i + (N_k - N_i) \exp\{-\alpha N_k (t - t_0)\}]^{-2} [(N_k - N_i) \exp\{-\alpha N_k (t - t_0)\}] (-\alpha N_k) \\ &= \alpha N_i (N_k)^2 [N_i + (N_k - N_i) \exp\{-\alpha N_k (t - t_0)\}]^{-2} [(N_k - N_i) \exp\{-\alpha N_k (t - t_0)\}] \end{aligned}$$

$$= \alpha N_i (N_k \times N_k) [N_i + (N_k - N_i) \exp\{-\alpha N_k (t-t_0)\}]^2 [(N_k - N_i) \exp\{-\alpha N_k (t-t_0)\}]$$

Because  $N_k N_i = N_g(t) [N_i + (N_k - N_i) \exp\{-\alpha N_k (t-t_0)\}]$

Substituting above

$$\begin{aligned} dN_g(t)/dt &= \alpha N_k N_g(t) [N_i + (N_k - N_i) \exp\{-\alpha N_k (t-t_0)\}] [N_i + (N_k - N_i) \exp\{-\alpha N_k \\ &\quad (t-t_0)\}]^2 [(N_k - N_i) \exp\{-\alpha N_k (t-t_0)\}] \\ &= \alpha N_k N_g(t) [N_i + (N_k - N_i) \exp\{-\alpha N_k (t-t_0)\}]^{-1} [(N_k - N_i) \exp\{-\alpha N_k (t-t_0)\}] \\ &= \alpha N_k N_g(t) [(N_k - N_i) \exp\{-\alpha N_k (t-t_0)\}] [N_i + (N_k - 1) \exp\{-\alpha N_k (t-t_0)\}]^{-1} \end{aligned}$$

Adding and subtracting  $\alpha N_k N_g$

$$= [\alpha N_k N_g(t) [N_k - N_i) \exp\{-\alpha N_k (t-t_0)\} + N_i] - \alpha N_k N_i N_g(t) / [N_i + (N_k - N_i) \exp\{-\alpha N_k (t-t_0)\}]$$

Because  $[N_k - N_i) \exp\{-\alpha N_k (t-t_0)\} + N_i] = N_k N_i / N_g$

Therefore  $dN_g(t)/dt = (\alpha N_k N_g(t) - \alpha N_i N_k N_g(t)) / (N_i N_k / N_g)$

$$dN_g(t)/dt = (N_k - N_g(t)) \alpha N_g \quad (3.6)$$

Here, it is interesting to note that the result for germination rate using reformulated Malthus-Verhulst equation is same as with using Malthus-Verhulst equation.

Again differentiating with respect to time t

$$\begin{aligned} (d/dt)(dN_g(t)/dt) &= (d/dt) (\alpha N_g N_k - \alpha N_g N_g(t)) \\ &= \alpha N_k (d/dt) (N_g) - (d/dt) (N_g^2 \alpha) \\ &= \alpha N_k (d/dt) (N_g) - 2 \times (d/dt) (N_g \alpha) \end{aligned}$$

Because  $dN_g(t)/dt = (N_k - N_g(t)) \alpha N_g$

$$(d/dt)(dN_g(t)/dt) = \alpha N_k (N_k - N_g(t)) \alpha N_g - 2 \alpha (N_k - N_g(t)) \alpha N_g$$

$$(d/dt)(dN_g(t)/dt) = \alpha^2 N_k N_g (N_k - N_g(t)) - 2 \alpha^2 (N_k - N_g(t)) N_g$$

$$(d/dt)(dN_g(t)/dt) = \alpha^2 N_g (N_k - N_g(t)) [N_k - 2 N_g]$$

$$d^2(N_g)/dt^2 = (d/dt)(dN_g(t)/dt) = \alpha^2 N_g (N_k - N_g(t)) (N_k - 2 N_g) \quad (3.7)$$

Double derivative of Ng or single derivative of germination rate using reformulated Malthus-Verhulst equation comes out the same as that of using Malthus-Verhulst equation.

### 3.4.2 Magnetic-time model

Established germinating models (discussed in chapter 1) explain the thermal and hydro parameters related to seeds germination but fail to include the effect of magnetic field. In order to understand the effect of magnetic field on plant growth we propose a new model which is Magnetic-Time and Hydrothermal-Magnetic models to incorporate the effect of applied magnetic field on growth of the seeds.

When other factors like temperature, water potential, etc. are considered constant for a given place then germination rate  $g(r)$  or  $1/t_g$  (Where  $g(r)$  is germination rate, and  $t_g$  is mean germination time of a given seed population) is a linear function of applied magnetic field  $B$ .

$$1/t_g = C + m B \quad (3.8)$$

In the above equation 3.8,  $C$  is intercept of  $1/t_g$ . Inverse of the slope of the straight line ( $1/m$ ) is denoted as  $\theta_B(g)$  and is called magnetic time constant for a given seed population.

If  $g(r)$  or  $1/t_g$  is taken along X-axis and  $B$  along Y axis, then slope of line directly gives the value of  $\theta_B(g)$ . Then the equation (3.8) becomes:

$$B = \theta_B(g) (1/t_g) - H_g \quad (3.9)$$

$$\theta_B(g) = (B + H_g) t_g \quad (3.10)$$

$$B + H_g = \theta_B(g) g(r) \quad (3.11)$$

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

### 3.4.3 Hydro-thermal-magnetic-time model

Thermal-time, Hydro-time and Magnetic-time have been combined into Hydrothermal-Magnetic-Time model that can describe seed germination patterns more precisely. By combining Equations 1.14 (chapter 1). 1.16 (chapter 1) and 3.10, a hydrothermal-magnetic time constant ( $\Theta_{HTB}$ ) for sub-optimal conditions can be defined as:

$$\Theta_{HTB} = (\Psi - \Psi_b) (T - T_b) (B + H_g) t_g \quad (3.12)$$

### 3.4.4 Water uptake model

Water absorption statistics is an important tool to understand basic germinating processes. Water uptake curve can be divided into three phases (Phase I, Phase II and Phase III). In phase I, there is rapid water absorption (independent of metabolic activity). In Phase II water absorption becomes small as the seed gets saturated in this phase. Enzyme activation and their synthesis increases in phase II. Activated enzymes break down storage materials like fats, proteins, carbohydrates and phosphorous containing compounds. In phase III water uptake again increases because radical emerge and elongation occurs. The rate of seed swelling ( $dw/dt$ ) during hydration often described by the equation  $dw/dt = k(w_{\max} - w)$  (Meyer *et al.*, 2007) (discussed in chapter 1). This model assumed that rate of water uptake is linearly proportional to  $w_{\max} - w$ , 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 water deficit in the seed. Solving the equation it becomes  $-kt = \ln((w_{\max} - w)/w_{\max})$ . To find  $w$  at any instant  $t$ ,  $w_{\max}$  is required. To get the solution of  $w$  at any instant  $t$ , two unknown parameters ( $w_{\max}$  and  $k$ ) are required. A prior guess about  $w_{\max}$  is very difficult. Therefore, to find  $w$  at any instant time  $t$  there is a need to develop a new statistic which could solve  $w$  without using  $w_{\max}$ . A new model for water up is formulated here (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  $w - w_{\text{dry}}$  where  $w_{\text{dry}}$  is 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.

$$(w - w_{\text{dry}}) \propto w_{\text{dry}} \times dt/t \quad (3.13)$$

or

$$(w - w_{\text{dry}}) / w_{\text{dry}} \propto dt/t \quad (3.14)$$

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

$$dw \propto dt/t \quad (3.15)$$

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

$$w_2 = k \times \ln(t) - k \times \ln(t_0) + w_1 \quad (3.16)$$

In this equation there is only one unknown parameter  $k$ .

or

$$w = k \times \ln(t) \pm k_2 \quad (3.17)$$

Where  $k_2 = -k \times \ln(t_0) + w_1$  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 electric field only; therefore,  $k$  is denoted as  $k_E$ .

$$w = k_E \times \ln(t) \pm k_{E2} \quad (3.18)$$

### 3.4.5 A simple approach to Stochastic model

When there are a large number of seeds in favorable conditions for germination in a the sample lot, then there is a definite probability that some particular proportion of germination will occur in a given time interval. Hence the rate of germination is proportional to the number or seeds present at that instant.

Let initially ( $t=0$ ),  $N_k$  seeds are under favorable conditions for germination. Let germination starts at time  $t_0$ . At  $t = t_0$ , the number of seeds germinated are  $N_i$ . At another time,  $t$  (where  $t$  is greater than  $t_0$ ),  $N_g(t)$  seed germinates, so at time  $t$ ,  $N_k - N_g$  equals to  $N$  seeds that are under favorable conditions for germination. Out of  $N$  seeds, a small fraction  $dN$  germinate in further small time ' $dt$ '.

$dN$  is directly proportional to  $N$  and  $dt$ ,

$$dN = -\lambda_{B,T} N dt \quad (3.19)$$

-ve sign shows that  $N$  is decreasing with time (more and more number of seeds are germinating), and  $\lambda_{B,T}$  (germination magnetic constant) is constant for a given magnetic field and for a given temperature.

Eqn. (3.19) can be rewritten as:

$$dN/N = -\lambda_{B,T} dt \quad (3.20)$$

At time  $t_0$ , number of seeds which are under favorable conditions to germinate are  $N_k - N_i$  and at time  $t$  un-germinated seeds left to  $N$ . Integrating Eq. (3.20) within these limits we get

$$N = (N_k - N_i) \exp(-\lambda_{B,T} (t - t_0)) \quad (3.21)$$

This is the same equation as that of the Stochastic model ( $E[M_1(t) = M_0 \exp(-\lambda_1 t)]$ ) for two-state germinating processes) [4]. Therefore, present theoretical approach proves that seed germination is a two-state process.

$N$  are the number of seeds in the first state (un-germinated seeds), number of seeds in 2<sup>nd</sup> state (germinated seeds) can be calculated as:

$$N_g = N_k - N = N_k - (N_k - N_i) \exp(-\lambda_{B,T} (t - t_0)) \quad (3.22)$$

### 3.5 Germination Parameters

#### 3.5.1 Mean germination time

Mean germination time  $\bar{t}$  [5, 6] is calculated as:

$$\bar{t} = \frac{\sum_{i=1}^k n_i \times t_i}{\sum_{i=1}^k n_i} \quad (3.23)$$

In Eqn. (3.23),  $t_i$  signifies the time from the start of the experiment to the  $i^{\text{th}}$  observation (in day or hour),  $n_i$  signifies number of seeds germinated for  $i^{\text{th}}$  observation, and  $t_k$  signifies the last time of germination for  $k^{\text{th}}$  observation.

#### 3.5.2 Germination capacity

The germination test was performed according to the guidelines issued by the International Seed Testing Association (ISTA Rules, 2007) with slight modifications. Germination capacity is also termed as Germination rate (%), is experimentally calculated as [7]:

$$\text{Germination capacity} = (\text{Number of germinated seeds} / \text{Number of total seeds}) \times 100$$

#### 3.5.3 Water uptake

Water uptake by seed is calculated using the formula [7]

$$\text{Water uptake (\%)} = (W_2 - W_1) / W_1 \times 100 \quad (3.24)$$

Where,  $W_1$  = initial weight of seed and  $W_2$  = weight of seed after absorbing water in a particular time.

#### 3.5.4 Transition time

Transition time is calculated using equation 3.21 of Stochastic model:

$$N = (N_k - N_i) \exp(-\lambda_{E,B,T} (t - t_0))$$

Substituting  $(t - t_0) = 1 / \lambda_{E,B,T}$  in equation (3.21) we get  $N = 0.368(N_k - N_i)$ . The constant  $\lambda_{E,B,T}$  is defined as the reciprocal of time  $(t - t_0)$  at which, the number of seeds left in un-germinated

state but are under favorable conditions to germinate from the seed sample reduces to 0.368 time the number of seeds in the sample at time  $t_0$ . Transition time of germination (between un-germinated and germinated state) can be defined from the Scholastic model as given in equation 3. 21. It is:

$$T_{\text{transition}} = (1/\lambda_{E,B,T}) + t_0 \quad (3.25)$$

### 3.6 Statistical methods

Parallel curve analysis method is applied to all the graphs related to water uptake and germinating models which are shown in results and discussion chapter. Three replications of each seed sample comprising of 40 seeds in each set has been investigated under laboratory condition. The average value is calculated and is considered as the experimental group. The experimental value is then compared with theoretically calculated values using different formulated models. The following statistical procedure is followed for best fitting of the experimental and theoretical values.

#### 3.6.1. Statistical procedure for finding the sum of squares

The variance between the samples (groups) measures the difference between the samples mean of each group and the overall mean weighted by the number of observations in each group. The difference between samples is taken into account as the random variations from observation to observation. It also measures the difference from one group to another. The sum of squares between samples is denoted by SSC. For calculating variance between samples, we take the total of the square of the deviations of the means of various samples from the grand average and divide this total by the degrees of freedom. The steps for calculating variance between samples is:

- (a) Calculate the mean of each sample
- (b) Calculate the grand average
- (c) Take the difference between the means of the various samples and the grand average
- (d) Square these deviations and obtain the total which will give sum of squares between the samples
- (e) Divide the total by the degree of freedom (The degrees of freedom will be one less than the number of samples).

### 3.6.2 Parallel curve analysis

Parallel curve analysis enables the comparison of two or more sets of data to which the model has been fitted. The procedure of parallel curve analysis is based on finding the significance of changes in residual sums of squares saved from a series of curve fitting procedures [8]. There are seven steps in this method.

- (1) Initially guess any random value of unknown parameters  $\alpha$  (MV model),  $K$  (Water model) and  $\lambda$  (stochastic model).

Let these values are:

$$\alpha = x$$

$$K = y$$

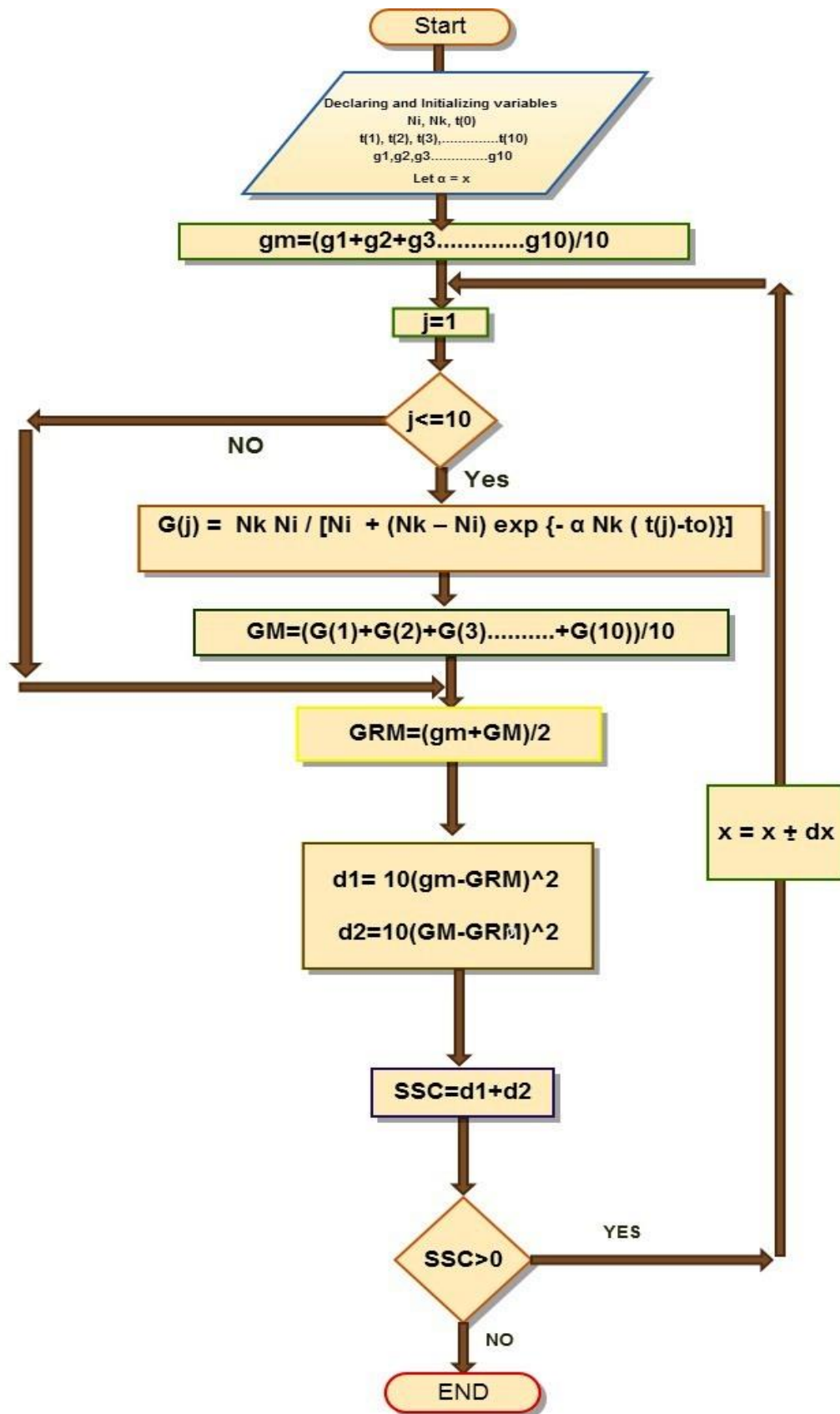
$$\lambda = z$$

- (2) Fit individual curves related to above models with these values.
- (3) Carry out an analysis of variance for finding the residual sums of squares (SSC)
- (4) If residual sum of squares comes a finite value then give a small increment  $x \pm dx$ ,  $y \pm dy$  and  $z \pm dz$
- (5) Go to step 2
- (6) If residual sum of square comes equal to zero or becomes minimum (close to zero) then, stop.
- (7) When the loop will be executed, then the last value of  $x$ ,  $y$  and  $z$  will signify the exact value of  $\alpha$ ,  $K$  and  $\lambda$  of MV model, Water model and Stochastic model respectively. The need for accurate and precise curve fitting depends on truly minimizing the residual sum of squares and obtaining the best possible fit of the growth model to the data.

Parallel curve analysis procedure is adopted for designing all the graphs related to water uptake and germinating models shown in results and discussion chapter.

### 3.6.3 Procedure for finding unknown constants of the different model formulated in the current research work

A flow chart (Figure 3.6) is made to make a computer programme for finding  $\alpha$  (germination rate coefficient) of Malthus-Verhulst function.



**Figure 3.6:** A flowchart used to find  $\alpha$  (germination rate coefficient) of MV function

## Steps

- ✚ Declare and initialize the input parameters of Malthus-Verhulst function [Number of seed germinated at the time  $t(0)$  is  $N_i$ .
- ✚ Let  $N_i = g_1$
- ✚ Consider 10 experimental germination data points, at  $t(1)$  is  $g_1$ , at  $t(2)$  is  $g_2$ .....at  $t(10)$  is  $g_{10}$ .
- ✚ The experimental germination data is  $[g_1, g_2, \dots, g_{10}]$ .
- ✚ Initialize any fractional value to  $\alpha$  of Malthus-Verhulst function, Let  $\alpha = x$
- ✚ The mean sum of experimental germination data is  $gm$ .
- ✚ Apply Malthus-Verhulst function with chosen value of  $\alpha$  and find germination data at the above defined time intervals. The calculated (theoretical) germination data is  $[G(1), G(2), \dots, G(10)]$ .
- ✚ The mean sum of theoretical data is  $GM$
- ✚ The grand average of experimental data and theoretical data are  $GRM$ , where  $GRM = (gm+GM)/2$
- ✚ Take the difference between the means of the two samples (theoretical and experimental) and the grand average. Square these deviations and obtain the total which will give sum of squares between the samples
- ✚ Take the difference between the means of the two samples (theoretical and experimental) and the grand average. Square these deviations and obtain the total which will give sum of squares between the samples
- ✚ In the present case, there are 10 rows in one column, Therefore,  $d_1 = 10 (gm-GRM)^2$   
 $d_2 = 10(GM-GRM)^2$  and  $SSC = d_1+d_2$ . Because there are two columns (experimental germinating data and theoretically calculated germinating data) therefore, degree of freedom in the present case, is 1.
- ✚ If  $SSC \geq 0$
- ✚ Give increment to  $\alpha$ , therefore  $\alpha$  is now  $x \pm dx$ , find  $SSC$  again.
- ✚ The process is put in the loop ( $x \pm dx, x \pm 2dx, x \pm 3dx, \dots$ ) till  $SSC$  comes close to zero.
- ✚ Lastly at minimum  $SSC$ , the value of  $\alpha$  is executed.
- ✚ The need for accurate and precise curve fitting depends on truly minimizing the residual sum of squares and obtaining the best possible fit of the growth model to the data.

The above method is used to find  $\lambda_{B,T}$  (germination magnetic constant) or  $\lambda_{E,T}$  (germination electric constant) of the Stochastic model (3.22). In case of water model (3.18)  $w = k_1 \times \ln(t) \pm k_2$  there are two unknown parameters  $k_1$  and  $k_2$ . Nested iterative procedures and least squares regressions are assimilated to estimate the water uptake coefficient  $k_1$  and  $k_2$ . First iterative procedure finds the best estimate of  $k_1$  for a starting value of  $k_2$  by comparing the residual sums of squares for the regression of theoretically calculated G on experimental data. Then the second iterative procedure finds the best estimate of  $k_2$ . In this way, the values of  $k_1$  and  $k_2$  are found, which minimize the residual sums of squares for the regression of theoretical and experimental data. This enables the comparison of two sets of data to which the water model has been fitted.

### 3.6.4 Sum of Squares due to error

This statistic measures the total deviation of the response values from the fit to the response values. It is also called the summed square of residuals and is usually labelled as SSE.

$$\text{SSE} = \text{Sum}_{(i=1 \text{ to } n)} \{w_i (y_i - f_i)^2\}$$

Here,  $y_i$  is the observed data value and  $f_i$  is the predicted value from the fit.  $w_i$  is the weighting applied to each data point, usually  $w_i = 1$ .

### 3.6.5 R<sup>2</sup> value

This statistic measures how successful the fit is in explaining the variation of the data [9]. Put another way, R-square is the square of the correlation between the response values and the predicted response values. It is also called the square of the multiple correlation coefficients and the coefficient of multiple determinations.

R-square is defined as

$$\begin{aligned} \text{R-square} &= 1 - [\text{Sum}_{(i=1 \text{ to } n)} \{w_i (y_i - f_i)^2\}] / [\text{Sum}_{(i=1 \text{ to } n)} \{w_i (y_i - y_{av})^2\}] \\ &= 1 - \text{SSE}/\text{SST} \end{aligned}$$

Here  $f_i$  is the predicted value from the fit,  $y_{av}$  is the mean of the observed data  $y_i$  is the observed data value.  $w_i$  is the weighting applied to each data point, usually  $w_i=1$ . SSE is the sum of squares due to error and SST is the total sum of squares. R-square can take on any value between 0 and 1, with a value closer to 1 indicating that a greater proportion of variance

is accounted by the water uptake model and germinating models. For example, an R-square value of 0.8932 means that the fit explains 89.32% of the total variation in the data about the average. In the chapter of result and discussion, the R-square values are measured for each graph.

## References

- [1] Pietruszewski S., Modeling by logistic curve germination of wheat seeds Henika cultivar in magnetic field, *Acta Agrophysica*, **58**, 143-151, 2001.
- [2] Pietruszewski S., Influence of magnetic and electric fields on seeds. Germination of selected cultivated plants, *Acta Scientiarum Polonorum*, **1**, 1, 75-81, 2002.
- [3] Pietruszewski S., and Kania K., Effect of magnetic field on germination and yield of wheat, *Int. Agrophys*, **24**, 297-302, 2010.
- [4] Tseng S., and Hsu J. P., A Stochastic Analysis of Seed Germination, *Botanical Bulletin of Academia Sinica*, **30**, 201-205., 1989.
- [5] Ranal M. A., and Santana D. G., How and why to measure the germination process?, *Revista Brasileira de Botânica*, **29**, 1, 1-11, 2006.
- [6] Salehzade H., Shishvan M. I., Ghiyasi M. *et al.*, Effect of seed priming on germination and seedling growth of wheat (*Triticum aestivum* L.), *Research Journal of Biological Sciences*, **4**, 5, 629-631, 2009.
- [7] Nizam I., Effects of salinity stress on water uptake, germination and early seedling growth of perennial ryegrass, *African Journal of Biotechnology*, **10**, 51, 10418-10424, 2011.
- [8] Berry G., Cawood R., and Flood R., Curve fitting of germination data using the Richards function, *Plant, Cell & Environment*, **11**, 3, 183-188, 1988.
- [9] Web\_page. "Goodness-of-Fit Statistics ", 2013;  
<http://web.maths.unsw.edu.au/~adelle/Garvan/Assays/GoodnessOfFit.html>.

# Chapter 4

## Results and Discussion

### (Effect of Electric Field on Seed Germination)

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#### Overview

In this chapter, the results of the electric field on seed germination are described and discussed. The seeds of Chickpea (*Cicer arietinum* L.), Mung bean (*Vigna Radiata*), Bitter Gourd (*Momordica Charantia*), Spinach (*Spinacia oleracea* L.), White gourd (*Benincasa hispida*), Okra (*Abelmoschus esculentus* L.) and Maize (*Zea mays* L.) were pre-treated with low-level electric field. The results of electric treatment were studied by measuring water uptake by the seed and germination capacity. To find early germination effects, mean germination time and transition time was calculated for each species. To explore dielectric nature of seed, germination coefficient  $\alpha_E$  and transition constant  $\lambda_{E,T}$  was calculated using our Re-formulated Malthus-Verhulst function and Stochastic function respectively for each seed. It was also proved that these functions worked well for all the studied species.

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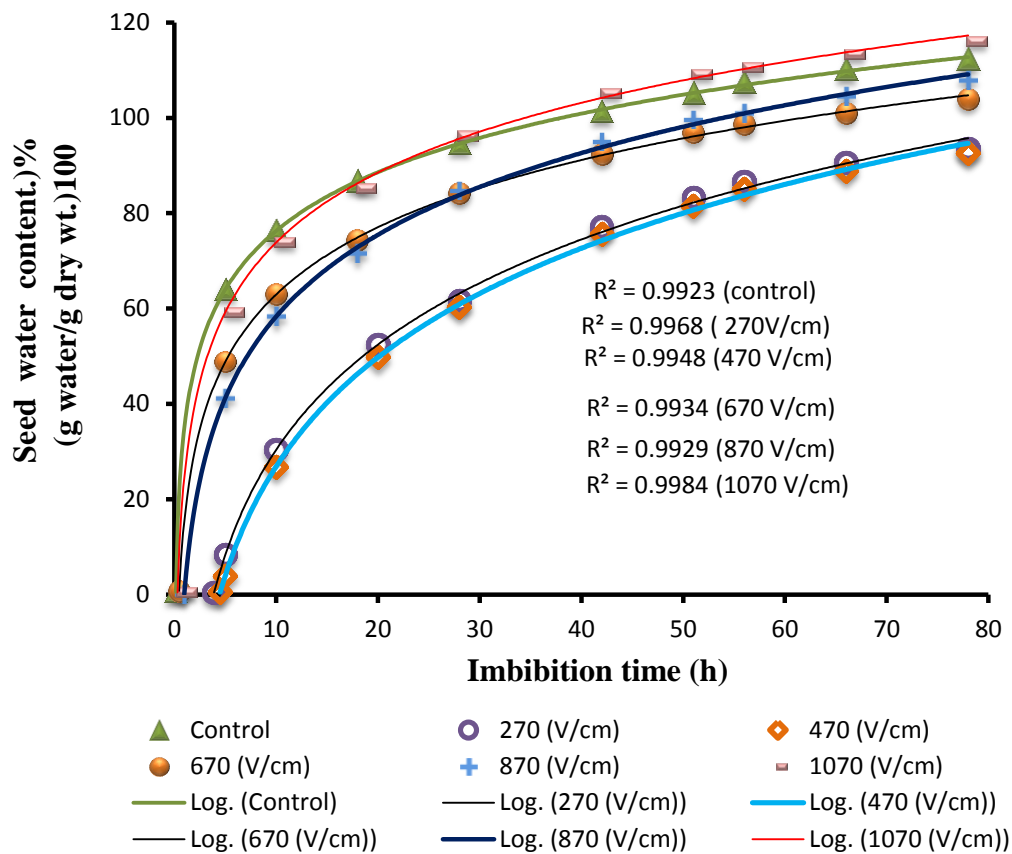
#### **4.1 EFFECT OF ELECTRIC FIELD ON SEED GERMINATION**

A large section of the poor, particularly women and children of the developing world are facing the problem of persistent hunger and suffering from the under-nutrition condition. Because of widespread poverty, it results in deterioration in physical growth and mental health. The people of the poor section fulfil major part of protein from cereal grains, pulses and vegetables. To increase the crop yield, pesticides are generally used, but their unwanted side effects on human health and the environment have become a major concern. Thus to enhance the productivity of the nutrition plant other methods like electric and magnetic field treatment of seeds before sowing has to be explored. However, there is controversy over the effects of a weak electromagnetic field on living organisms. There is a lack of understanding regarding electric or magnetic fields exposure that affect the living system. The influence of an induced electromagnetic field (EMF), which affects human beings directly and indirectly through the environment, especially in agriculture, is still unknown [1]. Both magnetic and electric fields significantly affect seed germination, but the energy needed to induce stimulation with a magnetic field is lower than the energy needed with an electric field [2]. It is well known that electric, magnetic and electromagnetic fields produce biochemical, physical and physiologic changes in cell structures [3, 4]. A survey of the plant life suggests that, near high-voltage transmission lines, electro-magnetic fields caused an influence on plant growth [5]. Exposure to an electric field increases the negative charge on the cell surface, whereas exposure to a magnetic field decreases the hydrophobic character of the cell surface [6]. The results show that electrically treated seeds produce a better growth rate, stem height and root length compared with non-exposed seeds [7, 8].

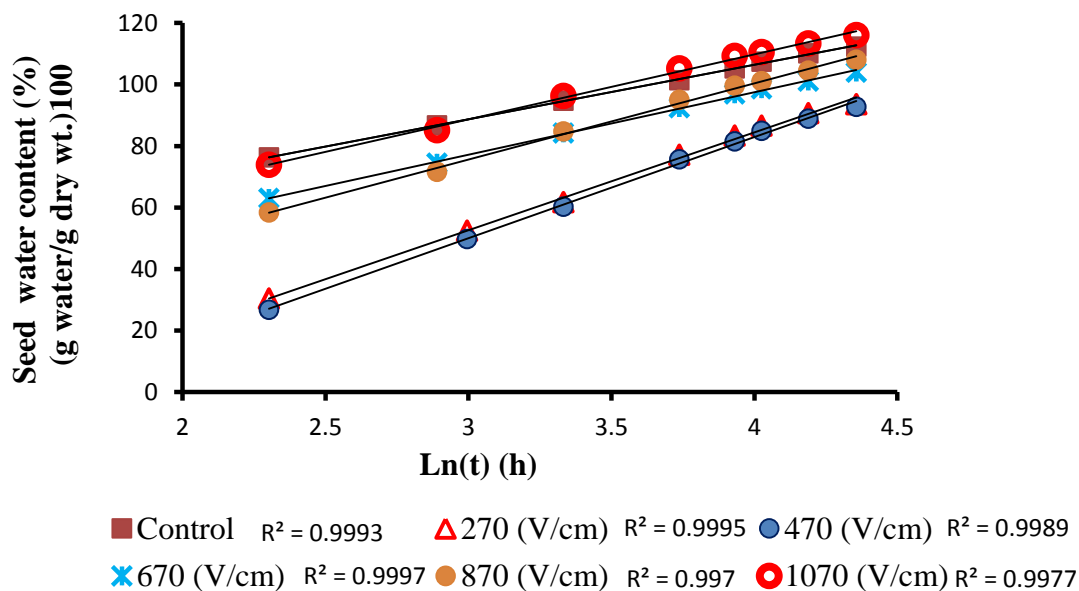
#### **4.2 Effect of pre-sowing electric treatment on chickpea seed at a constant temperature**

Chickpea (*Cicer arietinum* L.), which is also known as, Gram seed was treated with magnetic field and has been studied by many authors [9, 10] but till date no author has studied the effect of low static electric field on Chickpea seeds. The aim of the present study is to find the effect of low electric field (zero to 1200 Volt/cm) on germination, growth and water uptake of chickpea seeds at a constant temperature. Another aspect of the present study is to explore a cause for change in germination and water uptake by the electrically treated seeds. In the present research Pusa – 362, a variety of Chickpea is used. Its area of adoption is Punjab, Haryana, Delhi, North Rajasthan and West U.P (India). This variety is bold seeded

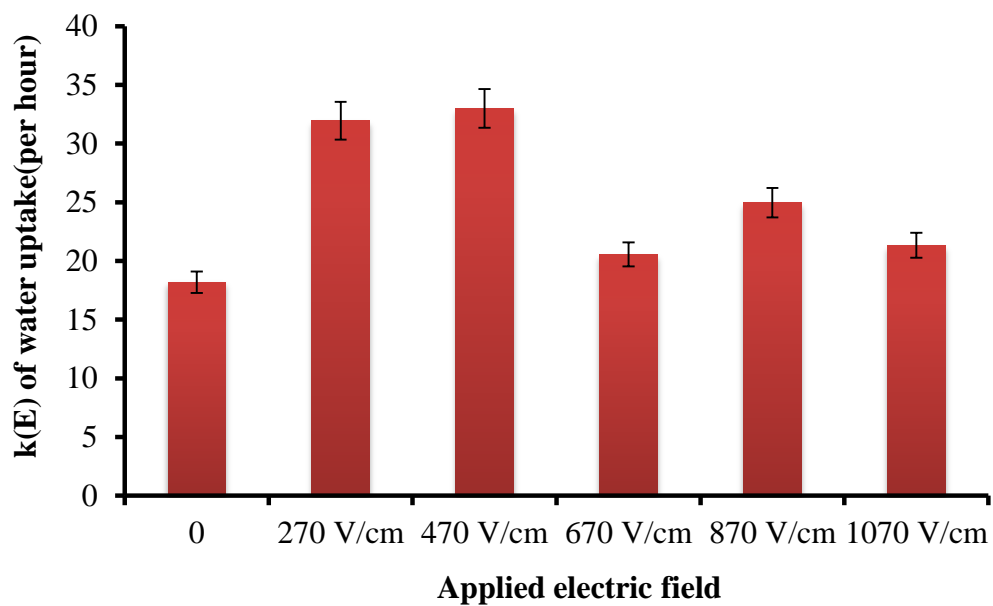
and is tolerant to wilt. Four replications of Chickpea seeds comprising of 40 seeds in each set were exposed for 15 minutes at electric field of 270, 470, 670, 870 and 1070 V/cm. In the present study, germination temperature was kept constant at 13°C. Sprouting experiment was performed in India at Patiala (Pb) (Khalsa College, Physics laboratory) in between 13<sup>th</sup> January to 17<sup>th</sup> January 2013. Sprouting was finished on 17<sup>th</sup> January then the seeds of each sample were transferred in different earthen pots. It was ensured that all the pots had the same type of soil (same by weight also) and the same amount of moisture content. Pots were kept in open natural environment. After 28 days from the start of experiment chickpea plants were taken out from pots and their root length and shoot length was measured. Average temperature and day length variation in 28 days during chickpea plant growth was 10 to 16°C and 10h 20min to 11h 03min respectively. Figure (4.1) shows the percentage of water uptake that increases with imbibition time. Water uptake curves are the function of the electric field strength in which the chickpea seeds are exposed. All curves satisfy proposed water uptake model (equation 3.18). At any time  $t = 10$  h, say water absorption (%) for control, 270, 470, 670, 870 and 1070 (Volt/cm) are 76.29, 30.36, 26.78, 62.95, 58.32 and 73.86 respectively. Water absorbed at 470 volt/cm is approximately 1/3<sup>rd</sup> as compared to control. Figure 4.1 shows that there is more delay in water absorption at low field values as compared to high field values. Maximum delay is shown at 470 Volt/cm. Figure (4.2) shows that the seed water content (%) (g water/g dry wt.) increases linearly with the logarithm of time. These observation again justify water uptake model (3.18). All straight lines have different slopes ( $k_E$ ). The value of slope ( $k_E$ ) signifies the rate of water uptake and is called the coefficient of water uptake. The value of  $k_E$  for control, 270, 470, 670, 870 and 1070 volt/cm are 18.2, 31.95, 33.01, 20.55, 24.96 and 21.33 ( $\text{h}^{-1}$ ) respectively. Coefficient of water uptake increased for all field values. It is highest in between 270 and 470 volt/cm) (Figure 4.3). Vashisth et al. [10] exposed seeds of chickpea in batches to static magnetic fields of strength varying from 0 to 250 mT in steps of 50 mT for 1-4 h and showed that among the various combinations of field strength and duration, 50 mT and 150 mT for 2 h exposures gave best results. Similarly in the present case among the various values of the electric field, 470 V/cm for 15 minutes exposures gave best results. For example as compared to control an increase in root length as shown in Figure 4.4 for 270, 470, 670, 870 and 1070 volt/cm are 16.74, 42.42, 3.59, 7.24, 24.91 (%) and increase in shoot length are 14.07, 30.68, 6.56, 13.66, 29.85 (%) respectively. Control implies zero applied field or untreated seeds.



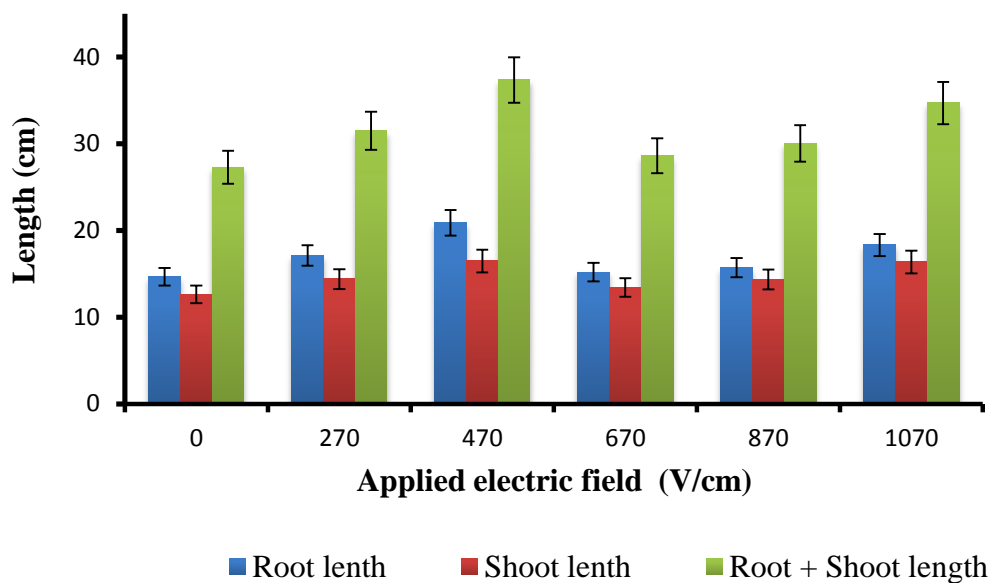
**Figure 4.1:** Variation of absorbed seed water content with the imbibition time for electrically treated seeds at different field strength.



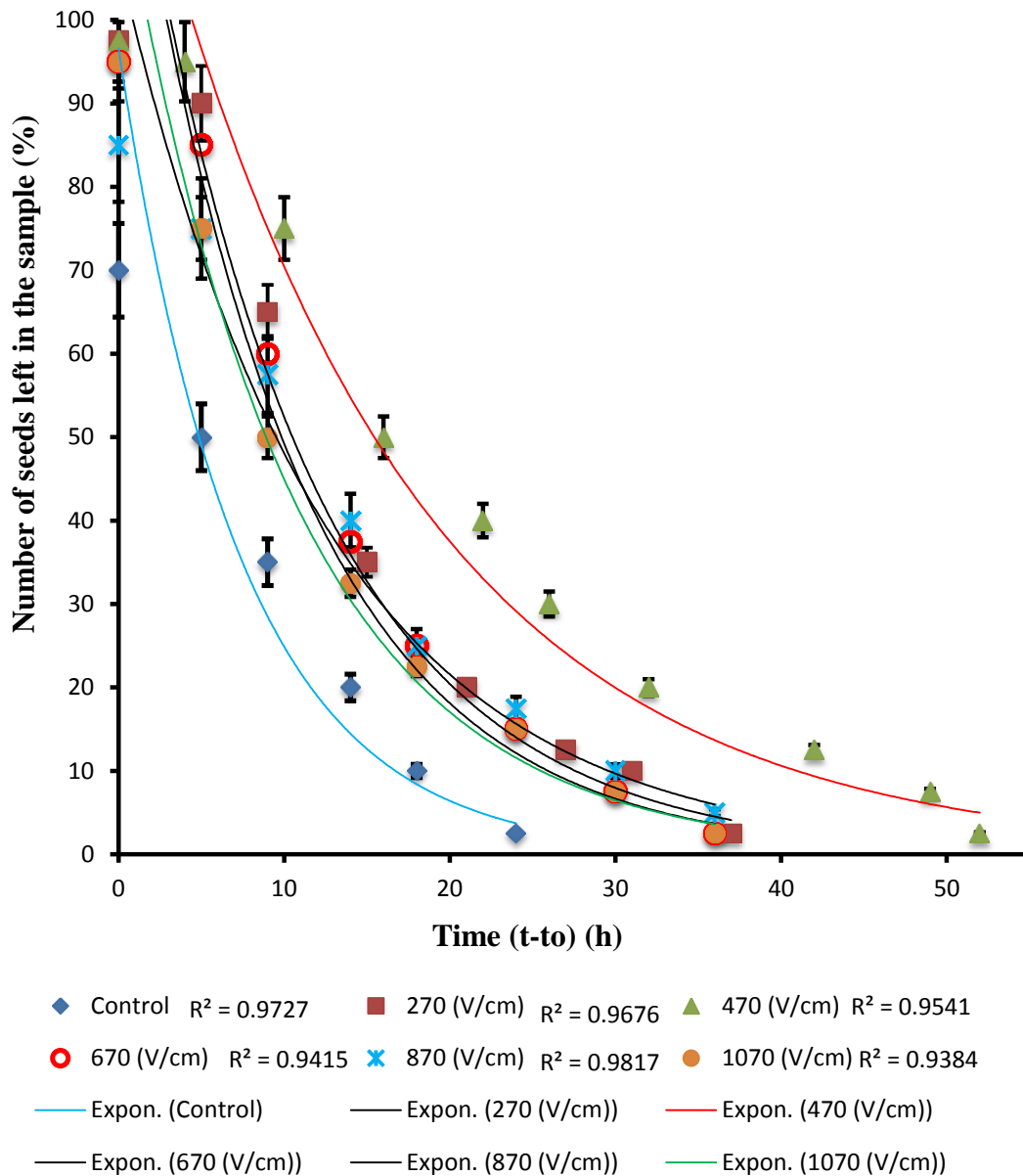
**Figure 4.2:** Graph showing the (%) water uptake with linear dependency to logarithm of time (h).



**Figure 4.3:** Variation of water uptake coefficient ( $k(E)$ ) as a function of exposed electric field.

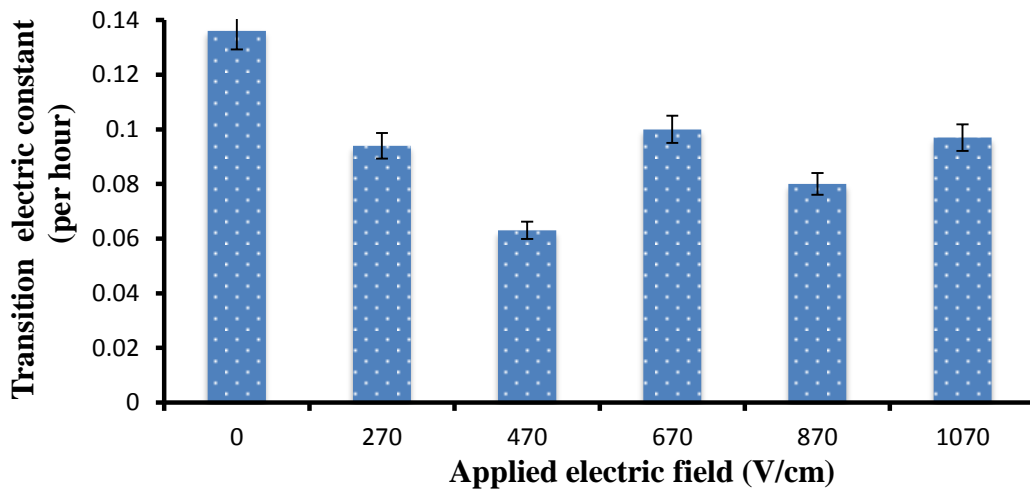


**Figure 4.4:** The bar graph showing the variation of average shoot length, root length and root plus shoot length with applied electric field for 28 days old plant  $p(\text{Root length and shoot length}) < 0.001$

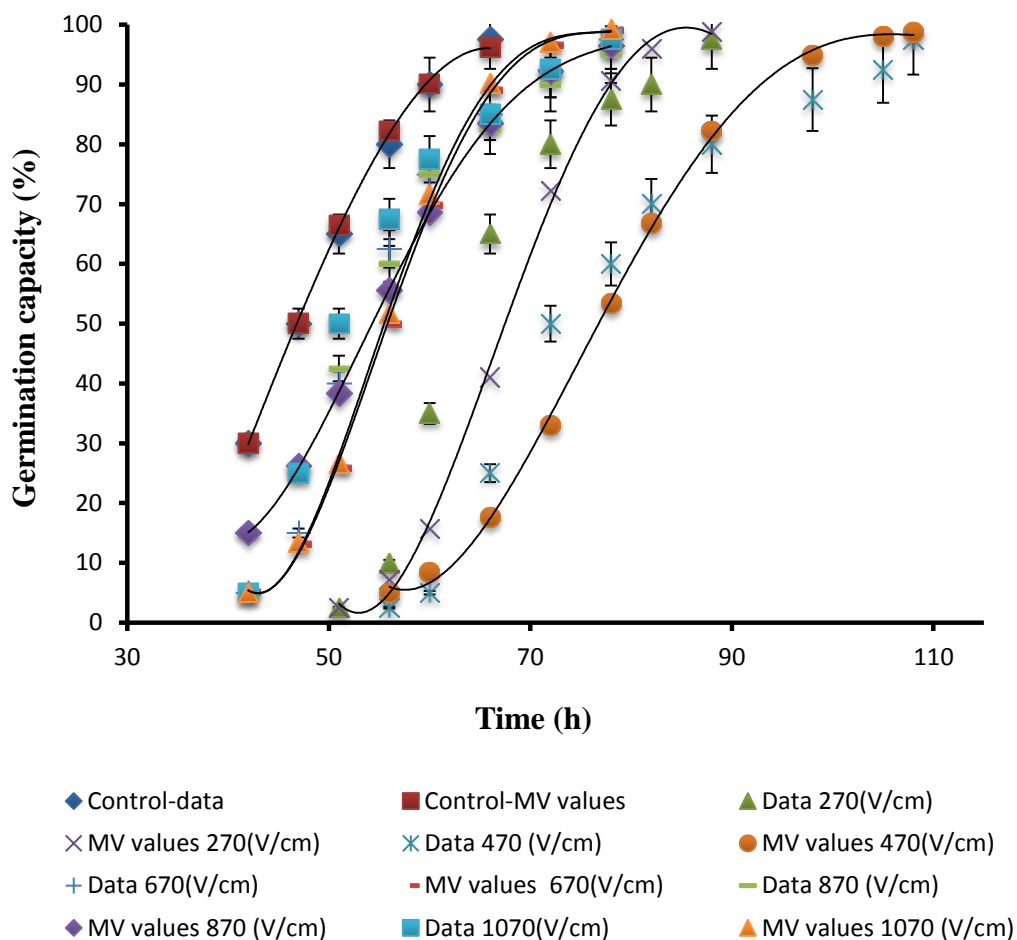


**Figure 4.5:** Variation in un-germinated seeds with time in the samples.

Data shows that at all the field values, germination after effects is enhanced. From various exposed field values, maximum germination occurs first at 470 volt/cm. It implies that after germination effects are linked with coefficient of water uptake ( $k_E$ ) (Figure 4.3). For any time  $t-t_0 = 18 h$  (say) (Figure 4.5) percentage of seeds left in the sample for control, 270, 470, 670, 870 and 1070 volt/cm are 10, 24, 42, 25, 25, 22 % respectively. It shows that in all seed samples retardation in germination capacity as compared to control occurs when seeds are pre-treated with electric field. The retarding effects in germination capacity is linked with water absorption curves shown in Figure 4.1.

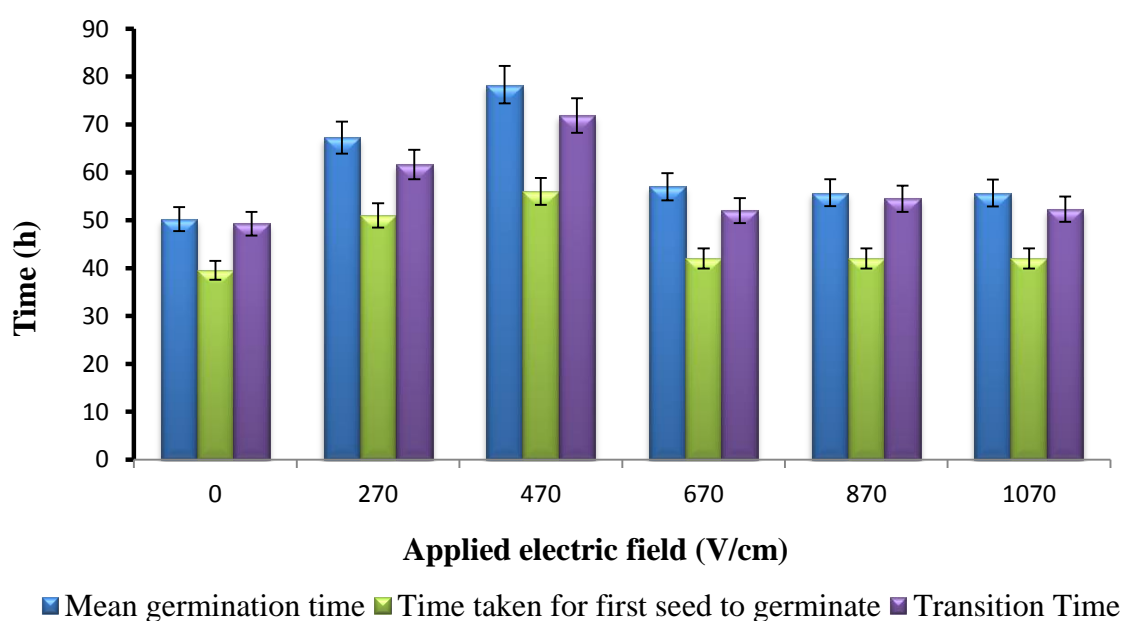


**Figure 4.6:** Bar graph showing variation in transition electric constant with increasing electric field on the chickpea seeds.

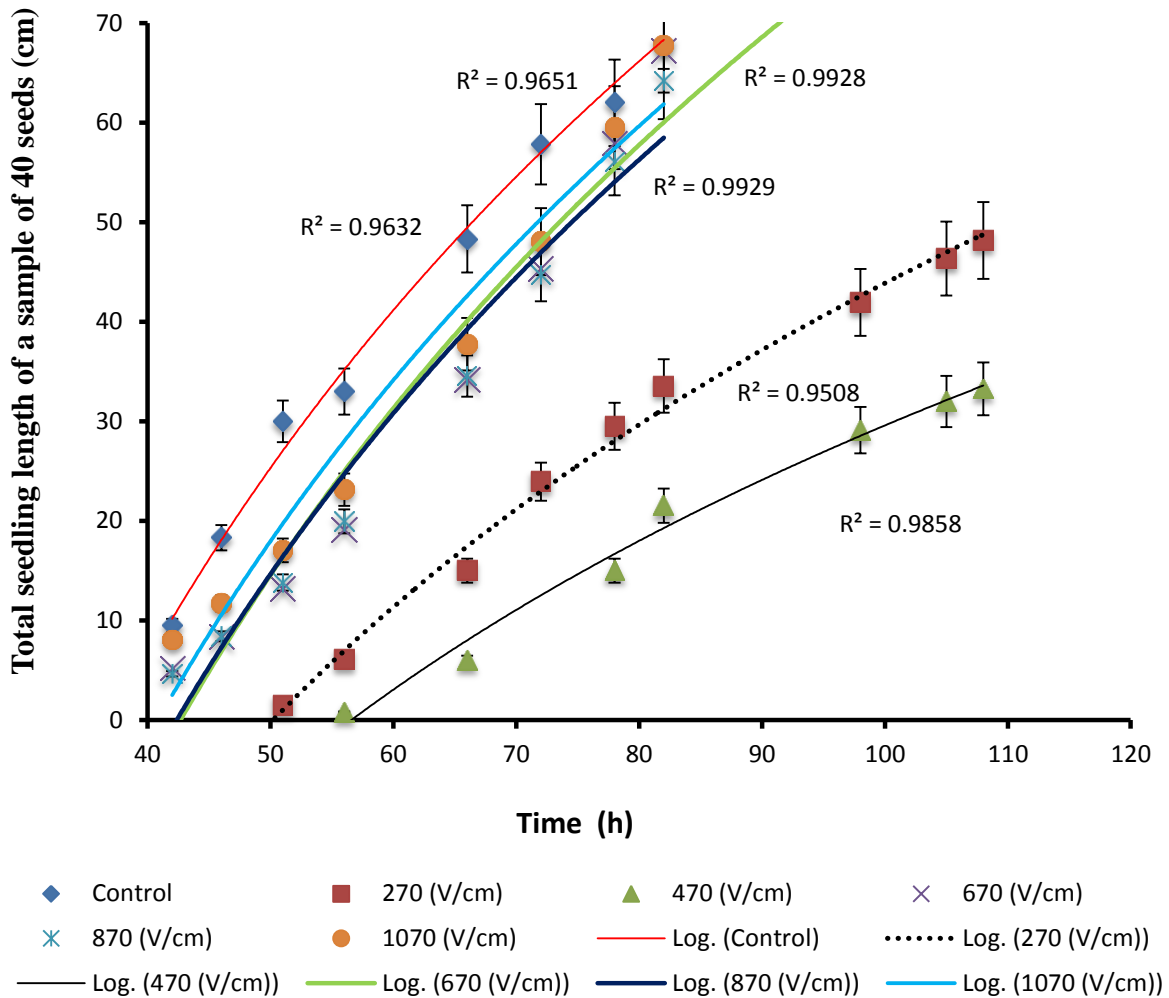


**Figure 4.7:** Showing variation in germination growth capacity for electrically treated seeds.

The reason for this retardation is a delay in water absorption by the seed. Maximum retardation happens at 470 volt/cm. Variation of electric transition constant  $\lambda_E$  with the electric field is shown in Figure (4.6). It exhibits least value at 470 volt/cm and maximum at control. Experimental data of germination capacity at any instant for different values of intensity of the electric field Control, 270, 470, 670, 870 and 1070 volt/cm for 15 minutes exposure fitted well in re-formulated Malthus-Verhulst equation  $N_g(t) = N_k N_i / [N_i + (N_k - N_i) \exp \{-\alpha_E N_k (t - t_0)\}]$  (equation 3.5). Where  $\alpha_E$  is germination coefficient which is a function of the electric field if other parameters are kept constant. The trend obtained for these curves is shown in (Figure 4.7). Mean germination time, transition time and time taken for the first seed to germinate are all physical parameters which describes the earlier germination effects and are calculated by using different formulas (equation 3.23 and 3.25) and Figure (4.8). There is an increase in mean germination time, transition time and time taken for the first seed to germinate at all electric field values and is highest at 470 volt/cm. Seedling length  $L$  of a group of 40 seeds (Figure 4.9) grows with logarithmic of time at any instant  $t$  and can be calculated by using equation for control  $L_{\text{control}} = 86.902 \ln(t) - 314.63$  as well as for treated seeds  $L_{270\text{V/cm}} = 63.656 \ln(t) - 249.27$ ,  $L_{470\text{V/cm}} = 51.944 \ln(t) - 209.62$ ,  $L_{670\text{V/cm}} = 91.903 \ln(t) - 344.95$ ,  $L_{870\text{V/cm}} = 88.533 \ln(t) - 331.67$  and  $L_{1070\text{V/cm}} = 88.705 \ln(t) - 329.04$  with the electric field. Experimental data fitted well ( $R^2$  very close to 1) in all these equations.



**Figure 4.8:** Variation in the mean germination time, transition time and time taken for the first seed to germinate for the electrically treated seeds.



**Figure 4.9:** Variation of total seedling length of 40 seeds with electric field.

Water uptake by the seed grows linearly with the logarithm of time according to our formulated water uptake model (equation 3.18). This model has been verified experimentally as shown in Figure (4.2). The positive point of this model is that it is free from  $w_{max}$  (explained in chapter 3). Electrical nature of seeds can be described by their dielectric properties [11]. The influence of electric fields on the seed provides a means for sensing those processes which are responsible for seed germination. Let  $E_0$  be the electric field produced by an external applied voltage to the plates of a parallel plate capacitor (plate area  $A$  and plate separation  $d$ ). Seeds layer of thickness  $t$  ( $t < d$ ) is then introduced between the plates. Electric field inside the seed now gets modified (reduced) and become  $E$ .  $E = E_0 - P/\epsilon$ . Here  $P$  is total dipole density and  $\epsilon$  is electric permittivity of the seed. Polarisation  $P$  is directly proportional to the reduced value of the electric field [12]. Ferroelectric crystals (Like KDP type,  $KH_2PO_4$ )

exhibits some residual electric dipole moment upon removal of external electric field [12]. Present experimental data of seed germination and water uptake shows small magnitude of electric dipole moment that is left inside the seed even upon removal of the electric field (ferroelectricity). Water is a polar molecule. A dipole-dipole interaction (interaction between water dipoles and electrically stressed dipoles inside the seed) leads to either a delay in water absorption or increased in water absorption. Vashisth et al. [13] in their study have shown that at certain combinations of magnetic field and exposure time, the germination coefficient 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 seeds treated from zero to 1200 V/cm at 13 °C, 470 V/cm (15 minutes exposure) stimulates chickpea seeds more as shown in Figure (4.4, 4.6 and 4.8). The reason of this is the dipole-dipole interactions between water dipole and micro dipoles inside the electrically treated seed. Some water dipoles are repelled by the seed dipoles when water dipoles approach with similar charge as the charge present on the dipoles inside the seed. This results in delay in water absorption. Some water dipoles are accelerated towards the seed when water dipoles approach with a charge which is of opposite sign in nature to the charge present on electrical dipoles inside the seed. This causes an increase in the coefficient of water uptake. Das and Bhattacharya [9] found that electromagnetic field (EMF) strength of 0.88 T for 80 min has maximum stimulating effect on germination of gram seeds (*Cicarietium*) and it may be assumed that under this condition the three-cell water potential forces act in the same direction on germinated seeds.

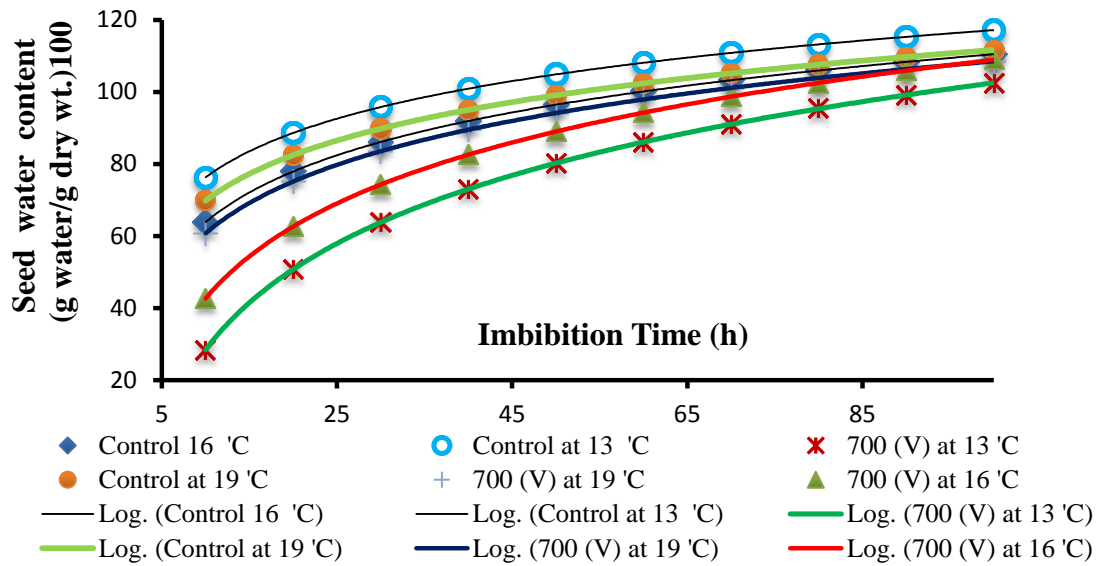
The decay function is used in the present investigation  $N = (N_k - N_i) \exp(-\lambda_E (t - t_0))$  (Stochastic function) to find the (%) seed left during germination with a minimum number of unknown parameters (Detail is given in chapter 3). This function is also having biological meaning. Its constant can be related with electric field or any other factor which affects the germination and gives best fitting with experimental data (Figure 4.5) (as fitting coefficient  $R^2 > 0.9$  for all curves). With the help of this function, number of un-germinated seeds  $N$  left in the sample can be calculated at any instant  $t$ . Upon Substituting  $(t - t_0) = 1/\lambda_E$  then  $N = 0.368(N_k - N_i)$ . Germinating electric constant  $\lambda_E$  is defined as reciprocal of time  $(t - t_0)$  at which, the number of seeds left in the un-germinated state reduces to 0.368 time the number of seeds in the sample at time  $t_0$ . Transition time can be defined with the help of germinating electric constant  $\lambda_E$  as  $\bar{t} = (1/\lambda_E) + t_0$  (equation 3.25). This equation shows that lesser the value of  $\lambda_E$  more is the value of transition time (from un-germinated to

germinated state). Values of  $\lambda_E$  at different electric field is calculated and is found be less at 470V/cm (Figure 4.6). Therefore conversion from un-germinated to germinated state becomes difficult at this electric field. Transition time values as calculated using eqn. 3.25 for different electric field exposure to seeds is very close to mean germination values calculated using equation 3.23 (Figure 4.8). Both times are peaked at 470 V/cm. Time taken for the first seed to germinate ( $t_0$ ) also exhibits the same trend as that of transition time and mean germination time. The reason for poor response in early germination parameters lies in the fact that there was a delay in water absorption at the start of germination for electrically treated seeds (Figure 4.1 & 4.2).

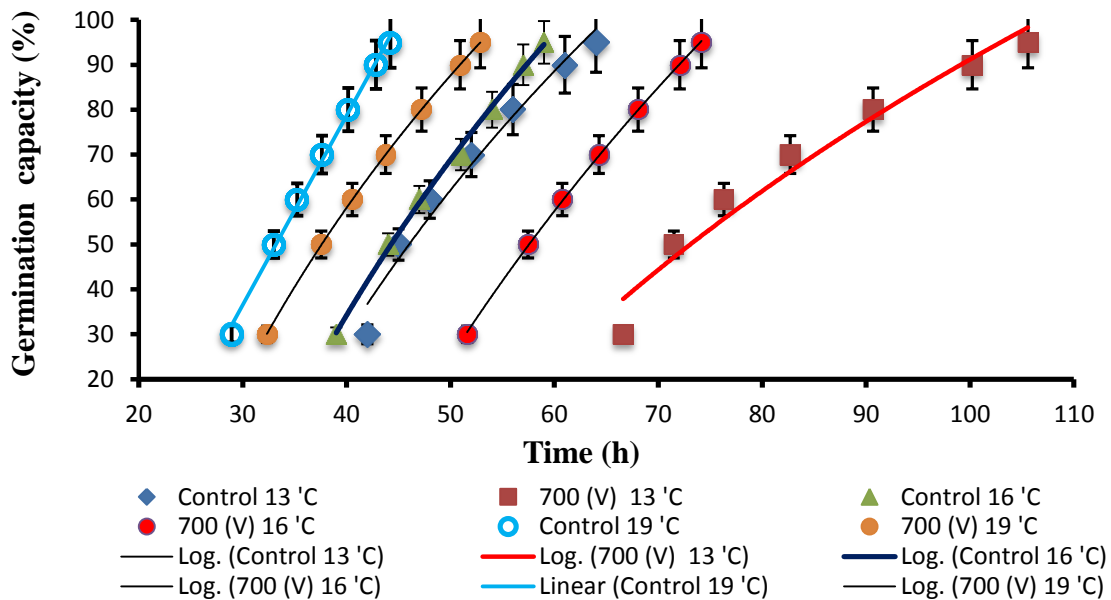
Seedling length (L) grows with logarithmic of time for control as well as for treated group of seeds (with the electric field). Seedling growth formula is  $L = \alpha_1 \ln(t) + \alpha_2$  (where  $\alpha_1$  and  $\alpha_2$  are some constants and are the function of the electric field if other parameters which effects the germination are kept constant. Karadavut [14] compared some statistical growth models for describing seedling growth in the early period and found quadratic model ( $L = a + bx + cx^2$ ) that explained better than other models for seedling growth. However, our findings proves that seedling growth is logarithm of time (Figure 4.9) as fitting coefficient  $R^2 > 0.95$ . It is not quadratic growth.

### **4.3 Effect of the electric field and temperature on germination of chickpea seed**

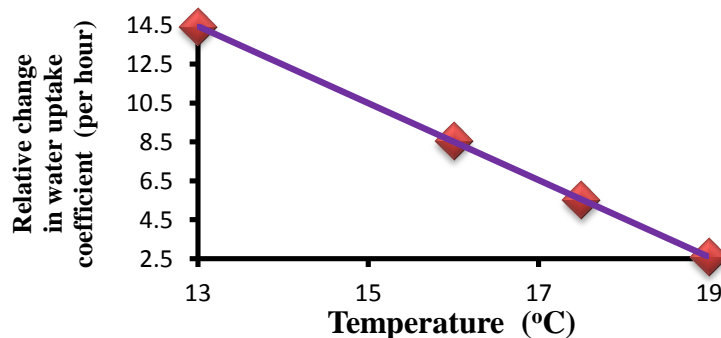
In a controlled environment, chickpea can germinate over a wider range (10°C to 45°C) of temperature [15]. In order to understand the role of temperature, an intermediate range 13, 16 and 19 °C is selected for the present study. For giving electrical treatment to chickpea seed, the distance between the two electrodes was kept 1.5cm. For electrical treatment, a constant voltage (700 V or 466.6 V/cm) was chosen (which is the approximate average of 0 to 1000V/cm). Water uptake curves showed a logarithm trend with time (Figure 4.10). Maximum difference in water absorption between treated and untreated seeds recorded was at 13 °C, and it was found to decrease with higher temperature. Lowest value of water absorption is recorded at 19 °C. Germination capacity follows the logarithmic trend with time at electric field of 466.6 V/cm with respect to control for various temperature treatments (Figure 4.11). Maximum effect on germination capacity for treated seeds is observed at 13 °C and minimum at 19 °C. The relative change in the water uptake coefficient at different temperatures is shown in (Figure 4.12).



**Figure 4.10:** Percentage variation in water uptake as a function of temperatures for seeds treated under constant electric field intensity of 466.6 V/cm.

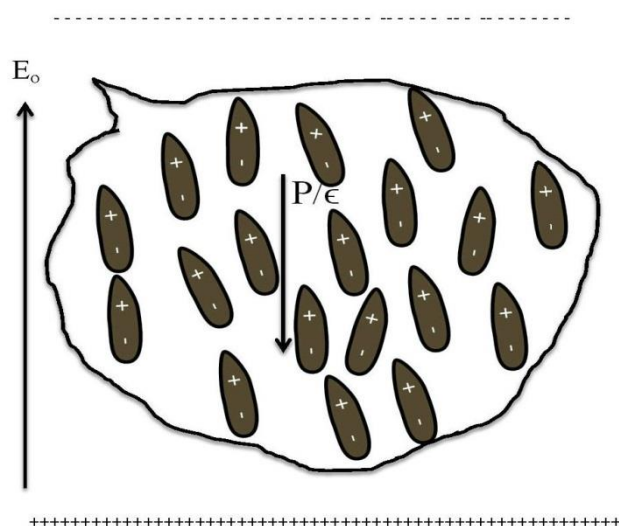


**Figure 4.11:** Percentage variation in germination capacity as a function of temperatures at fixed applied voltage.

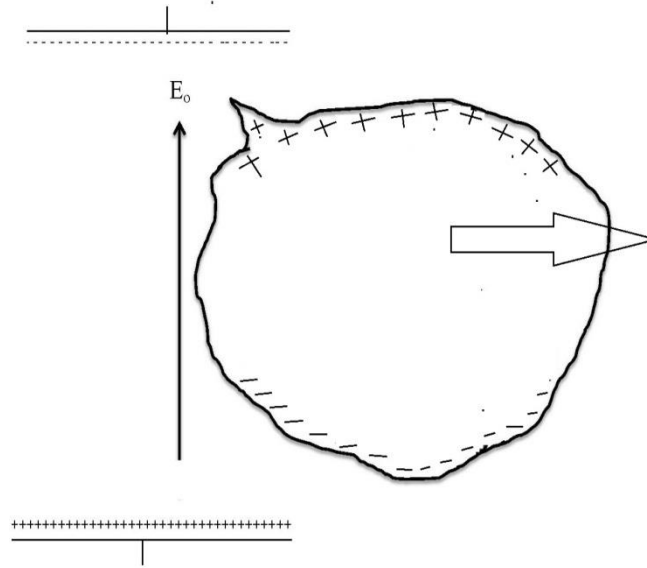


**Figure 4.12:** Negative slope between the relative change in water uptake coefficient and temperatures.

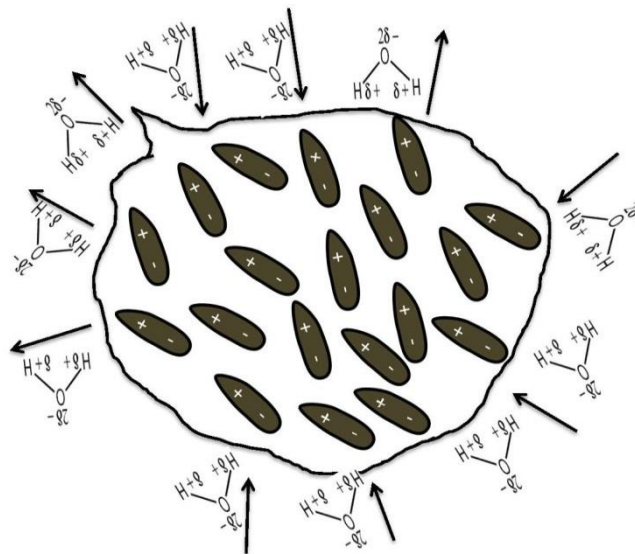
Many materials including living organisms and most of the agricultural products are dielectrics in nature. Seed also exhibits dielectric properties [11]. This dielectric property exhibited by seed under the applied electric field on the seeds is the basic process which is responsible for water uptake and seed germination. Ferroelectric crystals (Like KDP type,  $\text{KH}_2\text{PO}_4$ ) exhibit residual electric dipole moment upon removal of external electric field [12]. Moreover, *Cicer arietinum* also contain ions like  $^{32}\text{P}$ - and  $^{42}\text{K}$ - [16]. In resonating state it is possible that seeds may also exhibit ferroelectric properties. There may be a number of small electric dipoles inside the seed as shown in Figure 4.13. These dipoles align in the presence of the electric field. Upon removal of the electric field, induced dipoles may not vanish completely (Figure 4.14). Small dipole moments called residual dipole moments are still left inside the seed. Water is also a polar molecule. When it comes in contact with seeds having the oriented dipoles, may have dipole-dipole interaction between water dipole and residual or electrically formed stressed dipole inside the seed (Figure 4.15). 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.



**Figure 4.13:** Schematic diagram showing small dipoles produced inside the seed with the application of external electric field.



**Figure 4.14:** Schematic diagram showing pulled out seed from the external electric field: ferroelectric.



**Figure 4.15:** Schematic diagram showing dipole-dipole interactions between the seed dipoles and water dipoles.

As shown in Figure 4.10 the gap between voltage-water-uptake-curve and control-water-uptake-curve decreases with increase in temperature. Similarly, Figure (4.11) shows that, with increasing temperature, the gap between germination curve and control-curve decreases. It shows that effect of electrical field on the seed germination reduces upon increasing the temperature. Figure (4.12) shows that the relative change in the water uptake coefficient

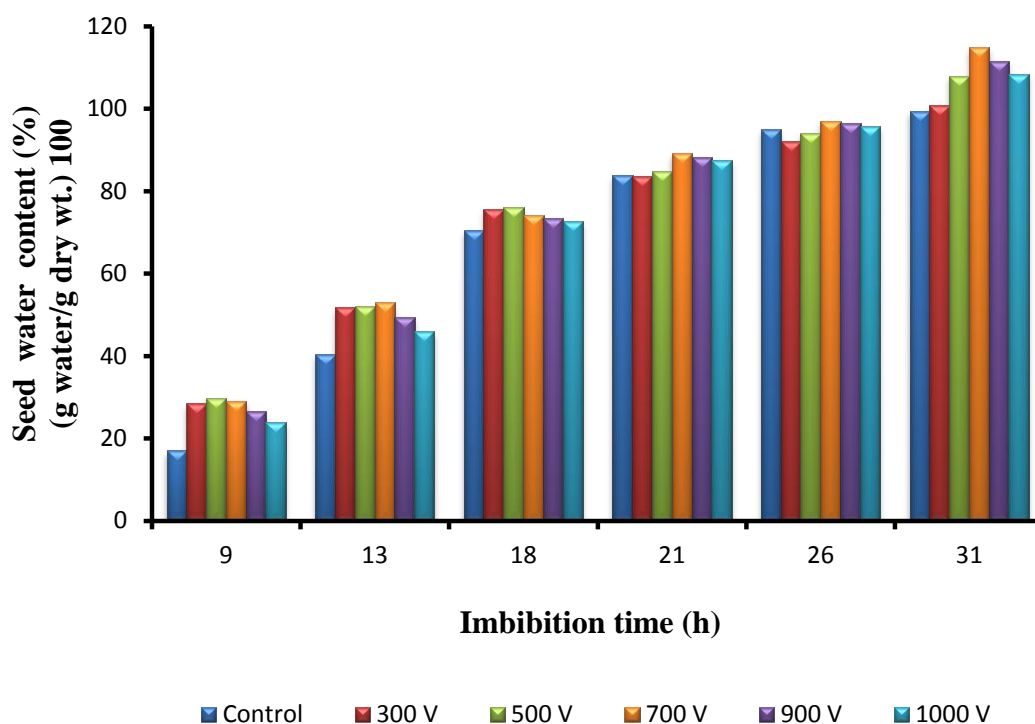
$[k(700 \text{ V}) - k(\text{Control})]$  is inversely proportional to the temperature. It shows that the electric susceptibility ( $\chi_e$ ) of the seed caused by retaining the dipole moment upon removal of the electric field is inversely proportional to the temperature (T). This behaviour is shown in Figure 4.12.

Some authors [1, 17] have already shown that seeds act like dielectric and show polarization in the presence of external electric field, but no author till date showed that seeds behave like ferroelectric. In the present study, the electrical treatment of the seeds was done before sowing. The change in germination parameters like germination capacity and water uptake proves that the seeds retain the stressed electricity even after the removal of electrical field (pre-sowing electrical treatment). It implies that seed behave like ferroelectric. However, it will be interesting to observe their behavior under the microscope to explain it properly which is beyond the scope of present work.

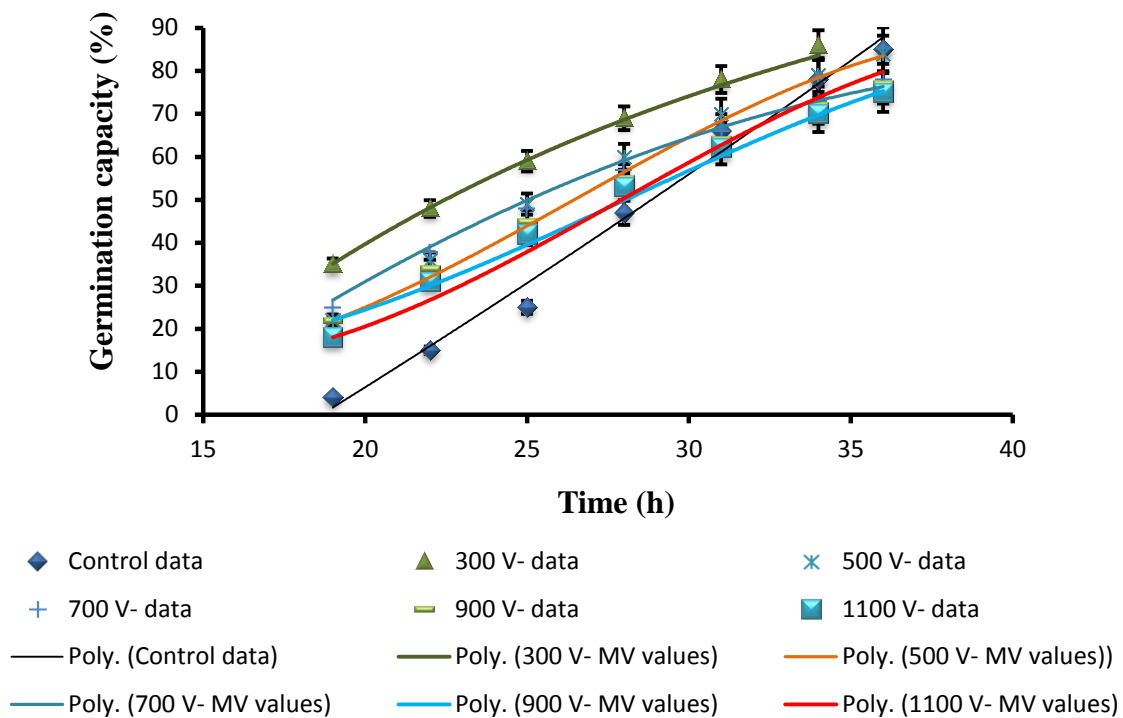
#### 4.4 Electrical Stimulation on the Germination of Mung (*Vigna Radiata*) Seed

The aim of present research is to see the effect of electrical treatment of low voltages (before sowing the seed into the field) on the improvement in early germination parameters of *Vigna radiata* seed. It has been observed that magnetic-field increases the germination rate [21]. On this basis, a magnetic-time model was formulated [18, 19]. Presently the role of electric field on the germination parameter of *Vigna radiata* has been analyzed to explore its behavior analogues to magnetic field. So *Vigna radiata* were treated with electric field of 300 V/cm to 1000 V/cm for 20 minutes exposure at 30 °C before planting. For giving electrical treatment, the distance between the two electrodes was kept 1 cm, therefore the voltage applied becomes numerically equal to electric field. Percentage seed water content in relative to its dry weight is measured at different intervals. Figure 4.16 shows the continuous increase in water absorption as compared to control at all field values varying from 0 to 1000 V; 20-minute duration at 30 °C. The water uptake data is fitted well in logarithmic function ( $w_{\text{control}} = 70.923 \times \ln(t) - 137.94$  ( $R^2 = 0.9812$ ),  $w_{500\text{V}} = 62.734 \times \ln(t) - 107.72$  ( $R^2 = 0.996$ ),  $w_{700\text{V}} = 68.151 \times \ln(t) - 121.38$  ( $R^2 = 0.9938$ ),  $w_{1000 \text{ V}} = 69.975 \times \ln(t) - 130.48$  ( $R^2 = 0.9921$ ). Maximum water intake is observed between 300 to 700 V. All the trends justifies to water absorption model ( $w = C_1 \times \ln(t) \pm C_2$ ). Germinating data of *Vigna radiata* seeds for different values of electric field at fixed time period of 20 minutes and at constant temperature (30 °C) is shown in Figure 4.17.

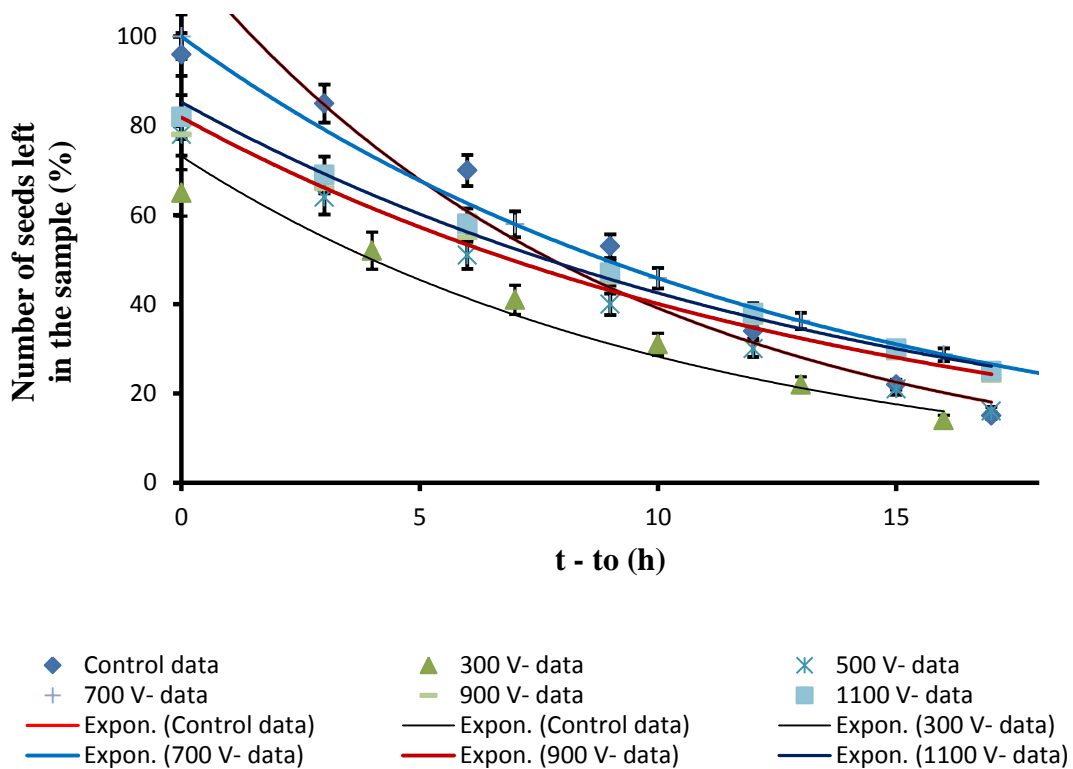
Using Re-formulated Malthus-Verhulst formula, the germination rate- coefficient was determined as:  $\alpha_{\text{control}} = 0.0032\text{h}^{-1}$ ,  $\alpha_{300\text{V}} = 0.0014\text{ h}^{-1}$ ,  $\alpha_{500\text{V}} = 0.0017\text{ h}^{-1}$ ,  $\alpha_{700\text{V}} = 0.0011\text{ h}^{-1}$ ,  $\alpha_{900\text{V}} = 0.0014\text{ h}^{-1}$ ,  $\alpha_{1000\text{V}} = 0.0017\text{ h}^{-1}$  by minimizing the residual sum of squares and executing the best possible fit for the growth model for the data. Stochastic function (two state process)  $N = (N_k - N_i) \exp(-\lambda_{E,T}(t - t_0))$  is applied to fit germinating data for different values of electric fields and for 20 minutes exposure at 30 °C which is shown in Figure 4.18. All curves are exponential in nature. There is a good match between experimental and theoretical values of Stochastic function. The variation in transition time, mean germination time, time taken for first seed to germinate and alpha-transition time for various electric field values (20 minute exposure at 30 °C) is shown in Figure 4.19. Total seedling length of a seed sample comprising of 40 seeds grows with logarithmic nature. Seeds belonging to electric exposure from 300 to 700 V for 20 minute at 30 °C are more influenced in seedling emergence as compared to control whereas 1000 V exposure has shown slight retarding effect with equations:  $L_{\text{control}} = 39.268\ln(t) - 114.96$ ;  $L_{500\text{V}} = 50.047\ln(t) - 145.06$ ;  $L_{1000\text{V}} = 38.46\ln(t) - 111.07$  ( $R^2 \geq 0.96$  for all curves) as shown in Figure 4.20.



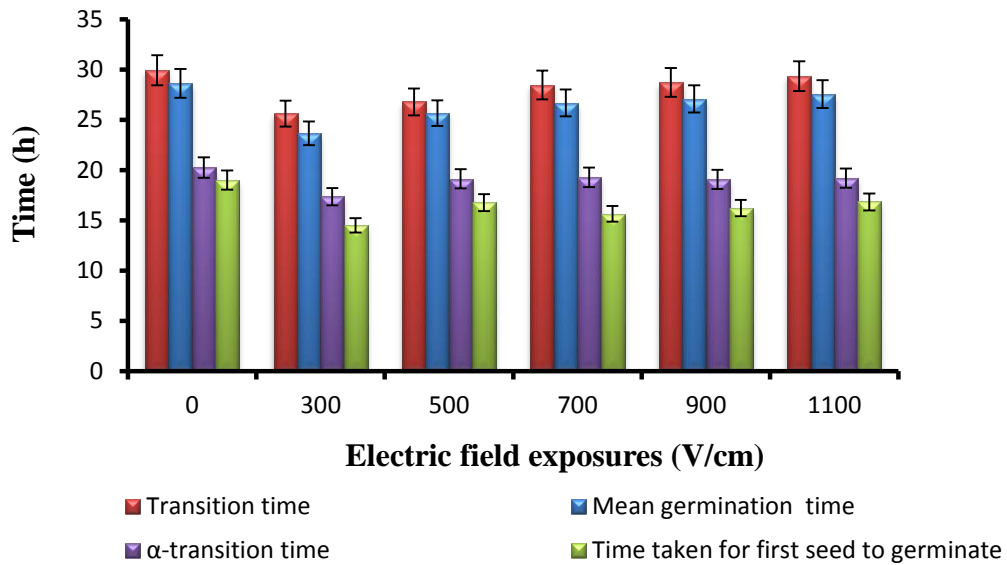
**Figure 4.16:** Variation of absorbed seed water content with the imbibition time for electrically treated seeds at different field strength.



**Figure 4.17:** Variation in germination growth capacity for electrically treated seeds.

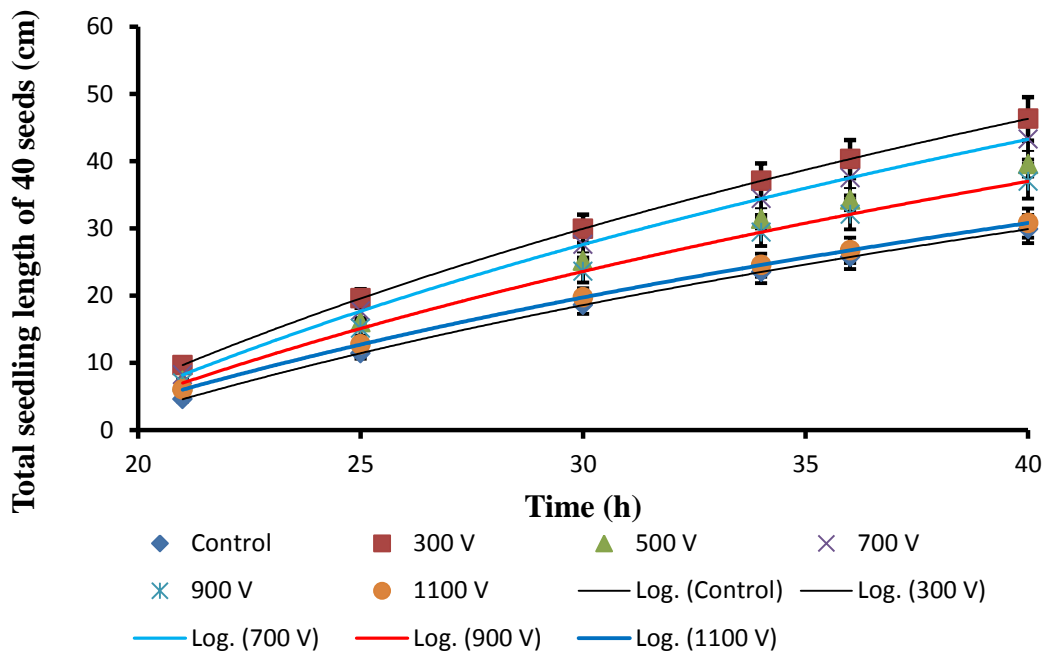


**Figure 4.18:** Variation of un-germinated seeds with time in the samples.

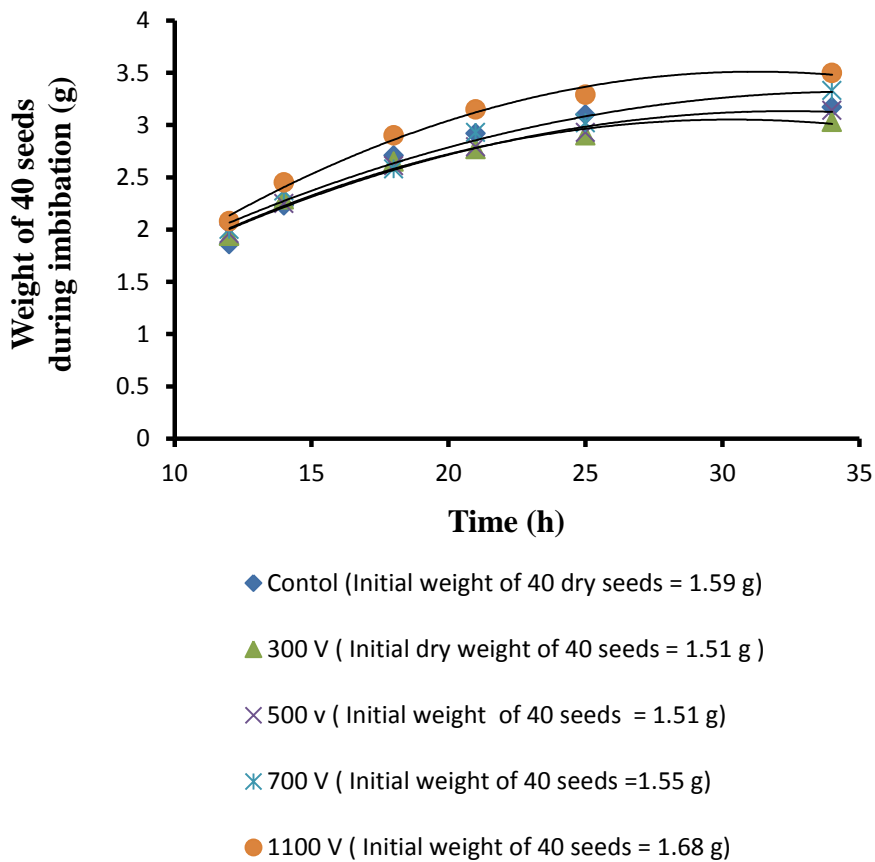


**Figure 4.19:** Variation in the mean germination time, transition time and time taken for the first seed to germinate for the electrically treated seeds.

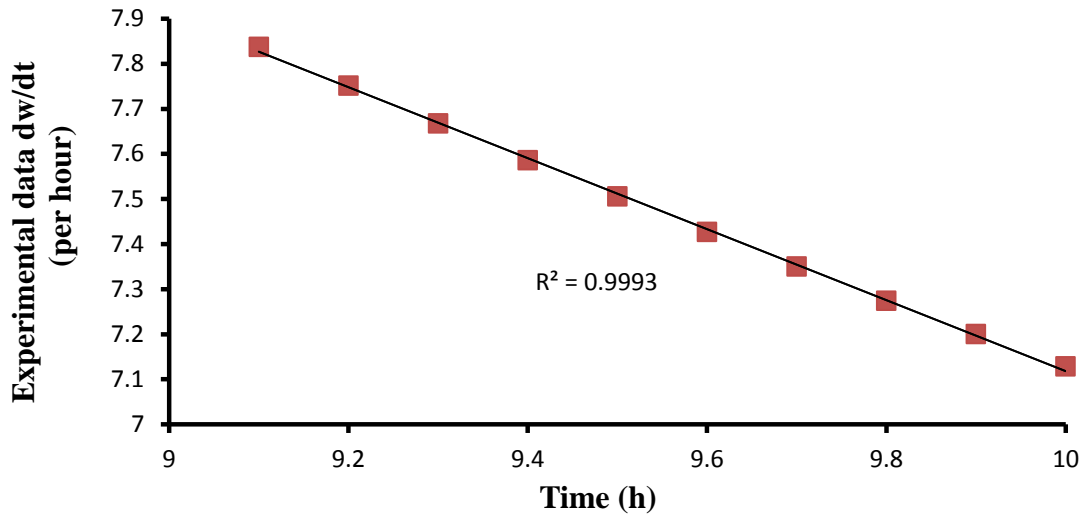
Weight of the seed ( $S_w$ ) at any instant ( $t$ ) is of polynomial nature as shown in Figure 4.21. Relative rate of water uptake ( $dw/dt$ ) is measured experimentally for short interval of time and is shown in Figure 4.22. The water intake by the seed during imbibition influences the subsequent nucleation and growth of the seeds. In plants, a group of hydrophilic proteins (Late Embryogenesis Abundant: LEA) accumulate to high levels during the last stage of seed maturation [20]. At the start of water uptake (phase I), dry seeds imbibe water; take up oxygen and as a result increases its seed mass. In this phase, percentage increase in water uptake relative to dry weight of seed as compared to control at 500 volt and at 30 °C with 20 minute exposure is 11.7 unit (at any time  $t = 13$  h as shown in Figure 4.16). In phase II, there is a metabolic plateau with low water absorption. As shown in Figure 4.16 that in Phase II percentage increase in water uptake relative to dry weight of seed as compared to control at 500 volt and 30 °C with 20 minute exposure is 5.6 unit at any instant  $t = 18$  h. The study indicates that there is an increase in water uptake relative to dry weight of seed as compared to control between 300 and 700 Volt/cm exposure for a fixed time period. Experimental data match well with water uptake formula  $w = C_1 \times \ln(t) \pm C_2$  with  $R^2 > 0.9$  for all the curves (where  $w$  is percentage of water uptake relative to dry weight, and  $C_1$  is water uptake coefficient).



**Figure 4.20:** Variation in total seedling length of a sample of 40 seeds with time for different values of electric field at 30 °C.



**Figure 4.21:** The graph shows the variation in weight of 40 seeds during imbibition of a control group and electrically treated seeds.



**Figure 4.22:** The variation in rate of water uptake with time for a control group of 40 seeds.

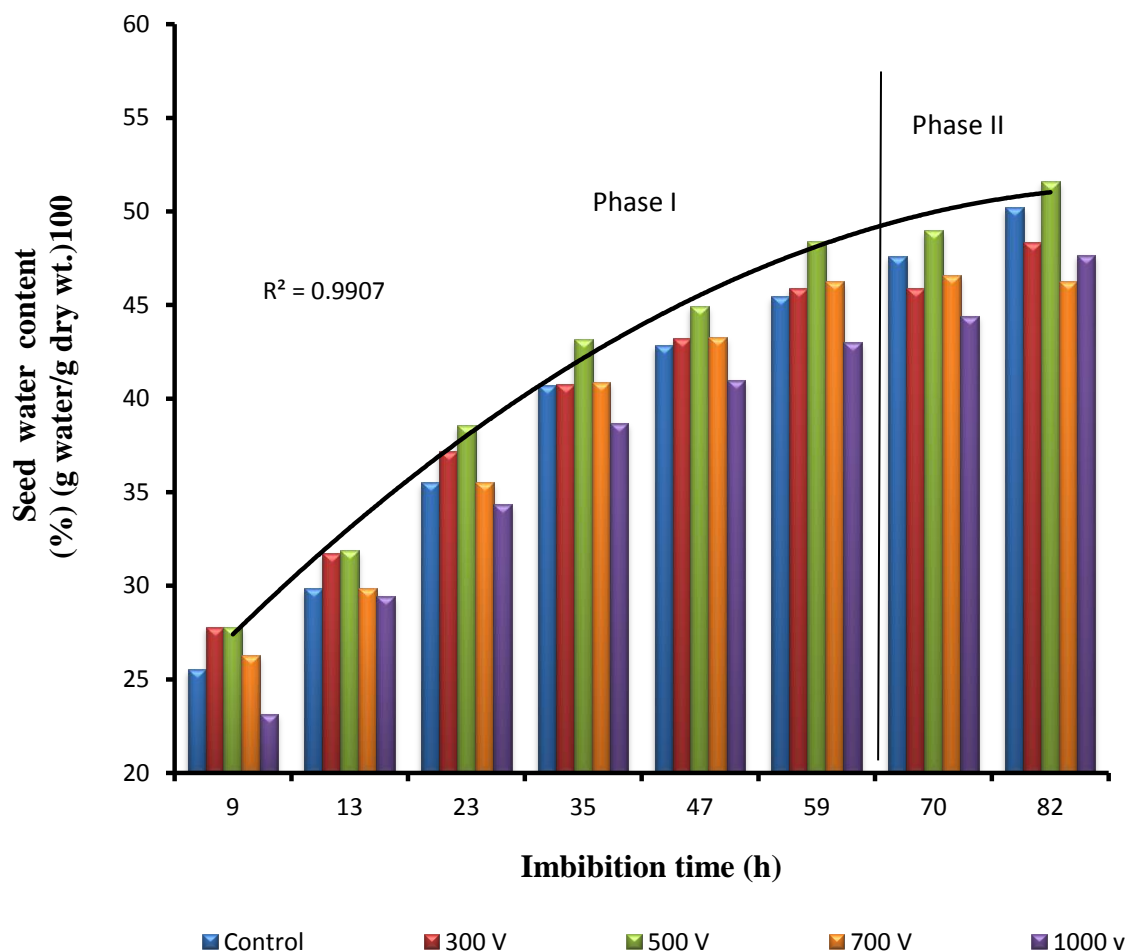
This formula indicates that rate of water uptake ( $dw/dt = C_1/t$ ) decreases linearly with time. Meyer [21] used a formula for rate of seed swelling ( $d(Sw)/dt$ ) during hydration as  $d(Sw)/dt = k(Sw_{max} - Sw)$  where  $Sw_{max}$  is weight of seed at full hydration,  $Sw$  is the weight of a seed at time  $t$  and  $Sw_{max} - Sw$  is the water deficit in the seed. Experimental data (Figure 4.21) shows that weight  $Sw$  of the seed at any instant  $t$  is of polynomial nature ( $Sw = -at^2 + bt + c$ ,  $Sw_{500} = -0.0027t^2 + 0.175t + 0.2868$ ,  $R^2 > 0.98$ ). Using this value of  $Sw$  in the formula  $d(Sw)/dt = k(Sw_{max} - Sw)$ , implies that nature of  $d(Sw)/dt$  is linear with time. The value of  $dw/dt$  is measured experimentally for short interval of time ( $Lt \frac{\Delta w}{\Delta t}$ ) ( $dw/dt$  is calculated after every six minute for one hour during imbibition) for the control group at 30 °C and rate of water uptake by the seed is determined (Figure 4.22). The plot of  $dw/dt$  is linear with time. This fact justifies that water intake equation  $w = C_1 \times \ln(t) \pm C_2$  is correct. The data of germination capacity as given in Figure 4.17 shows that electric field between 300 and 700 Volt/cm stimulates to *Vigna radiata* seed for better yield. It is interesting to note that water uptake and germination capacity results are coinciding; more water uptake implies to high germination capacity. Germinating data of *Vigna radiata* seeds of different values of electric-field and with varying time-exposures as shown in Figure 4.17 fitted well in Re-formulated Malthus-Verhulst equation (equation 13.1) Using Re-formulated Malthus-Verhulst formula [22-25], the germination rate-coefficient was determined by minimizing the residual sum of squares and executing the best possible fit for the growth model to the data.

As such germination rate- coefficient does not signify to any definite result, but upon taking its reciprocal and multiplying it with some constant then adding into it the initial time of germination, it shows the same trend as that of mean germination time or transition time for different electrical exposures (Figure 4.19). The transition constant  $\lambda_{E,T}$  which is a function of electric field, and temperature is determined experimentally for different field values, time-exposures and temperatures.  $\lambda_{E,T}$  play an important role in transition from un-germinated to germinated state. This constant  $\lambda_{E,T}$  decides the transition time between these two states. Transition time is calculated by taking the reciprocal of transition constant and adding the initial time of germination in it. Data shows the trend/pattern of transition time that matches with mean germination time (Figure 4.19). The mean germination time, transition time, time taken for first seed to germinate and alpha-transition time show a great improvement in germination time of *Vigna radiata* seeds when these are exposed to electric field in between 300 to 700 V/cm for 20 minutes exposure. Seedling length of a sample of 40 seeds grows in logarithmic trend (Figure 4.20) and again signifies the same result as that of the result given by water uptake, germination capacity and germination time. As the *Vigna radiata* are sensitive to electric dose in the range 300 to 700 V/cm for 20 minute exposure, so they cannot fit to a model like 'magnetic time model' (main requirement of a magnetic time model is the linear increase in germination rate with the linear increase of field). It clearly indicates that electric field behavior of seed germination is totally different from that of the magnetic field.

#### **4.5 Electrical effects on the Germination of Bitter Gourd (*Momordica charantia*) Seed**

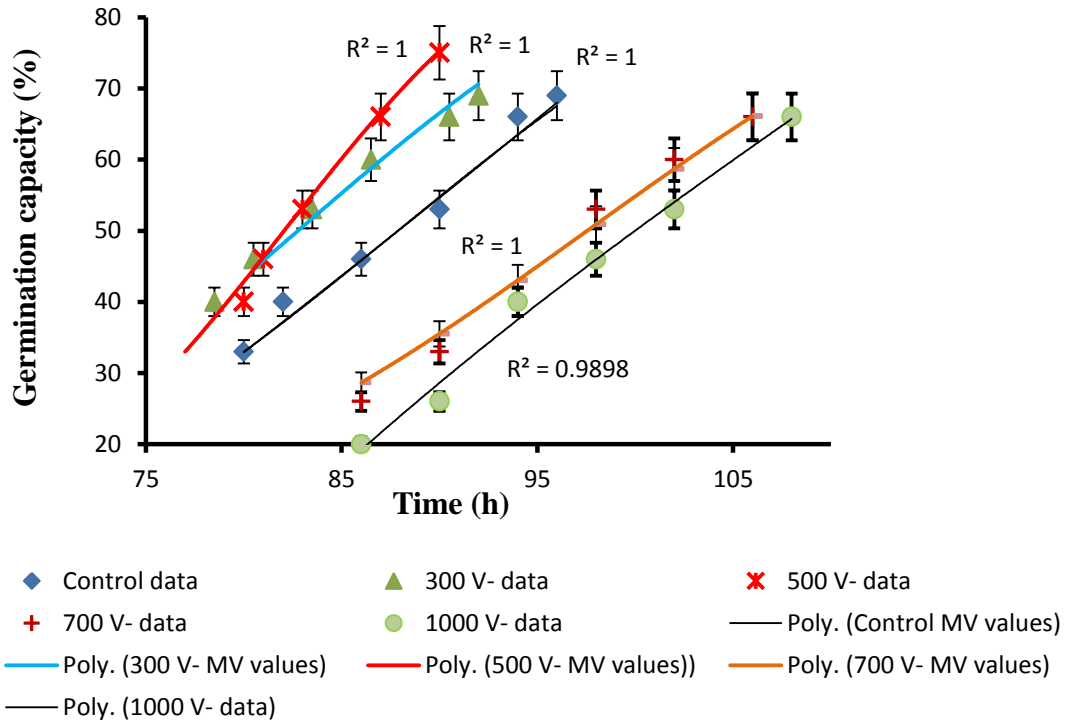
*Momordica charantia* is a medicinal plant which is also known as bitter gourd, bitter melon and Karela belonging to the Cucurbitaceae family. It is commonly consumed as a food (bitter flavouring) in India. It has been traditionally used to treat diabetes. To increase the *Momordica charantia* yield, pesticides are generally used, but their unwanted side effects on human health and the environment have become a major concern. Thus, studying other methods and techniques such as electric and magnetic field treatments to enhance the productivity of this medicinal plant has become important. For giving electrical treatment, the distance between the two electrodes was kept 1 cm, therefore the voltage applied becomes numerically equal to electric field. For example, a 300 V potential signifies an electric field of

300 V/cm. The bitter gourd variety of *Momordica charantia* was used to study the effects of electric fields on the seed germination parameters. The optimal germination temperature for this variety is 24–27 °C. A slightly off temperature (34 °C) was chosen for the electrically treated bitter gourd seeds to determine the field effects under off-season germination conditions. The percentage water content absorbed by electrically treated *Momordica charantia* seeds differs significantly from the control group under the 500 and 1000 volt/cm electric fields which is shown in Figure 4.23 and is given by the following equations:  $w_{\text{control}} = 10.804 \ln(t) + 1.8548$  ( $R^2 = 0.9972$ ),  $w_{500 \text{ v}} = 10.545 \ln(t) + 4.9615$  ( $R^2 = 0.9957$ ) and  $w_{1000 \text{ v}} = 10.175 \ln(t) + 2.0567$  ( $R^2 = 0.9889$ ). As shown in Figure 4.24, the seeds show a wide range of their germination capacity between the electrically treated and control groups. The germination capacity of the electrically treated seeds differs considerably from that of the control group for both the 500 and 1000 V/cm treatments (Figure 4.24). The Stochastic model and experimental data support a high retardation in the germination capacity under the 1000 V/cm electric field (Figure 4.25) and small positive growth at 300 and 500 V/cm. The water absorption of untreated *Momordica charantia* seeds in their best season (27 °C) is compared with the water absorption of the same seeds in their off season (34 °C) with 500 V/cm treatment (Figure 4.26). With the electric treatment (Figure 4.27), all time values (e.g., mean germination time and transition time) show a dip between 300 and 500 V/cm and an increase at 1000 V/cm. When the seeds are placed in the electric field of  $E_o$  (between the electrodes), then the magnitude of the electrostatic field inside the seed drops to the value  $E$ , depending upon the relative permittivity,  $\epsilon_{r(\text{seed})}$ , of the seed [1], which can be determined by the ingredient content and tissue structure of the seed. The actual permittivity,  $\epsilon$ , is then calculated by multiplying the relative permittivity by the electric constant,  $\epsilon_o$  (vacuum permittivity):  $\epsilon = \epsilon_o \epsilon_{r(\text{seed})} = \epsilon_o (1 + \chi)$ , where  $\chi$  is the electric susceptibility of the seed. The electric susceptibility indicates about the medium that polarises in response to an electric field. Seeds become polarized in the presence of an electric field. Upon removal of the applied field, the seeds retain some polarisation, known as remnant polarisation. When these seeds come into contact with the water dipoles, an interaction between the seed dipoles and water dipoles occurs. This interaction affects the water uptake by the seed, which further affects the germination time and germination rate. The dipole-dipole interactions of the *Momordica charantia* seeds are optimised at 500 and 1000 volt/cm as the water content absorbed in presence of variable electric fields differs significantly from that of the control group (Figure 4.23).

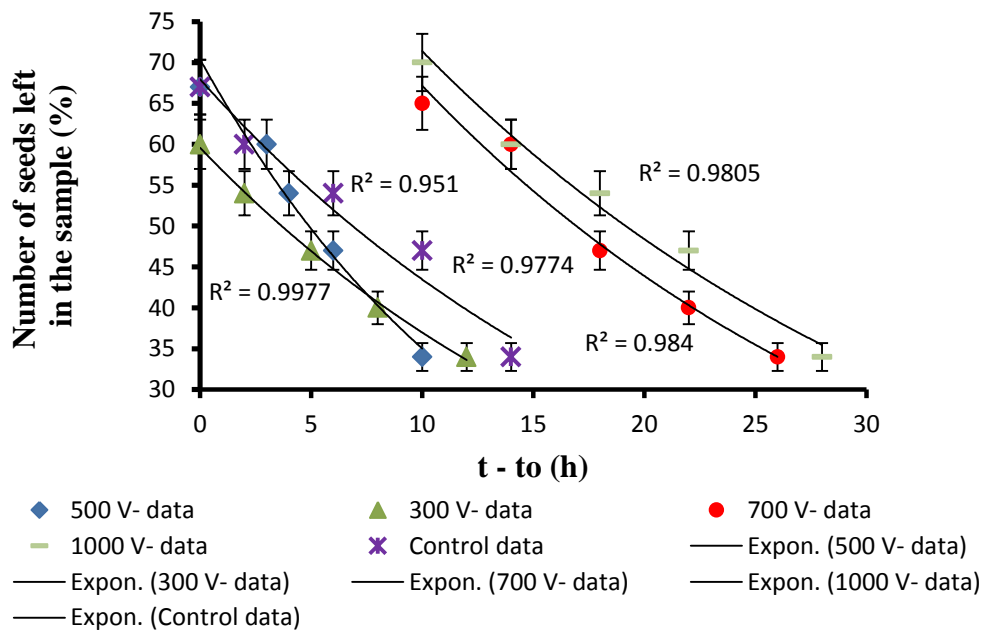


**Figure 4.23:** Variation of absorbed seed water content with the imbibition time for electrically treated seeds at different voltage level.

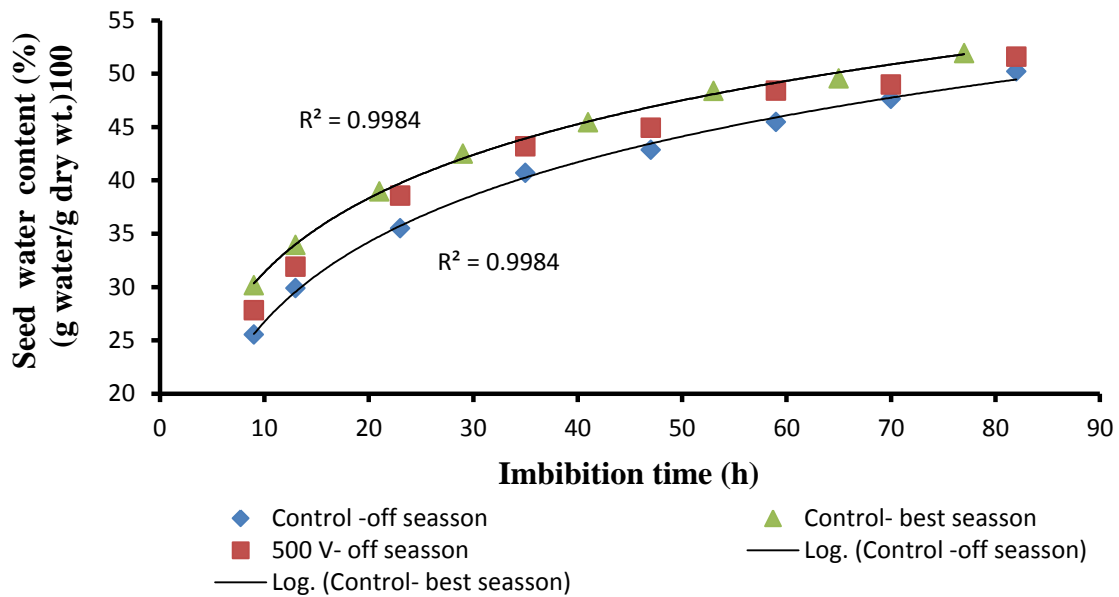
As the relative water absorption is increased at 500 volt/cm and decreased at 1000 volt/cm, the germination capacity is also increased at 500 volt/cm and decreased at 1000 volt/cm (Figure 4.24) and (Figure 4.25). These results indicate that information on the germination capacity can be retrieved from the water absorption curves. The water absorption of *Momordica charantia* seeds in their off-season (34 °C) and in their best season (27 °C) is compared and shown in Figure 4.26. In the off-season, the water absorption is lower than that in the best season. Interestingly, in the off-season, the electrically treated seeds (500 V/cm) used for germination provided almost the same amount of germination as that by the control seeds in their best season.



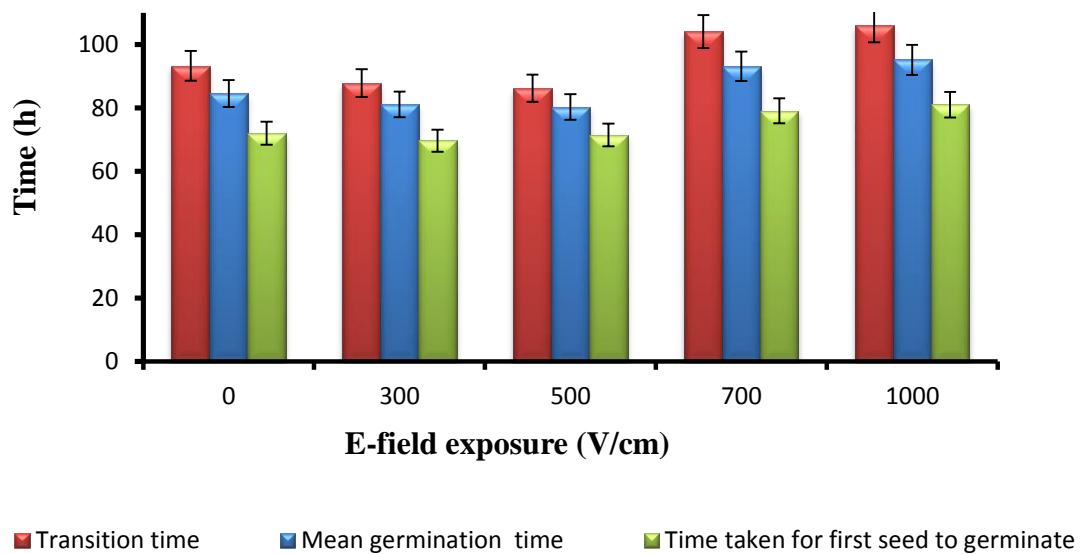
**Figure 4.24:** Showing variation in germination growth capacity for electrically treated seeds.



**Figure 4.25 :** Variation of un-germinated seeds with time in the samples.



**Figure 4.26:** Comparison of the water absorption of untreated *Momordica charantia* seeds in their best season (27 °C) with the water absorption of the seeds in the off season (34 °C) with and without the treatment at 500 V.

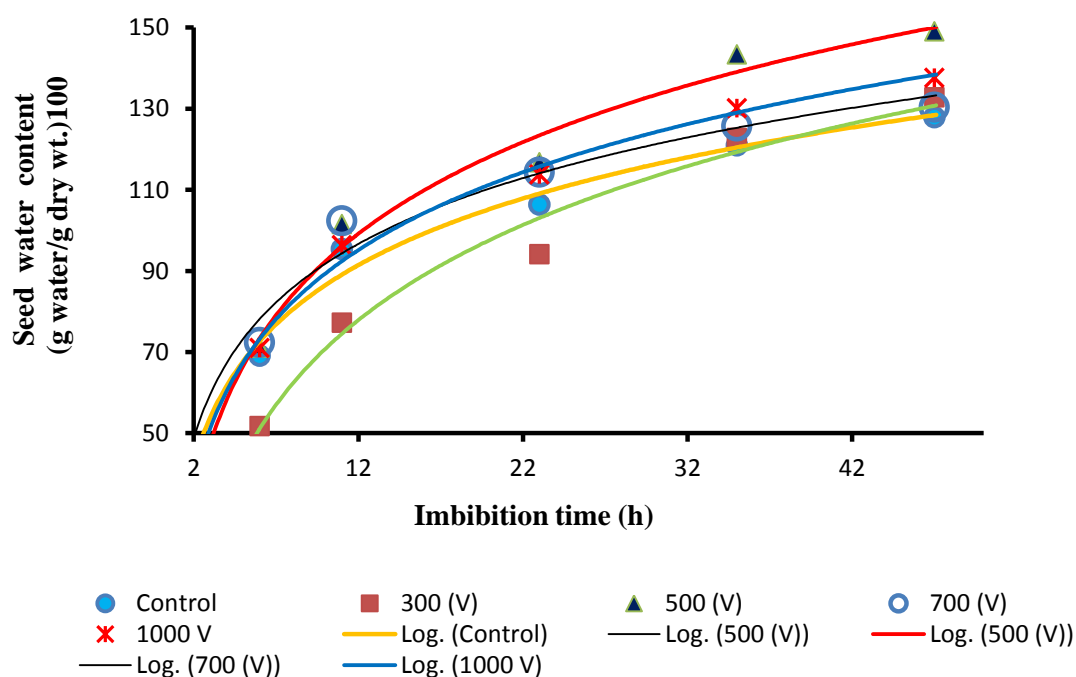


**Figure 4.27:** The variation in the mean germination time, transition time and time taken for the first seed to germinate for the electrically treated seeds.

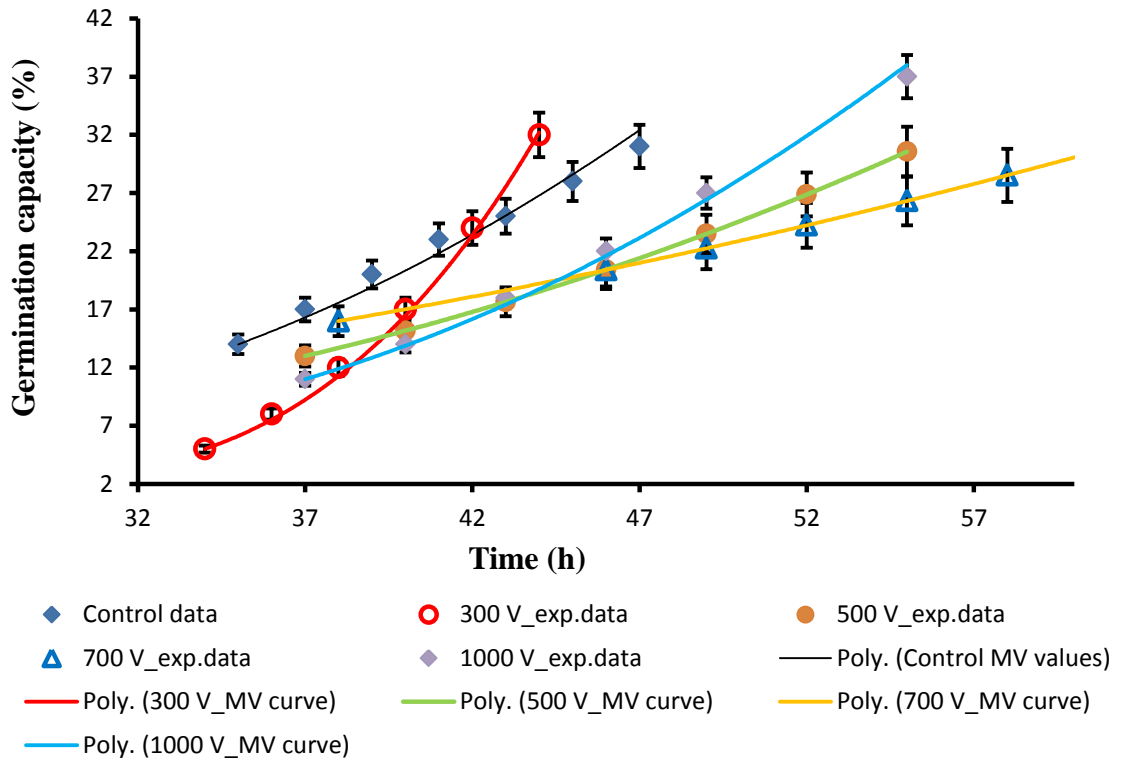
#### 4.6 Effect of electric field on germination and water uptake of ash gourd

The white gourd also called, winter melon, winter gourd, or ash gourd, is eaten like a vegetable. It is the only member of the genus *Benincasa* (Botanical name: *Benincasa hispida*

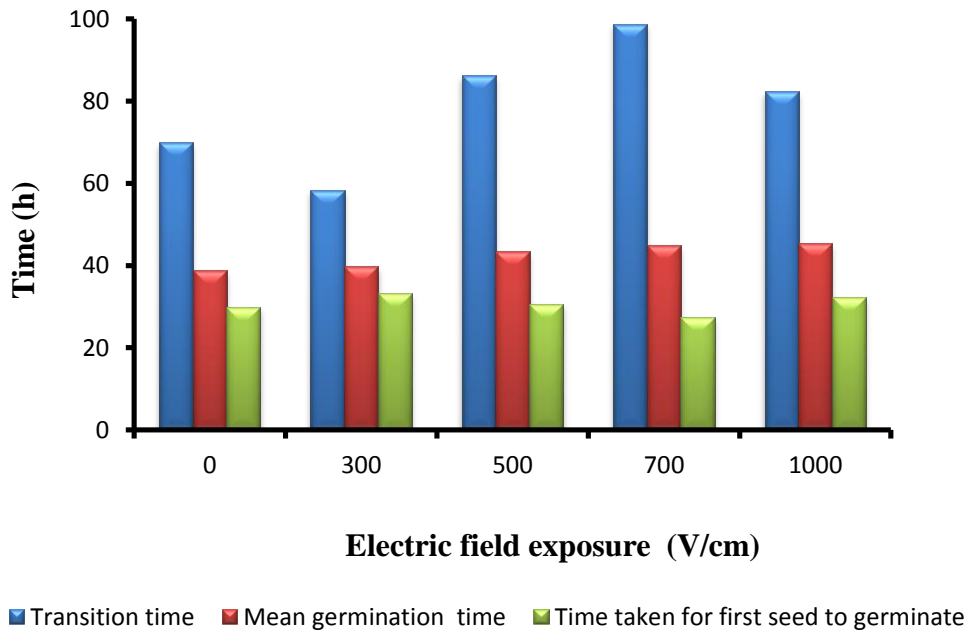
Family: Cucurbitaceae (Pumpkin family)). In India, it is called petha. The seed variety ‘Hyb. Pumpkin Vnr P-6 (VNR Seeds Pvt. Ltd.) was treated with electric field before sowing. The electric exposure of 300V/cm to 1000V/cm was used at 30 °C and its effect on water uptake and germination were studied. The percentage of water content absorbed by electrically treated white gourd seeds differs from the control group (Figure 4.28). The trend of water absorption curves are logarithmic ( $w_{\text{control}} = 27.085\ln(t) + 24.125$  ( $R^2 = 0.9722$ ),  $w_{300 \text{ V}} = 38.698\ln(t) - 18.285$  ( $R^2 = 0.9764$ ),  $w_{1000 \text{ V}} = 31.638\ln(t) + 16.53$  ( $R^2 = 0.9911$ ). The experimental data fitted well in Re-formulated Malthus-Verhulst equation (Figure 4.29) for all electrical treatments of white gourd seeds  $N_g(t) = N_k N_i / [N_i + (N_k - N_i) \exp \{-\alpha N_k (t - t_0)\}]$ . Experimental germinating data of white gourd seeds in Malthus-Verhulst equation has shown good fitting. Using a Stochastic model and experimental data, transition time for different electric treatments of white gourd seeds has been calculated and is shown in Figure 4.30. Mean germination time has been calculated using equation 3.23.



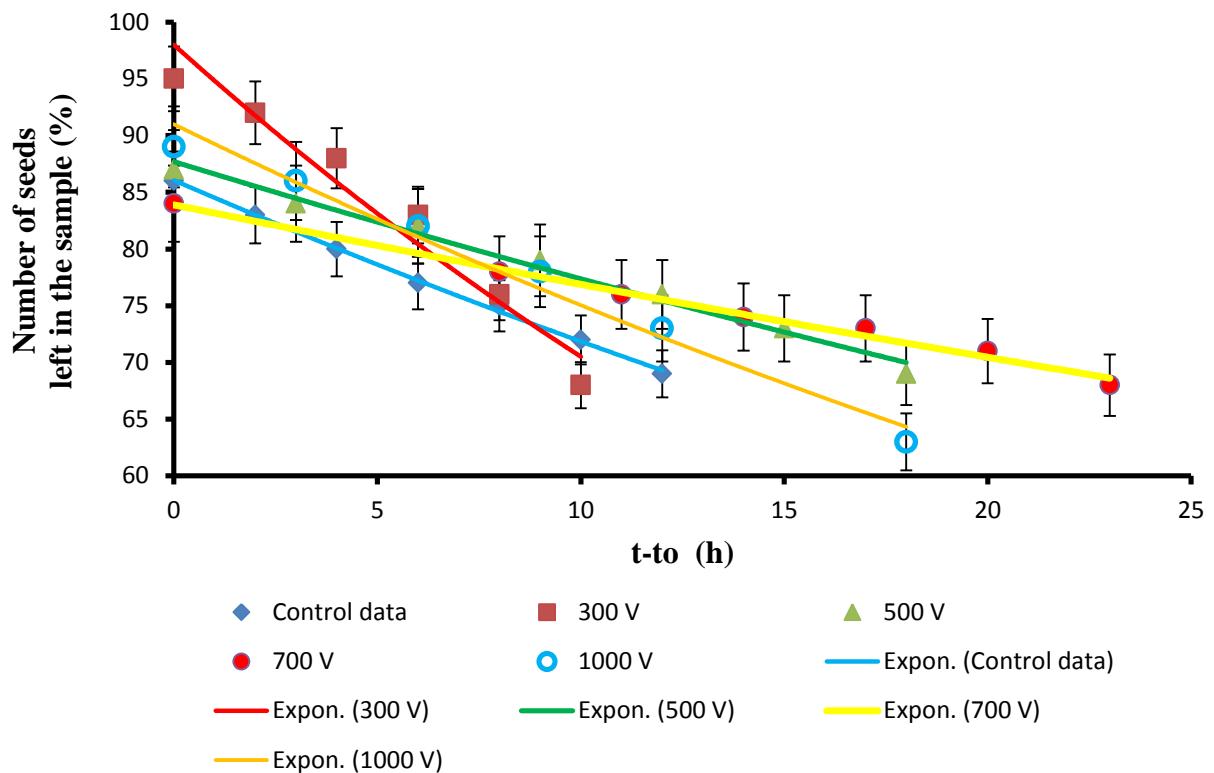
**Figure 4.28:** Variation of absorbed seed water content with the imbibition time for electrically treated seeds at different voltage levels.



**Figure 4.29:** Showing variation in germination growth capacity for electrically treated seeds.



**Figure 4.30:** Variation in the mean germination time, transition time and time taken for the first seed to germinate for the electrically treated seeds.



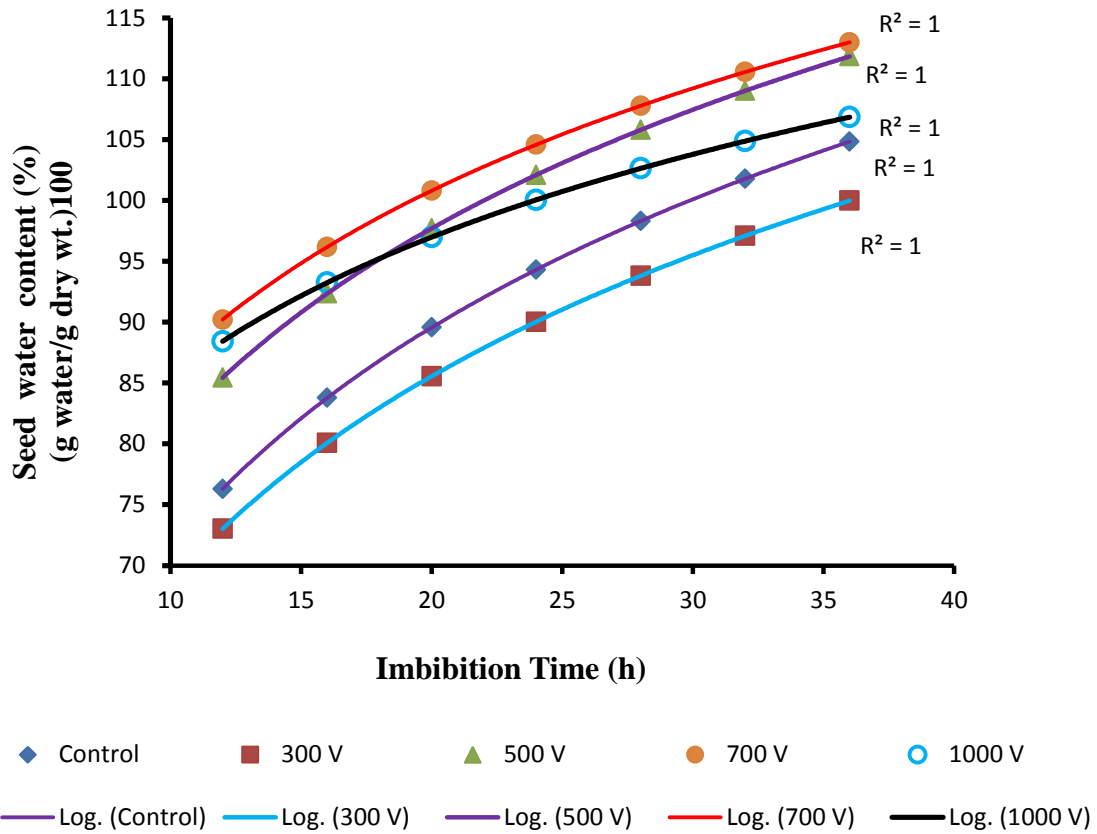
**Figure 4.31:** Variation of un-germinated seeds with time in the samples.

When electrically stressed seeds come into contact with the water dipoles, an interaction between the seed dipoles and water dipoles occurs. This interaction influences the water uptake of seeds which further affects the germination time and germination rate. Figure 4.28 shows that the change in water uptake of the treated seeds is appreciably different from that of the control group. Lowest absorption of water by the treated seed is observed for an electric field of 300 volt/cm and highest is observed for 1000 volt/cm. Using Re-formulated Malthus-Verhulst equation (3.5) and (Figure 4.29), the germination rate-coefficient has been determined by minimizing the residual sum of squares and executing the best possible fit for the growth model to the data. The value of germination rate-coefficient of electrically treated seeds are  $\alpha_{\text{control}} = 0.0009\text{h}^{-1}$ ,  $\alpha_{300\text{V}} = 0.0022\text{ h}^{-1}$ ,  $\alpha_{500\text{V}} = 0.0006\text{ h}^{-1}$ ,  $\alpha_{700\text{V}} = 0.00037\text{ h}^{-1}$  and  $\alpha_{1000\text{V}} = 0.00089\text{ h}^{-1}$ . Pietruszewski [26] determined germination rate-coefficient ( $\alpha_c = .005155$ ,  $\alpha_{D11} = .007625$ ,  $\alpha_{D13} = .007625$ ,  $\alpha_{D21} = .007085$ ,  $\alpha_{D23} = .005855$ ) by treating wheat seeds with the magnetic field at 45mT and 30 mT for different time intervals. Pietruszewski showed that more value of germination rate-coefficient implies to better germination (less germination time and more germination rate). The value of germination rate-coefficient

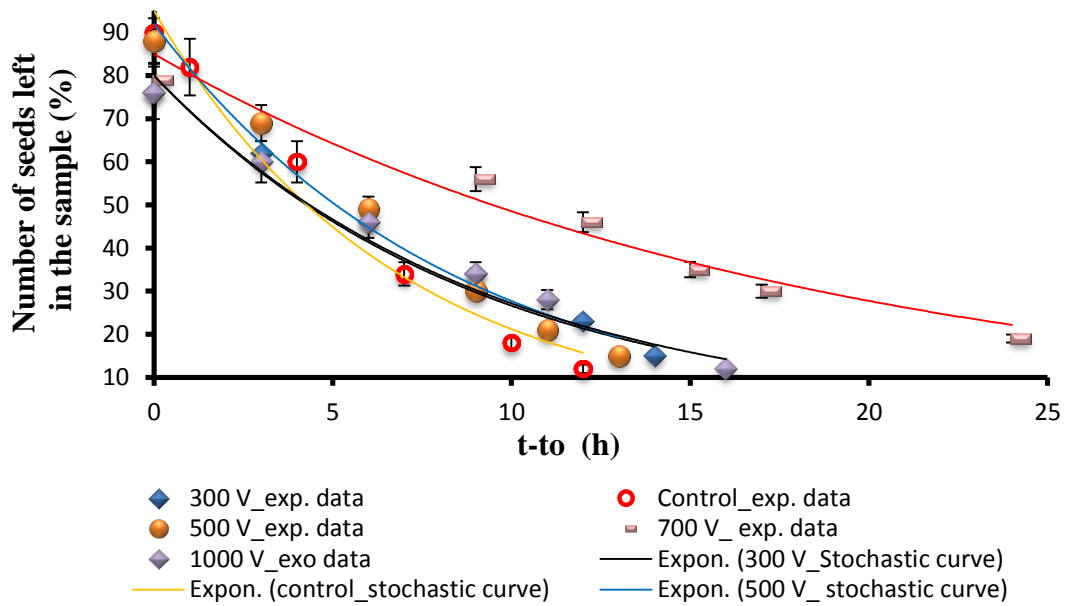
obtained in the present case is minimum at 700 V/cm and maximum at 300 V/cm. The variation in the value of germination rate- coefficient has been matched with the variation in a transition time (which is calculated by using a Stochastic model) as shown in Figure 4.30. Transition time at 700 V/cm (30 °C) shows an increase in its value, which results poor germination. The transition constant  $\lambda_{E,T}$ , which is a function of the electric field and the temperature is determined experimentally for different field values by keeping the temperature constant and is shown in Figure 4.31. Transition time is calculated by taking the reciprocal of transition constant and adding the initial time of germination in it (Figure 4.30).

#### 4.7 Effect on germination of electrically treated okra (*Abelmoschus esculentus* L.) seed

The popular varieties of okra (*Abelmoschus esculentus* L.), which are cultivated, in Punjab (India) are Pusa, Sawani, Punjab Padmani, Punjab-7, Punjab-8, Pb. Kranti, Pb. Varsha, Uphan A-11 and AR-SELECTION. In the present study the role of electric field on the germination of okra using variety AR-SELECTION (Armaan Seed Farms, Patiala) has been analyzed. Okra seed was treated with electric field varying from 300 V/cm to 1000 V/cm for 20 minutes exposure at 32 °C before planting. For giving electrical treatment, the distance between the two electrodes was kept 1 cm, therefore the voltage applied becomes numerically equal to electric field. The percentage of seed water content absorbed by okra seeds relative to its dry weight is plotted at all field values varying from 0 to 1000 V; 20-minute duration at 32 °C and is shown in Figure 4.32. The water uptake data of okra seeds is fitted well in logarithmic function ( $w_{\text{control}} = 25.98 \times \ln(t) + 11.74$ ,  $w_{300\text{V}} = 24.54 \times \ln(t) + 12$ ,  $w_{700\text{V}} = 20.74 \times \ln(t) + 38.68$  ( $R^2 = 1$  for all curves)). Maximum water intake observed is at 700 V, and the minimum at 300 V. All the trends justify to water absorption model ( $w = C_1 \times \ln(t) \pm C_2$ ). Stochastic function (equation 3.21) (two state process)  $N = (N_k - N_i) \exp(-\lambda_{E,T} (t - t_0))$  is applied to fit germinating data of okra seeds for different values of electric fields and 20 minutes exposure at 32 °C and is shown in Figure 4.33. All curves are exponential in nature. There is a good match between experimental data and theoretical values of Stochastic function of okra seeds. The variation in a transition time, mean germination time and time taken for the first seed to germinate for various electric field values (20 minute exposure at 32 °C) of okra seeds is shown in Figure 4.34.

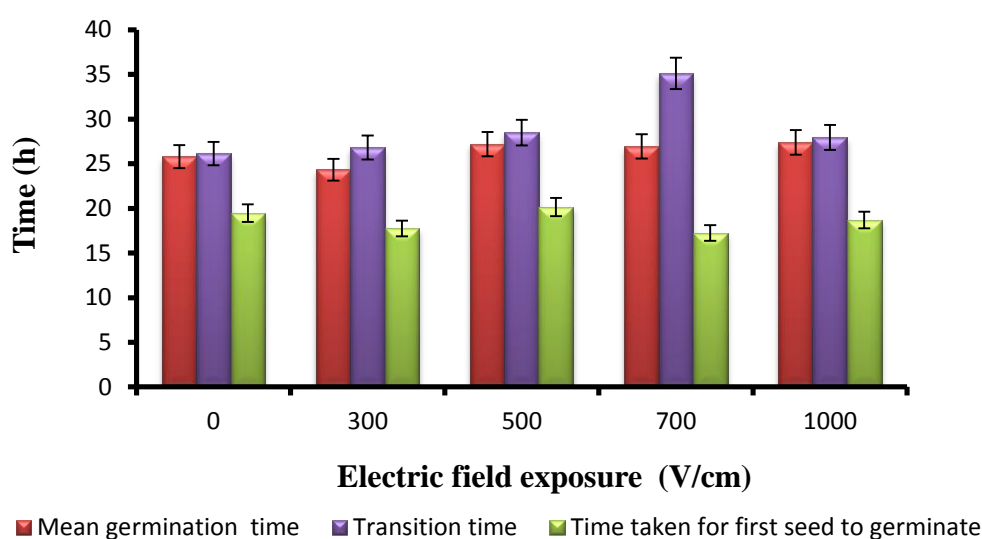


**Figure 4.32:** Variation of absorbed seed water content with the imbibition time for electrically treated seeds at different voltage levels.



**Figure 4.33:** Showing variation in germination growth capacity for electrically treated seeds.

At the start of water uptake (phase I), dry seeds imbibe water and take up oxygen from atmosphere. As a result, the seed mass increases. In this phase percentage change in water uptake relative to dry weight of seed at 32 °C with 20 minute exposure is decreased 3.3 unit with respect to control for 300 V and increased 14 unit with respect to control for 700 V respectively at any time  $t = 12$  h as shown in Figure 4.32. In phase II when germination starts, at any instant  $t = 20$  h, there is a metabolic plateau with low water absorption. Phase II shows that the percentage change in water uptake relative to dry weight of seed for 300 and 700 V at 32 °C with 20 minute exposure is decreased 4 unit with respect to control and increased 11 unit with respect to control. Using Re-formulated Malthus-Verhulst the germination rate-coefficient was determined by minimizing the residual sum of squares and executing the best possible fit for the growth model to the data ( $\alpha_{\text{control}} = 0.004\text{h}^{-1}$ ,  $\alpha_{300\text{V}} = 0.002 \text{ h}^{-1}$ ,  $\alpha_{700\text{V}} = 0.0012 \text{ h}^{-1}$ ). The value of germination rate- coefficient value at 700 V/cm is relatively poor than at 300 V/cm. The transition constant  $\lambda_{E,T}$  which is a function of the electric field, and the temperature is determined experimentally using Figure 4.33 for different field values, time-exposures and temperatures. This constant  $\lambda_{E,T}$  decides the transition time between un-

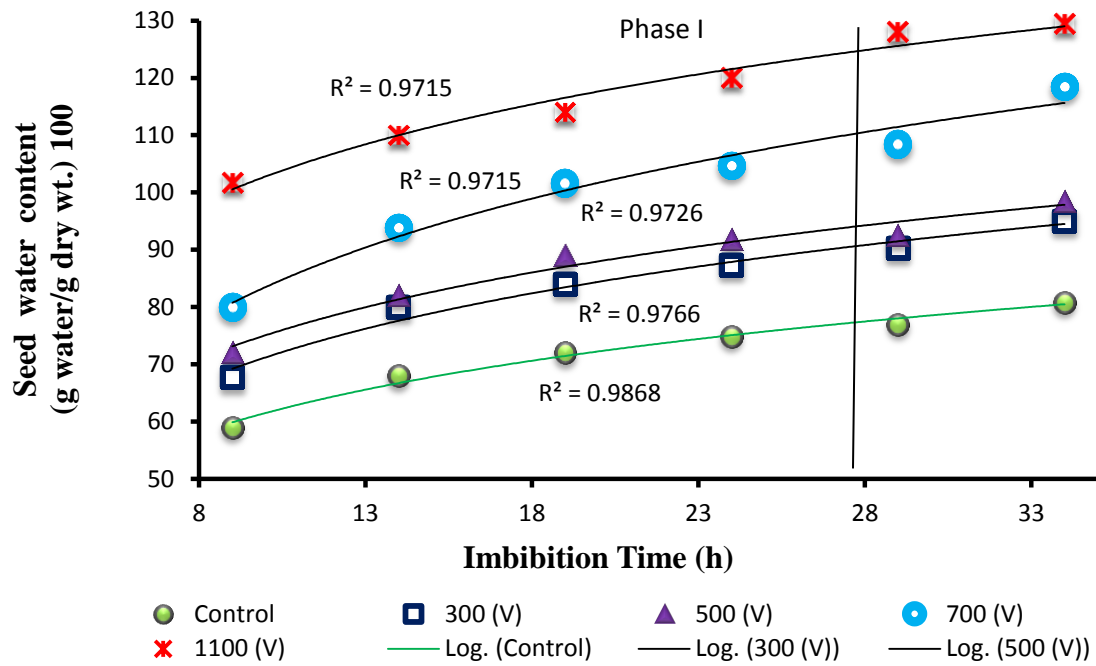


**Figure 4.34:** Variation in the mean germination time, transition time and time taken for the first seed to germinate for the electrically treated seeds.

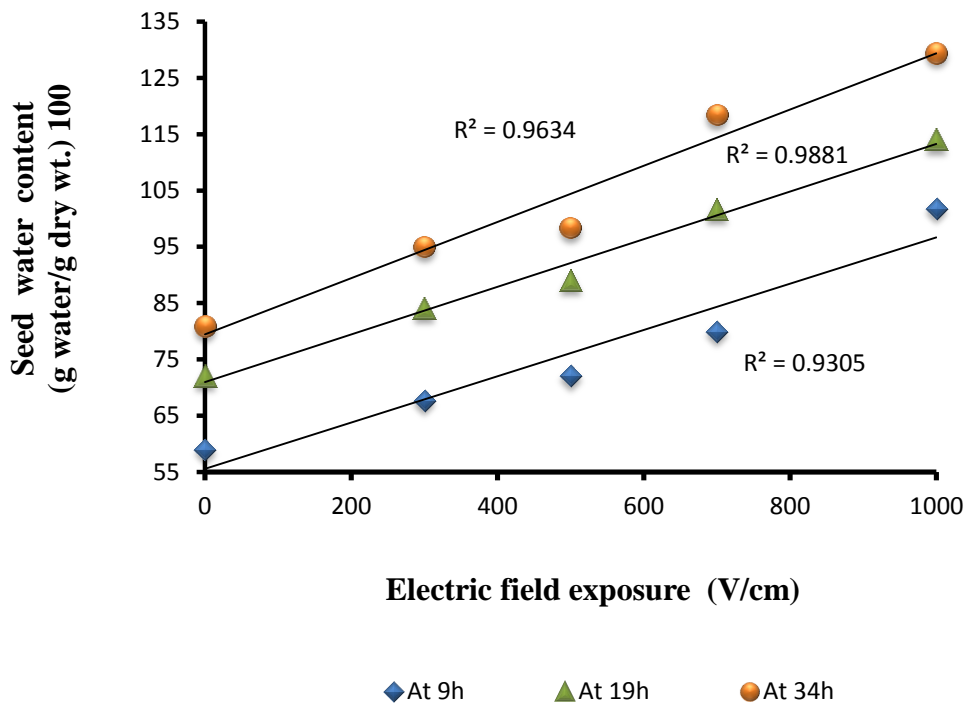
germinated to germinated state. Transition time at 700 V/cm (32 °C) shows an increase, which results poor germination.

#### 4.8 Effect of pre-sowing electrical treatment on germination of Spinach seed

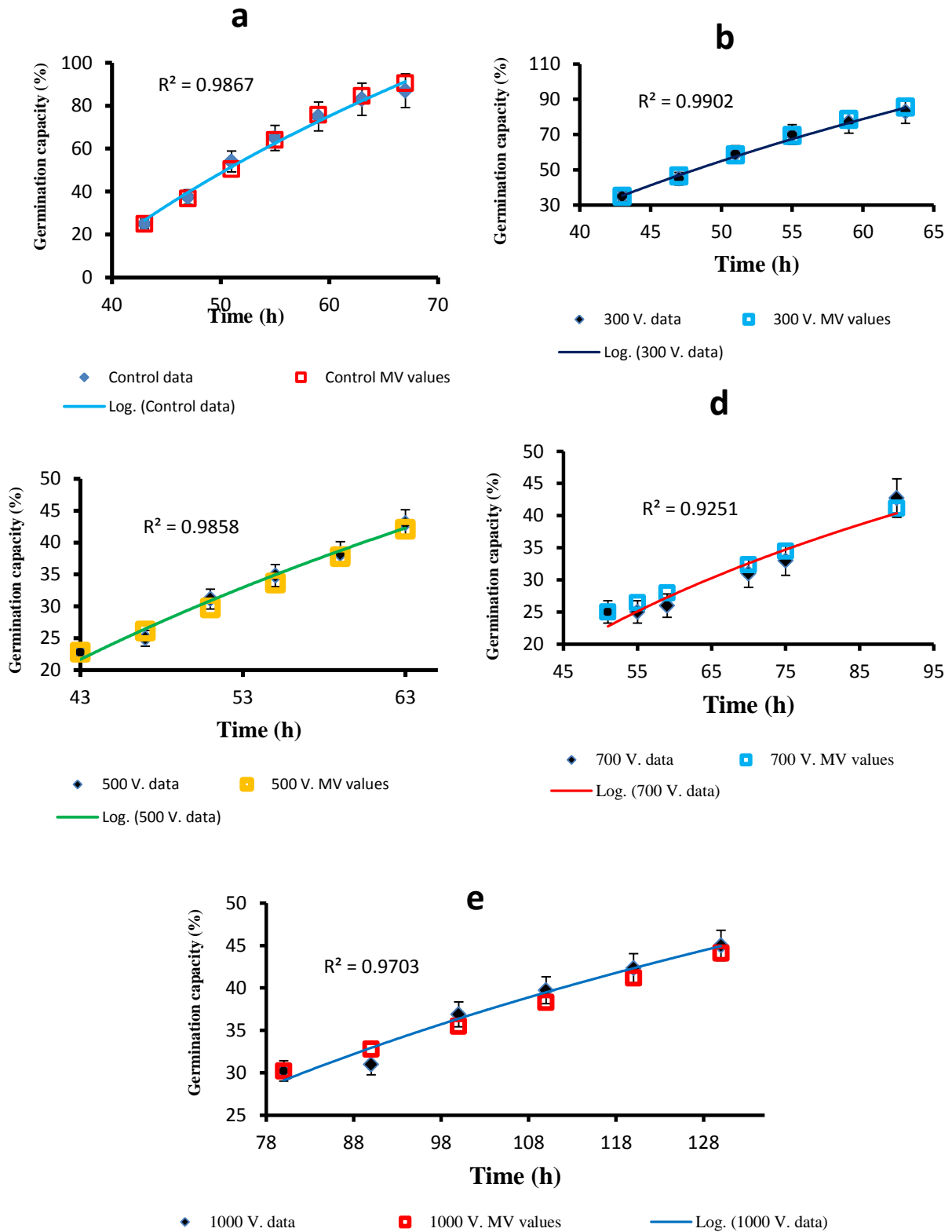
*Spinacia oleracea* is an edible flowering plant in the family of Amaranthaceae. This plant has been related with various biological activities like virus inhibitor, anthelmintic, antioxidant, hepatoprotective and reducing risk of breast cancer [27]. Important varieties of Spinach cultivated in Punjab (India) are Pb.selection and Pb.Green. Extensive literature survey revealed that no reports were available on the effects of electric field treatment on germination of spinach seeds. The present study was undertaken to explore the germination effects of spinach seed in the environment of electric fields. Presently the role of electric field on the germination parameter of *Spinacia* has been analyzed using variety All-GRE 118 (Armaan seed Farms, Patiala). *Spinacia* were treated with electric field varying from 300 V/cm to 1000 V/cm for 20 minutes exposure at 32 °C before planting. For giving electrical treatment, the distance between the two electrodes was kept 1 cm, therefore the voltage applied becomes numerically equal to electric field. Percentage seed water content relative to its dry weight of *Spinacia oleracea* L. is measured at different intervals. Figure 4.35 shows the continuous increase in water absorption with time at all field values varying from 0 to 1000 V; 20-minute duration at 32 °C. The water uptake data is fitted well in logarithmic function ( $w_{\text{control}} = 15.509\ln(t) + 25.799$ ,  $w_{300\text{V}} = 19.043\ln(t) + 27.362$ ,  $w_{1000\text{V}} = 21.415\ln(x) + 53.484$  ( $R^2 > 0.9$ , for all curves). Maximum increase in water intake is observed at 1000 V and minimum increase is observed at 300 V. All the trends justify to water absorption model ( $w = C_1 \times \ln(t) \pm C_2$ ). At any time during imbibition, the seed water content absorbed is a linear function of applied voltage/electric-field as shown in Figure 4.36. Using Figure 4.37 and Re-formulated Malthus-Verhulst function, the germination rate-coefficient was determined by minimizing the residual sum of squares and executing the best possible fit for the growth model for the data as:  $\alpha_{\text{control}} = 0.0014\text{h}^{-1}$ ,  $\alpha_{300\text{V}} = 0.0012\text{h}^{-1}$ ,  $\alpha_{500\text{V}} = 0.0004\text{h}^{-1}$ ,  $\alpha_{700\text{V}} = 0.0002\text{h}^{-1}$ ,  $\alpha_{1000\text{V}} = 0.0001\text{h}^{-1}$ . The data fitted well in Re-formulated Malthus-Verhulst equation  $N_g(t) = N_k N_i / [N_i + (N_k - N_i) \exp\{-\alpha N_k (t - t_0)\}]$ . Stochastic function (two state process)  $N = (N_k - N_i) \exp(-\lambda_{E,T} (t - t_0))$  is applied to fit germinating data for different values of electric fields and for 20 minutes exposure at 32 °C is shown in Figure 4.38. All curves are exponential in nature. There is a good match between experimental and theoretical values of Stochastic function. The variation in transition time, mean germination time and time taken for first seed to germinate for various electric field values (20 minute exposure at 32 °C) is shown in Figure 4.39. At the start of water uptake (phase I), dry seeds imbibe water;



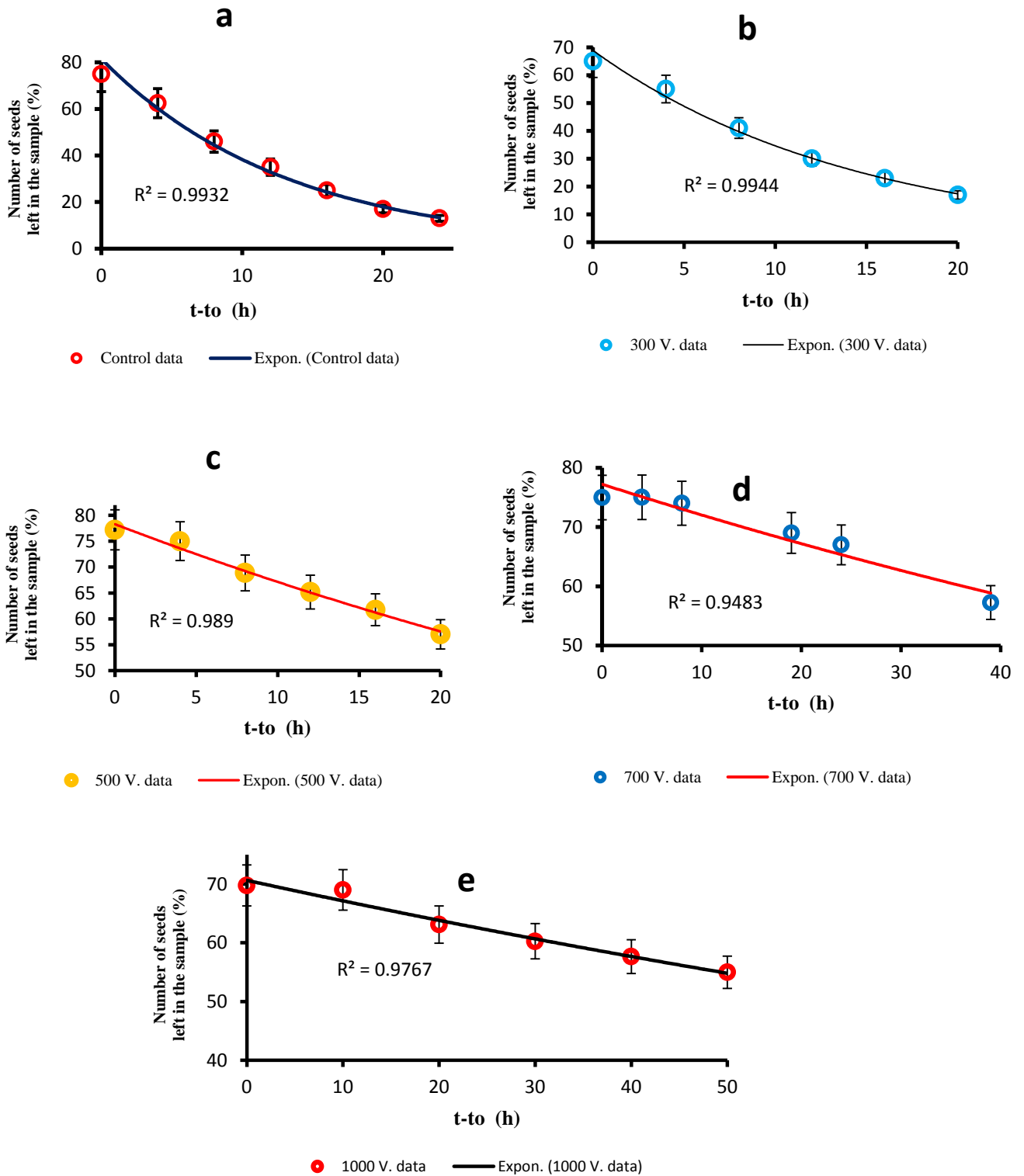
**Figure 4.35:** Variation of absorbed seed water content with the imbibition time for electrically treated seeds at different voltage levels.



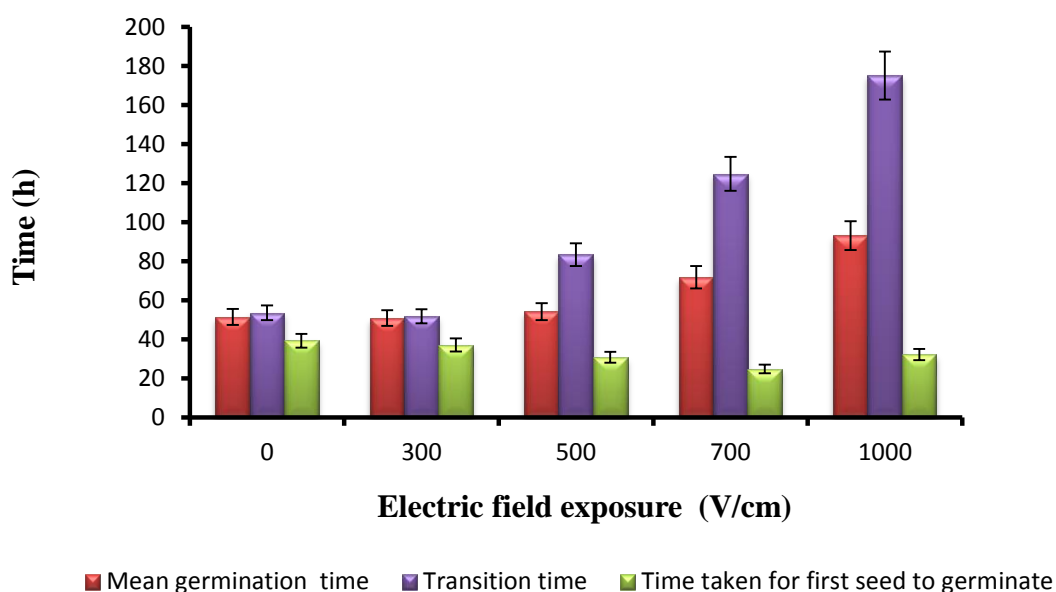
**Figure 4.36:** Variation of seed water content absorbed as a function of applied electric-field.



**Figure 4.37 (a-d):** Variation in germination growth capacity for electrically treated seeds.



**Figure 4.38(a-e):** Variation of un-germinated seeds with time in the samples.



**Figure 4.39:** Variation in the mean germination time, transition time and time taken for the first seed to germinate for the electrically treated seeds.

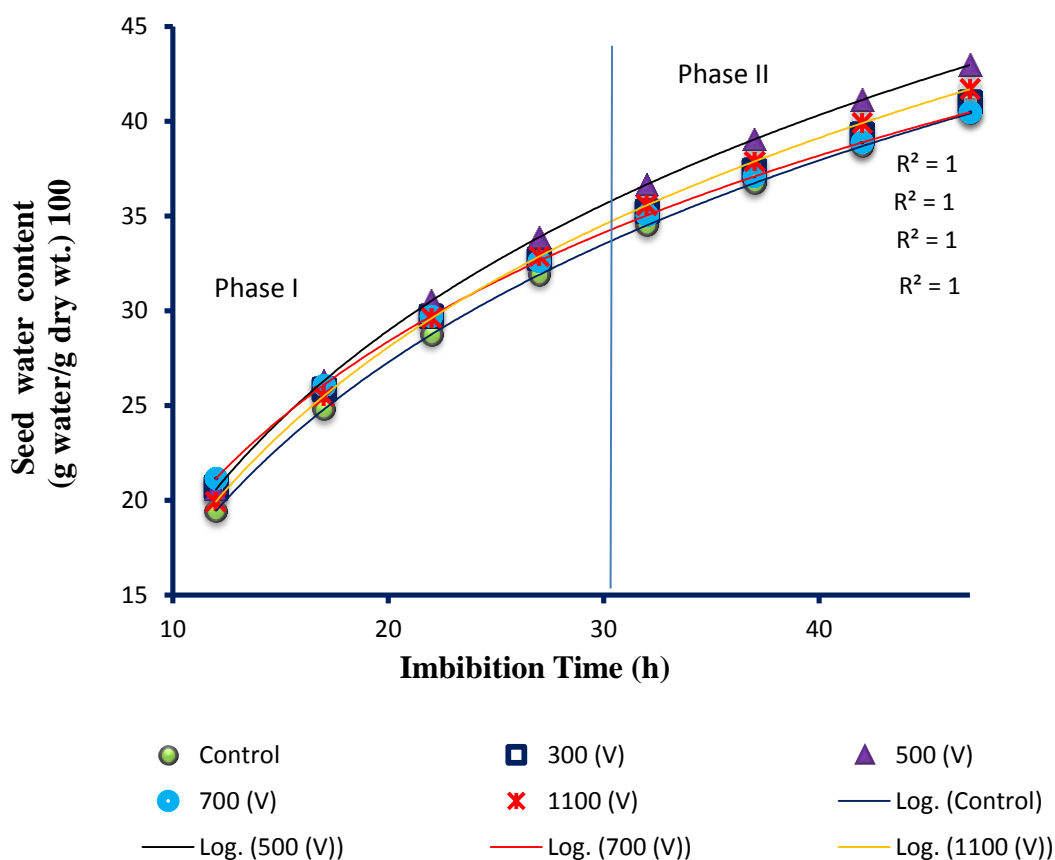
take up oxygen and as a result increases its seed mass. In this phase percentage change in water uptake relative to dry weight of *Spinacia oleracea* L. seed as compared to control for 300 and 1000 V at 32 °C with 20 minute exposure is 8.7 and 42.7 unit respectively (at any time  $t = 9$  h as shown in Figure 4.35). In phase II, there is a metabolic plateau with low water absorption. Phase II shows that percentage increase in water uptake relative to dry weight of seed as compared to control for 300 and 1000 V volt at 32 °C with 20 minute exposure is 13 and 51 unit (at any instant  $t = 29$  h). The seeds treated with more electric dose absorbs more water, there is linear relation between the seed water content absorbed at any time during imbibition with applied voltage/electric-field (Figure 4.36). The data of germination capacity as given in Figure 4.37 shows that electric field between 300 and 1000 Volt/cm stimulates negatively to of *Spinacia oleracea* L. seed for 20 minutes exposure time. It is interesting to note that water uptake results and germination capacity results are in opposite; more water uptake implies to low germination capacity and vice versa. Germinating data of *Spinacia oleracea* L. seeds of different values of electric-field exposure fitted well in Re-formulated Malthus-Verhulst equation  $N_g(t) = N_k N_i / [N_i + (N_k - N_i) \exp \{- a N_k (t - t_o)\}]$  [23-26]. Using Re-formulated Malthus-Verhulst the germination rate- coefficient was determined by

minimizing the residual sum of squares and executing the best possible fit for the growth model to the data. With increasing the electric-field the germination rate- coefficient decreases. The transition constant  $\lambda_{E,T}$  which is a function of electric field, and temperature is determined experimentally for different field values, time-exposures and temperatures.  $\lambda_{E,T}$  play an important role in transition from un-germinated to germinated state. This constant  $\lambda_{E,T}$  decides the transition time between these two states (Figure 4.38). With increasing electric-field, there is increase in mean germination time as well as in transition time indicating a poor germination process of seed where mean germination time becomes almost double as compared to control at 1000V/cm electrical treatment (Figure 4.39).

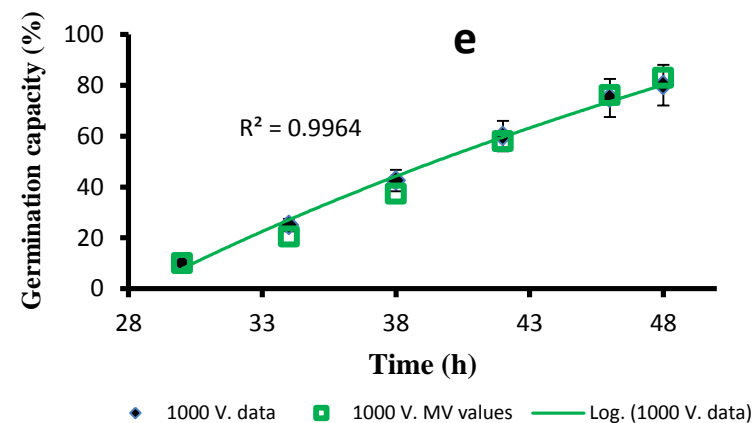
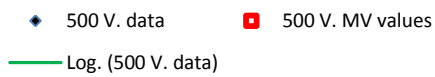
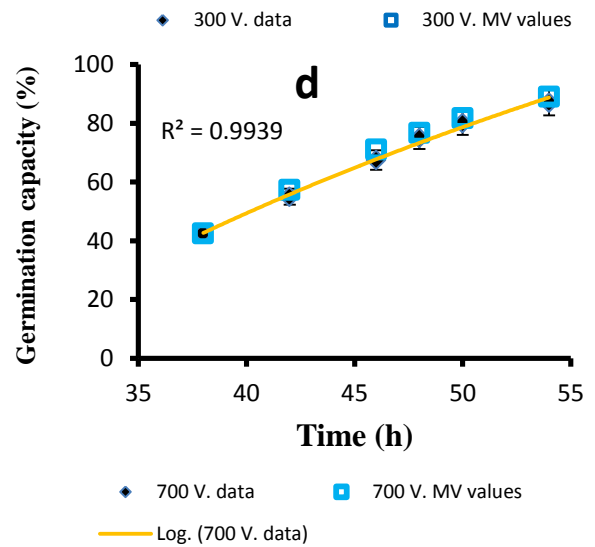
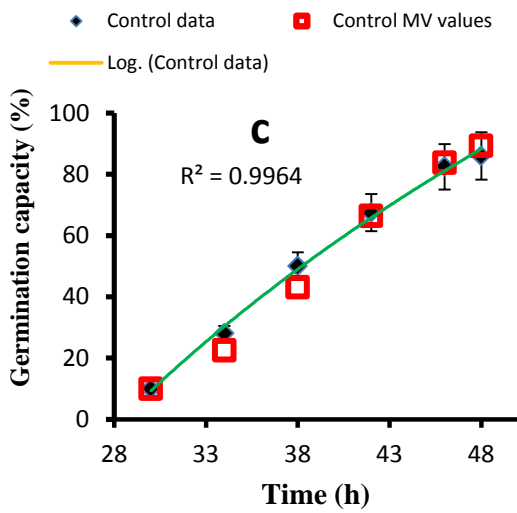
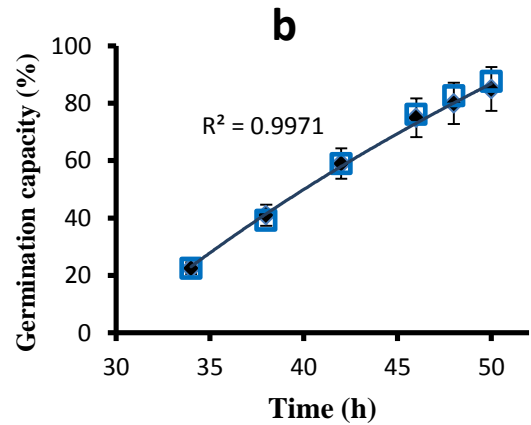
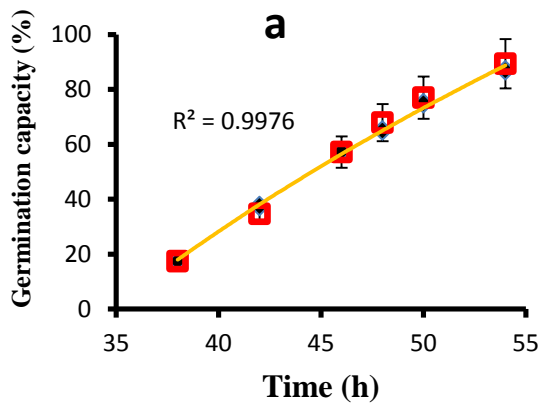
#### 4.9 Effect of electric field on germination and water uptake of maize seed

Traditionally maize is grown as kharif crop. However, sowing during rabi season has also started in some districts of Punjab with new varieties. To study the effect of electric field on the germination of Maize, hybrid Maize seeds P-55 of 80-85 days maturity period were obtained from Proline seeds company (India) Pvt. Ltd. and was used in the present research. Maize seeds of this variety were treated with electric field varying from 300V/cm to 1000 V/cm for 20-minute duration at 34 °C before sowing and its effect on water absorption and germination were studied. Percentage seed water content relative to its dry weight is measured at different intervals. Figure 4.40 shows the continuous increase in water absorption with time at all field values varying from 0 to 1000 V; 20-minute duration at 34 °C. The water uptake data is fitted well in logarithmic function ( $w_{\text{control}} = 15.36 \times \ln(t) - 18.75$ ,  $w_{500\text{V}} = 16.40 \times \ln(t) - 20.18$  ( $R^2 > 0.99$ ). Maximum water intake is observed at 500 V and at other voltages water absorption is approximately same with control group. All the trends justifies to water absorption model ( $w = C_1 \times \ln(t) \pm C_2$ ). Using Re-formulated Malthus-Verhulst function the germination rate- coefficient was determined by minimizing the residual sum of squares and executing the best possible fit for the growth model for the data as:  $\alpha_{\text{contro}} = 0.0023 \text{ h}^{-1}$ ,  $\alpha_{300 \text{ V}} = 0.002 \text{ h}^{-1}$ ,  $\alpha_{500 \text{ V}} = 0.0024 \text{ h}^{-1}$ ,  $\alpha_{700 \text{ V}} = 0.0015 \text{ h}^{-1}$ ,  $\alpha_{1000 \text{ V}} = 0.0021 \text{ h}^{-1}$ . The germination data as shown in Figure 4.41 fitted well in Re-formulated Malthus-Verhulst equation  $N_g(t) = N_k N_i / [N_i + (N_k - N_i) \exp \{-\alpha N_k (t - t_0)\}]$ . Stochastic function (two state process)  $N = (N_k - N_i) \exp(-\lambda_{E,T} (t - t_0))$  is applied to fit germinating data for different values of electric fields and for 20 minutes exposure at 34 °C is shown in Figure 4.42. All curves are exponential in nature. There is a good match between experimental and theoretical values of Stochastic

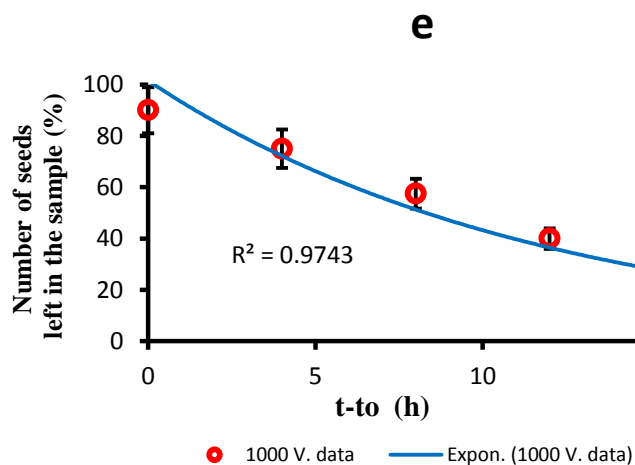
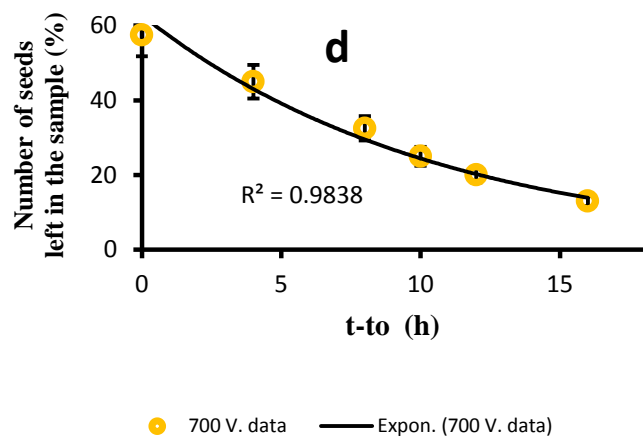
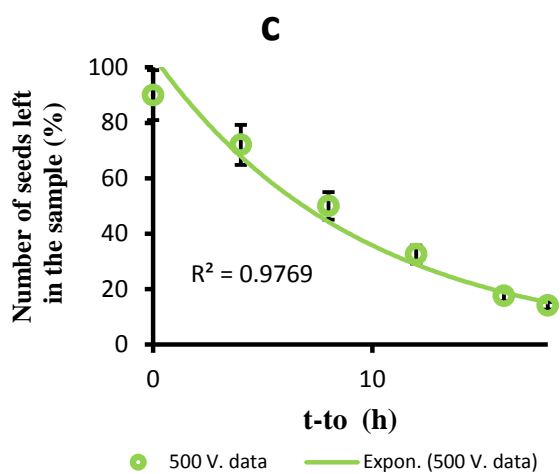
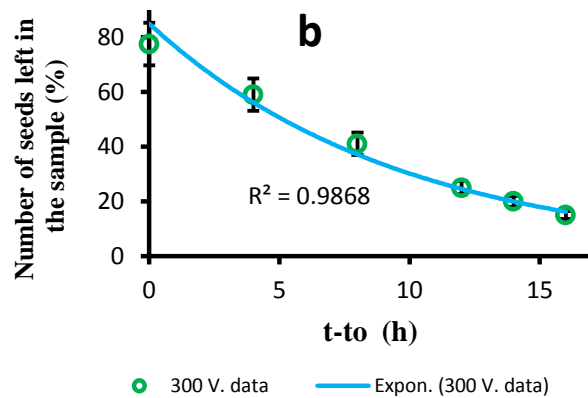
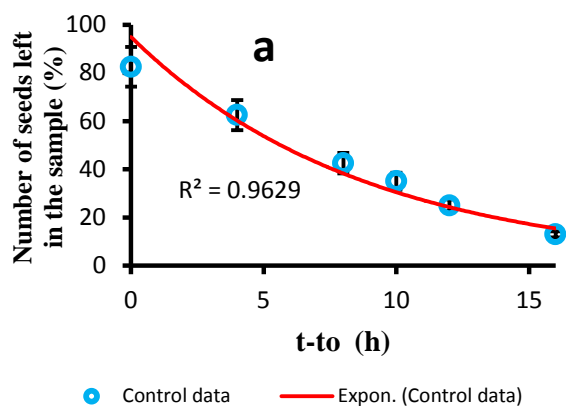
function. The variation in transition time, mean germination time and time taken for first seed to germinate for various electric field values (20 minute exposure at 34 °C) is shown in Figure 4.43. At the start of water uptake (phase I), dry seeds imbibe water; take up oxygen and as a result increases its seed mass. In this phase percentage change in water uptake relative to dry weight of seed as compared to control for 500 V at 34 °C with 20 minute exposure increased 1.77 unit as compared to control at any time  $t = 22$  h as shown in Figure 4.40. In phase II, there is a metabolic plateau with low water absorption. Phase II in Figure 4.40 shows that percentage increase in water uptake relative to dry weight of seed as compared to control for 500 V volt at 34 °C with 20 minute exposure is 2.44 unit (at any instant  $t = 42$  h).



**Figure 4.40:** Variation of absorbed seed water content with the imbibition time for electrically treated seeds at different voltage levels.

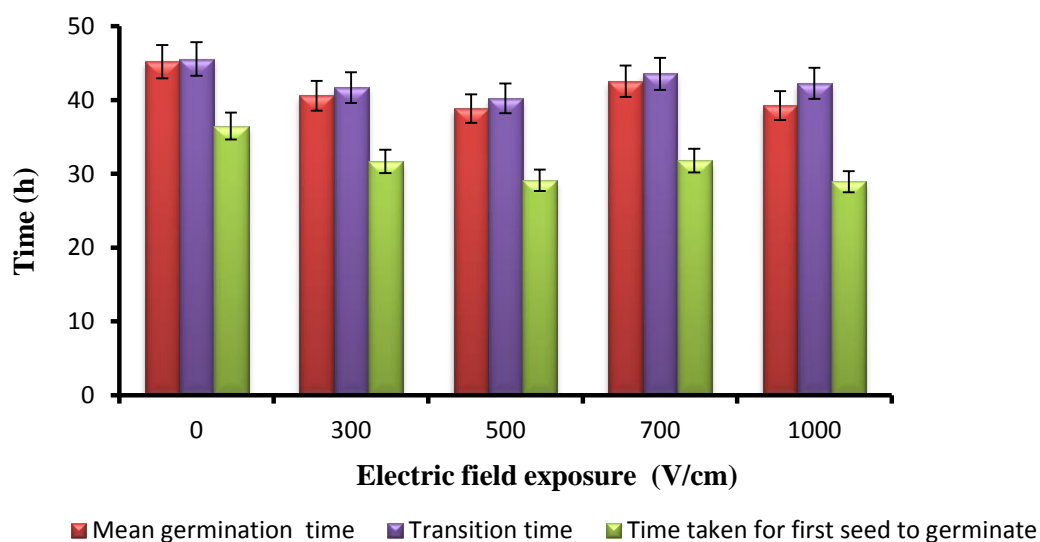


**Figure 4.41(a-e):** Showing variation in germination growth capacity for electrically treated seeds.



**Figure 4.42(a-e):** Variation of un-germinated seeds with time in the samples.

The data of germination capacity as shown in Figure 4.41 shows that electric field at 500 Volt/cm stimulates so it results in improvement in early germination parameters of maize seed for 20 minutes exposure. It is interesting to note that water uptake and germination capacity results are in favour of each other where more water uptake implies to high germination capacity. Germinating data of maize seeds for different values of electric-field exposure fitted well in Re-formulated Malthus-Verhulst equation  $N_g(t) = N_k N_i / [N_i + (N_k - N_i) \exp\{-\alpha N_k (t - t_0)\}]$  [23-26]. Using Re-formulated Malthus-Verhulst the germination rate-coefficient was determined by minimizing the residual sum of squares and executing the best possible fit for the growth model to the data. The value of germination rate-coefficient is improved at 500 V. It implies good production yield at 500 V. The transition constant  $\lambda_{E,T}$  which is a function of electric field, and temperature is determined experimentally for different field values, time-exposures and temperatures. Transition time is calculated by taking the reciprocal of transition constant and adding the initial time of germination in it. The trend of transition time and mean germination time is approximately same at all voltages. There is an improvement in mean germination time, transition time and time taken for first seed to germinate at 500 V stimulation (Figure 4.43).



**Figure 4.43:** The variation in the mean germination time, transition time and time taken for the first seed to germinate for the electrically treated seeds.

## References:

- [1] Pietruszewski S., Muszynski S., and Dziwulska A., Electromagnetic fields and electromagnetic radiation as non-invasive external stimulants for seeds (selected methods and responses), *International agrophysics*, **21**, 1, 95, 2007.
- [2] Blank M., Biological effects of environmental electromagnetic fields: molecular mechanisms, *Biosystems*, **35**, 2, 175-178, 1995.
- [3] Wadas R. S., *Biomagnetism*: Polish Scientific Publishers. Warsaw, 1991.
- [4] Rani V. M. S., Kalarani V., and Karuna R., Influence of low frequency electromagnetic radiation on germination and growth of sunflower seeds (*Helianthus annuus* L.), *Current Biotica*, **5**, 4, 436-445, 2012.
- [5] Hart F. X., and Marino A. A., Energy flux along high voltage transmission lines, *Biomedical Engineering, IEEE Transactions on*, **5**, 493-495, 1977.
- [6] Marron M. T., Goodman E. M., Sharpe P. T. *et al.*, Low frequency electric and magnetic fields have different effects on the cell surface, *FEBS letters*, **230**, 1, 13-16, 1988.
- [7] Kiatgamjorn P., Tarateeraseth V., Khan-ngern W. *et al.*, "The effect of electric field intensity on bean sprout growing," in Proc. Int. Conf. Electromagnetic Compatibility, October, pp. 7-11, 2002.
- [8] Kiatgamjorn P., Khan-ngern W., and Nitta S., "The Effect of Electric Field on Bean Sprout Growing," in International Conference on Electromagnetic Compatibility (ICEMC2002), Bangkok, Thailand, pp. 237-241, 2002.
- [9] Das R., and Bhattacharya R., "Impact of electromagnetic field on seed germination," in Proceedings of the International Conference on Modern Electrostatics, pp. 141-145, 2006.
- [10] Vashisth A., and Nagarajan S., Exposure of seeds to static magnetic field enhances germination and early growth characteristics in chickpea (*Cicer arietinum* L.), *Bioelectromagnetics*, **29**, 7, 571-8, 2008.
- [11] Nelson S. O., Fundamentals of dielectric properties measurements and agricultural applications, *J. Microwave Power Electromagnetic Energy*, **44**, 98-113, 2010.
- [12] Kittel C., *Introduction to Solid State Physics*, seventh ed., p. 383-398: John Wiley & Sons, 2012.
- [13] Vashisth A., and Nagarajan S., Effect on germination and early growth characteristics in sunflower (*Helianthus annuus*) seeds exposed to static magnetic field, *Journal of Plant Physiology*, **167**, 2, 149-156., 2010.
- [14] Karadavut U., Palta C., Kökten K. *et al.*, Comparative study on some non-linear growth models for describing leaf growth of maize, *Int. J. Agric. Biol*, **12**, 227-230, 2010.
- [15] Singh F., and Diwakar B., Chickpea botany and production practices, *Skill development series*, 16, 1995.
- [16] Das B., and Sen S., Effect of nitrogen, phosphorus and potassium deficiency on the uptake and mobilization of ions in Bengal gram (*Cicer arietinum*), *Journal of Biosciences*, **3**, 3, 249-257, 1981.
- [17] Piras A., Gui Z., Qiao L. *et al.*, Effect of Negative Electrostatic Field Treatment on Germination of Seeds Soaked GA3, *International Journal of Soft Computing and Engineering (IJSCE)*, **3**, 3, 2231-2307, 2013.
- [18] Mahajan T. S., and Pandey O. P., Magnetic-time model for seed germination, *African Journal of Biotechnology*, **11**, 88, 15415-15421, 2012.

- [19] Mahajan T. S., and Pandey O. P., Magnetic-time Model at off Season Germination, *International Agrophysics*, **28**, 1, Accepted. in press doi: 10.2478, 2014.
- [20] Battaglia M., Olvera-Carrillo Y., Garcarrubio A. *et al.*, The Enigmatic LEA Proteins and Other Hydrophilins, *American Society of Plant Biologists*, **148**, 16-24, 2008.
- [21] Meyer C. J., Steudle E., and Peterson C. A., Patterns and kinetics of water uptake by soybean seeds, *J Exp Bot*, **58**, 3, 717-32, 2007.
- [22] Pietruszewski S., and Kania K., Effect of magnetic field on germination and yield of wheat, *Int. Agrophys*, **24**, 297-302, 2010.
- [23] Pietruszewski S., Influence of magnetic and electric fields on seeds. Germination of selected cultivated plants, *Acta Scientiarum Polonorum*, **1**, 1, 75-81, 2002.
- [24] Pietruszewski S., Modeling by logistic curve germination of wheat seeds Henika cultivar in magnetic field, *Acta Agrophysica*, **58**, 143-151, 2001.
- [25] Mahajan T. S., and Pandey O. P., Re-formulation of Malthus-Verhulst equation for black gram (*Cicer arietinum* L.) seeds pre-treated with magnetic field, *International Agrophysics*, **25**, 4, 355-359, 2011.
- [26] Pietruszewski S., and Kania K., Effect of magnetic field on germination and yield of wheat, *International Agrophysics*, **24**, 297-302., 2010.
- [27] Dande P. R., Sharma G., Sharma R. *et al.*, Pharmacognostical Studies Of Leaves Of *Spinacia Oleracea* Linn, *International Journal of Pharmaceutical Sciences and Research*, **1**, 9, 41-46, 2010.

# Chapter 5

## Results and Discussion

### (Effect of Magnetic Field on Seed Germination)

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#### Overview

In this chapter, the results of the magnetic field on seed germination have been described and discussed. Different seeds used in present work are pre-treated with different intensity of magnetic field and for different time duration. The results of magnetic treatment are studied by measuring the water uptake by the seed and also by measuring germination capacity. Magnetic time model and water uptake model are tested for different species and is presented in this chapter. Magnetic time model is used to understand the results. Magnetic time constant  $\theta_B$  is calculated, to understand the germination process. The use of mean germination time, mean germination rate, germination rate coefficient, germination magnetic constant, transition time, water uptake is discussed in this chapter to find the effects of magnetic field on germination of seeds.

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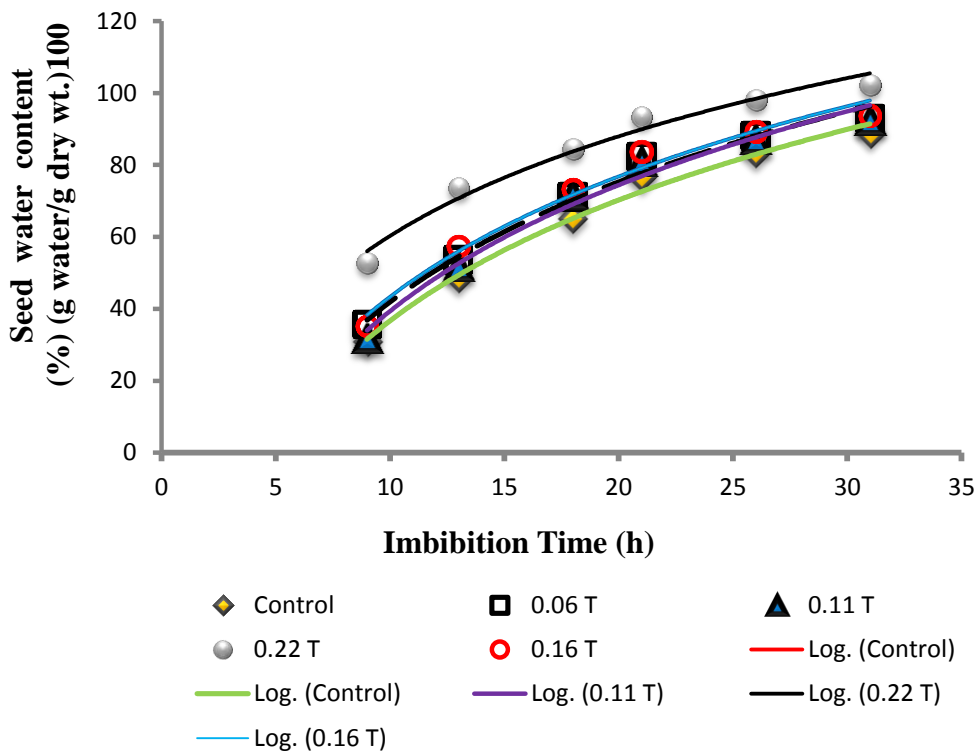
## 5.1 EFFECT OF MAGNETIC FIELD ON SEED GERMINATION

Magnetic field of earth which is around 50  $\mu\text{T}$  is a natural component of the environment for living organisms [1]. The role of weak magnetic field and its influence on plants is not fully understood [1]. A number of experiments related to seedlings of different plant species in the environment of weak magnetic field have shown that the growth of their primary roots is inhibited during early germination stages in comparison with control [1]. Plant cells when exposed to the weak magnetic field have shown that the functional activity of genome at early pre-replicate period decreases [1]. The effect of magnetic-field treatment on plants have been studied by various researchers since the 19<sup>th</sup> century to enhance the germination rate, seedling vigour and growth at the later stages of plant development [2, 3]. Investigations of many authors show that the magnetic-field treatment of seeds increases the germination capacity, accelerates the seedling growth, protein's formation and root development [4].

### 5.2 Effect of magnetic field on water uptake and germination capacity of Chickpea seed

Chickpea (*Cicer arietinum* L.) is an important leguminous food crops in India. Globally, chickpea is the third most important pulse crop, next to dry beans and pea in production [5]. It is a good source of carbohydrates and protein where protein quality is considered to be better than other pulses. Chickpea has all the essential amino acids [6]. Chickpea in combination with other pulses and cereals has many potential health benefits. It could have beneficial effect on some important human diseases [6]. There are two types of chickpea, Desi and Kabuli [6]. The desi seed weight generally ranges from 0.1 to 0.3g and kabuli types from 0.2 to 0.6g [7]. The desi types of chickpea account for about 80-85% of the total Chickpea area (desi and kabuli) and is mostly grown in Asia and Africa [8]. There is a growing demand for chickpea due to its nutritional value and is an important component of the diets of those who cannot afford animal proteins or that who is vegetarian by choice. To improve the yield of this crop, recent advances in biotechnology such as plant tissue culture and genetic transformation, etc. have been used. To increase the crop production by using chemical inputs such as pesticides and insecticides has resulted in damage to the environment [9]. Considering these facts, it has become necessary to turn over other new methods and technologies to meet the demands of an ever-increasing population [10].

The seed water content as compared to its dry weight is measured at different time intervals. Figure (5.1) shows the continuous increase in water absorption with time for all field values (0.06, 0.11, 0.16 and 0.22 T) with 100 minute exposure at 15 °C.



**Figure 5.1:** Variation of absorbed seed water content with the imbibition time for magnetically treated seeds at different field intensities.

Water uptake curves are satisfying the equation  $w = C_1 \times \ln(t) \pm C_2$  with  $R^2 > 0.96$  (for all the curves), where  $w$  is the percentage of water uptake relative to seeds dry weight, and  $C_1$  is water uptake coefficient ( $w_{\text{control}} = 25.321\ln(t) - 17.367$  ( $R^2 = 0.9826$ ),  $w_{0.06T} = 25.246\ln(t) - 12$  ( $R^2 = 0.9792$ ),  $w_{0.11T} = 26.623\ln(x) - 17.675$  ( $R^2 = 0.9761$ ),  $w_{0.16T} = 25.493\ln(t) - 11.357$  ( $R^2 = 0.9792$ ),  $w_{0.22T} = 21.173\ln(t) + 14.748$  ( $R^2 = 0.9850$ )). Germinating data of Chickpea seeds is fitted well in Re-formulated Malthus-Verhulst equation (3.5)  $N_g(t) = N_k N_i / [N_i + (N_k - N_i) \exp \{-\alpha N_k (t - t_0)\}]$  for magnetic field 0.06, 0.11, 0.16 and 0.22 T with 100-minute exposure at 15 °C, is shown, in Figure 5.2a-e. Using Re-formulated Malthus-Verhulst, the germination rate-coefficient was determined ( $\alpha_{\text{control}} = 0.0014 \text{ h}^{-1}$ ,  $\alpha_{0.06T} = 0.0018 \text{ h}^{-1}$ ,  $\alpha_{0.11T} = 0.00185 \text{ h}^{-1}$ ,  $\alpha_{0.16T} = 0.0013 \text{ h}^{-1}$ ,  $\alpha_{0.22T} = 0.0013 \text{ h}^{-1}$ ) by minimizing the residual sum of squares and executing the best possible fit for the growth model for the data. Experimental data of un-germinated Chickpea seeds versus time is plotted along with the theoretical values which are calculated using the Re-formulated stochastic function (equation 3.21) for different values of magnetic-intensities and for 100-minute exposure at 15 °C (Figure 5.3a-e).

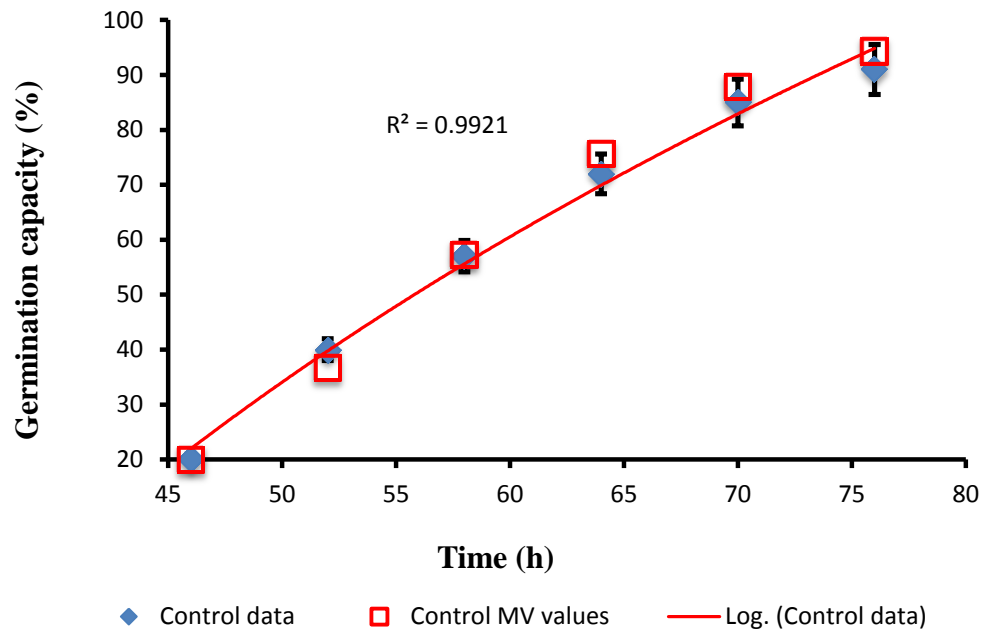


Figure 5.2a

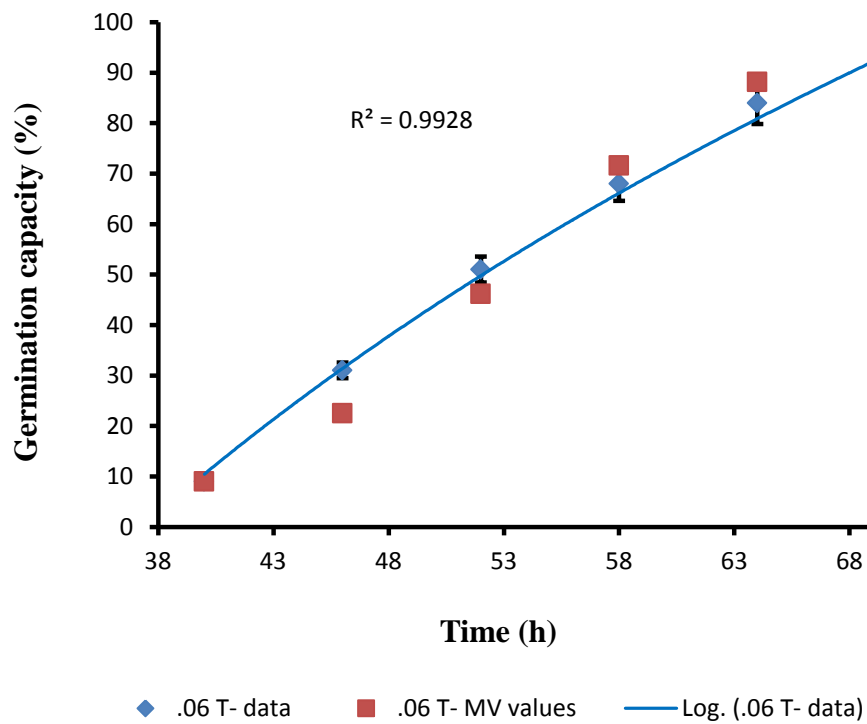


Figure 5.2b

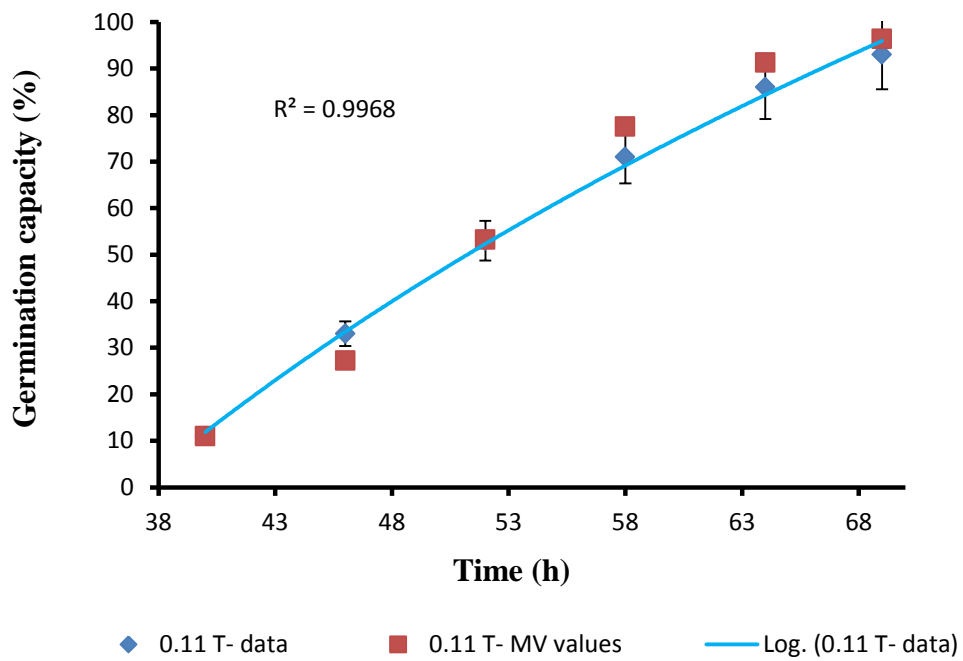


Figure 5.2c

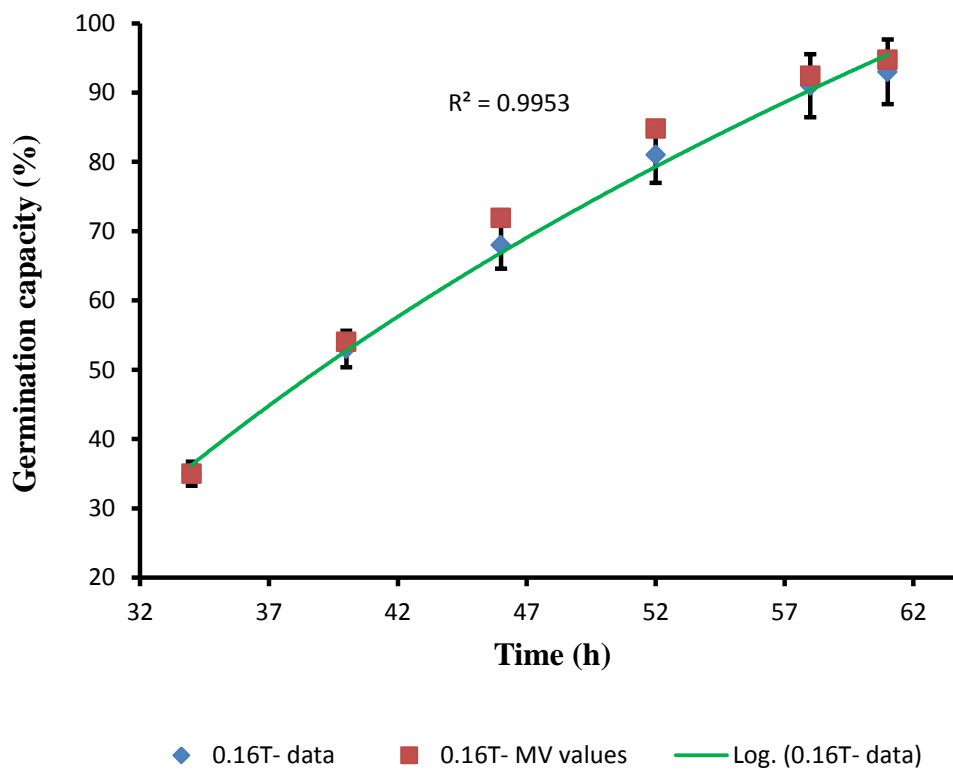


Figure 5.2d

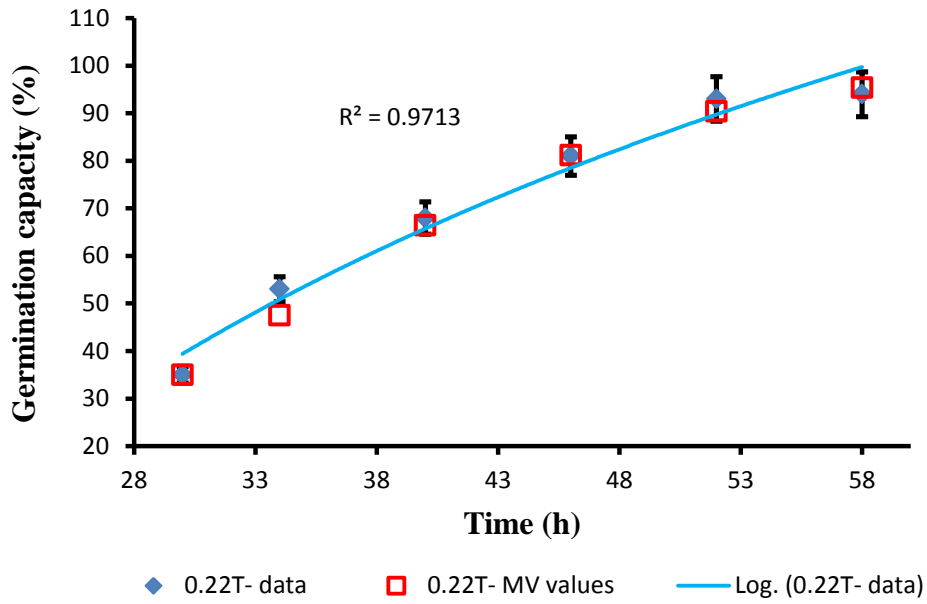


Figure 5.2e

**Figure 5.2(a-e):** Showing variation in germination growth capacity for magnetically treated seeds.

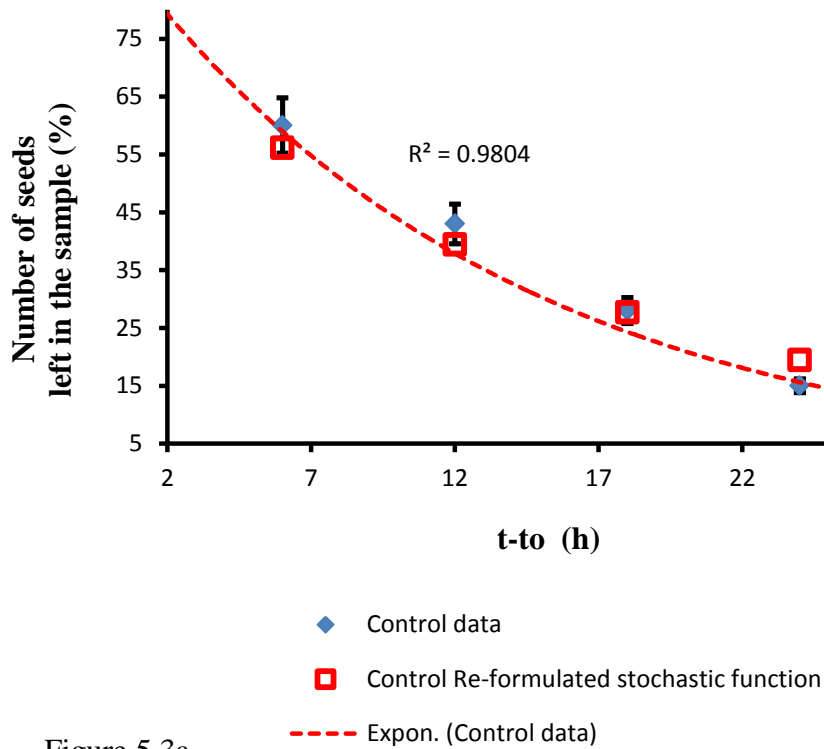
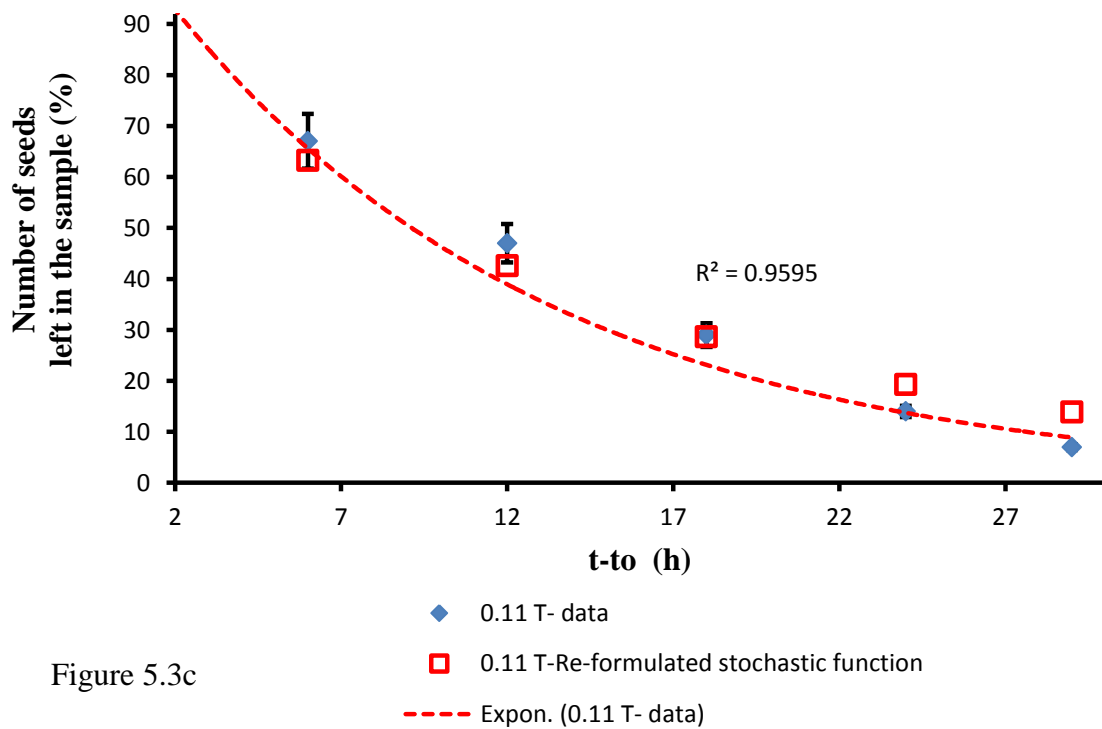
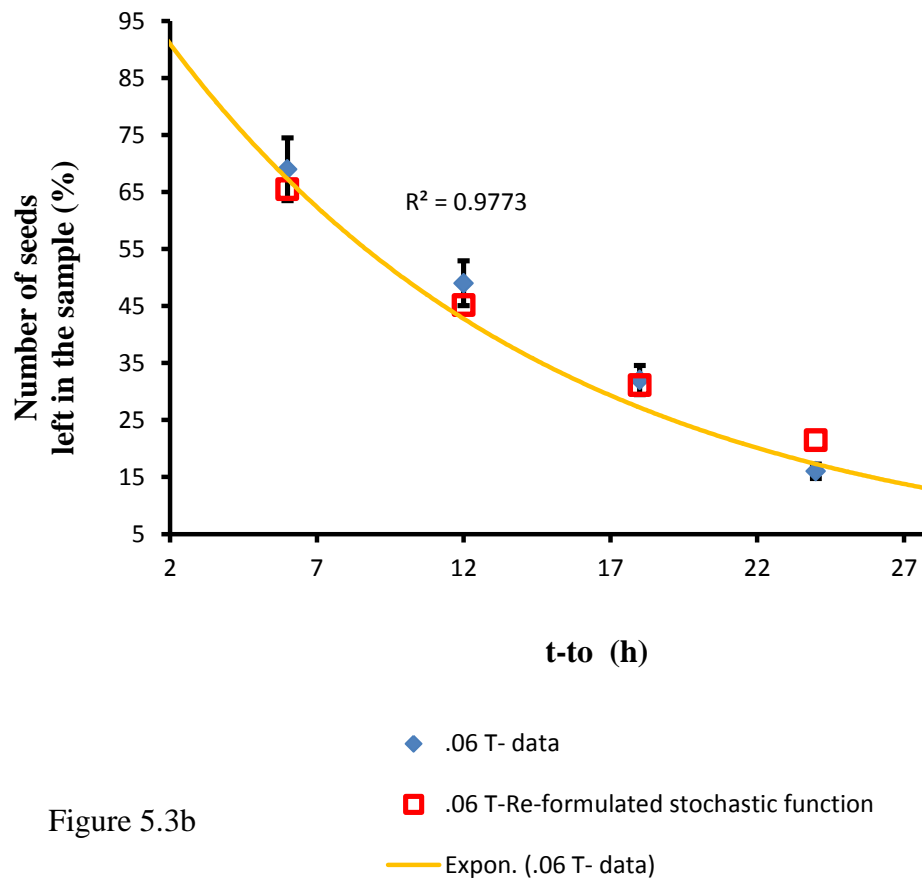


Figure 5.3a



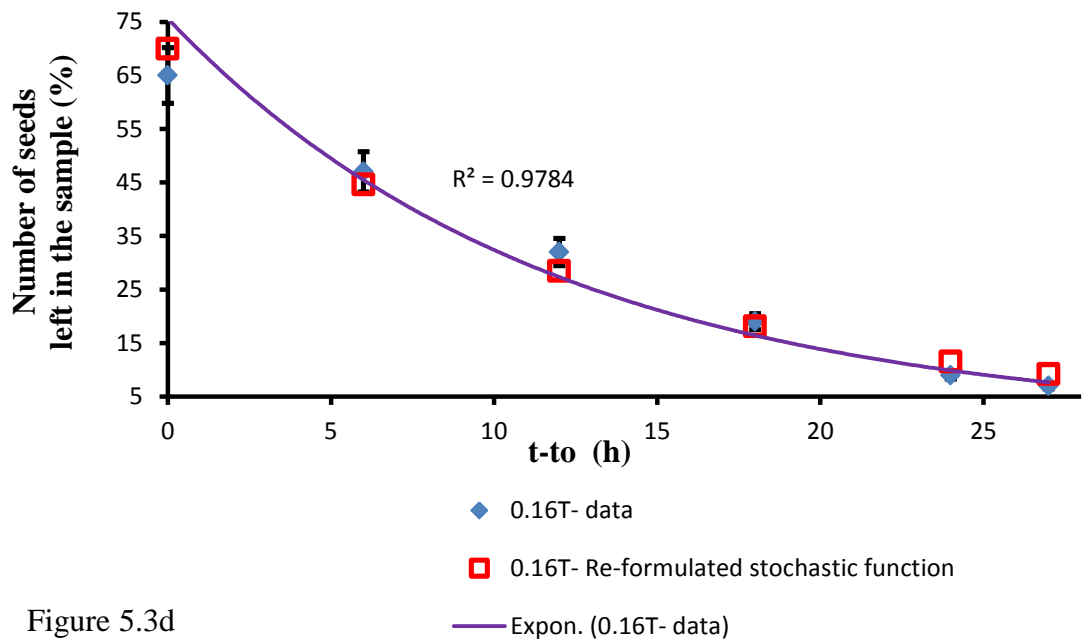


Figure 5.3d

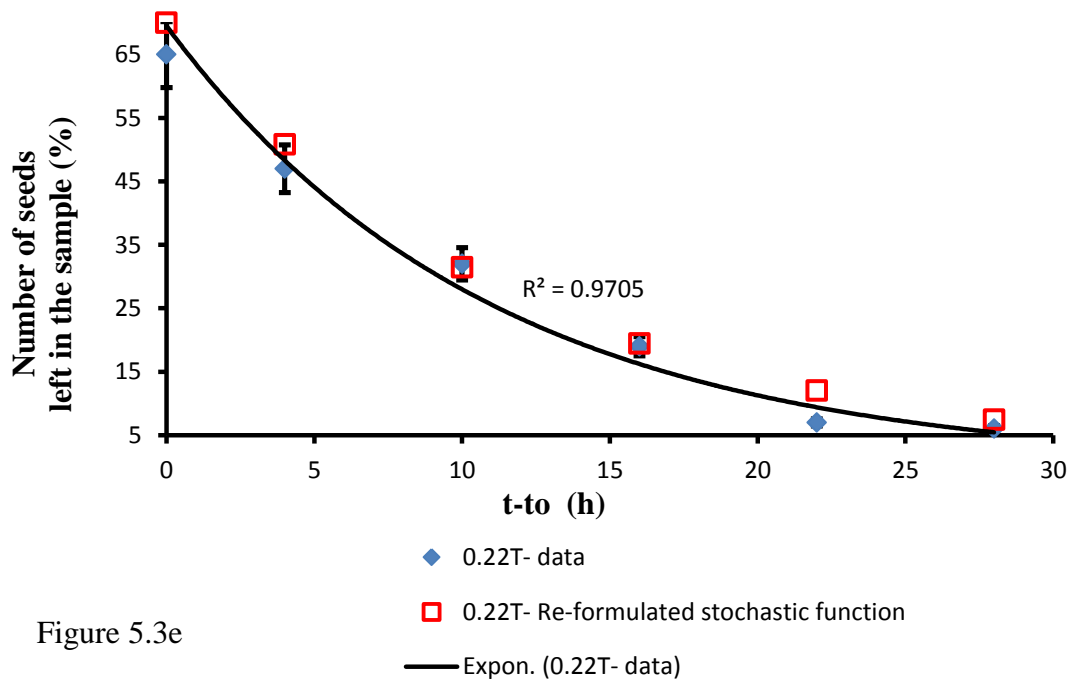
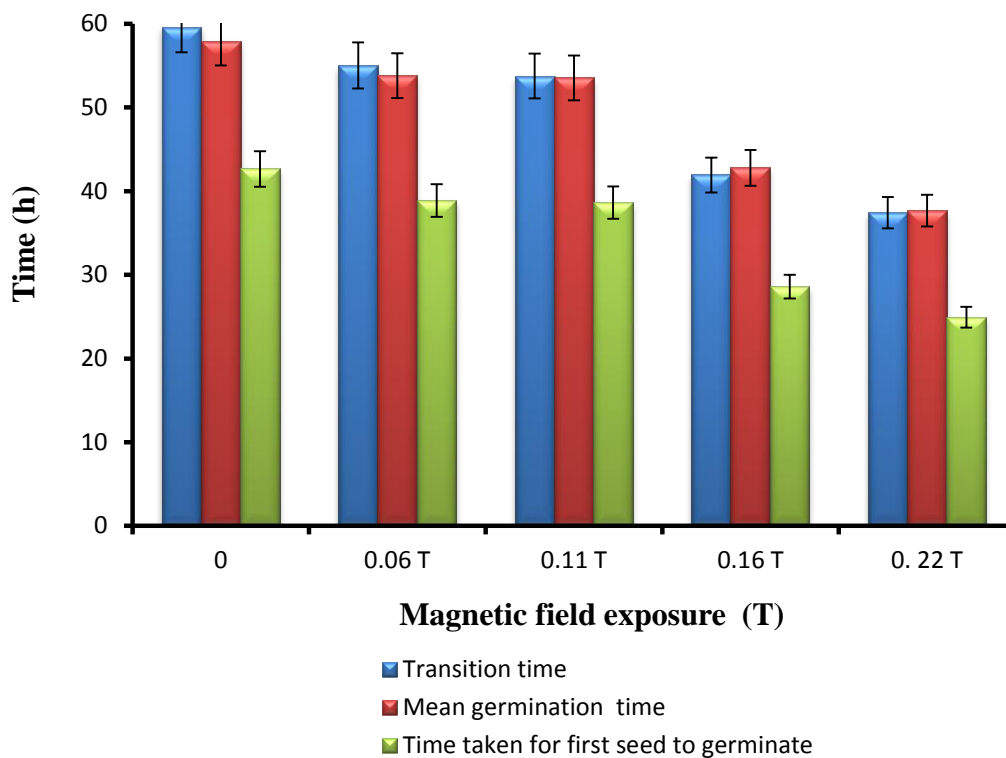


Figure 5.3e

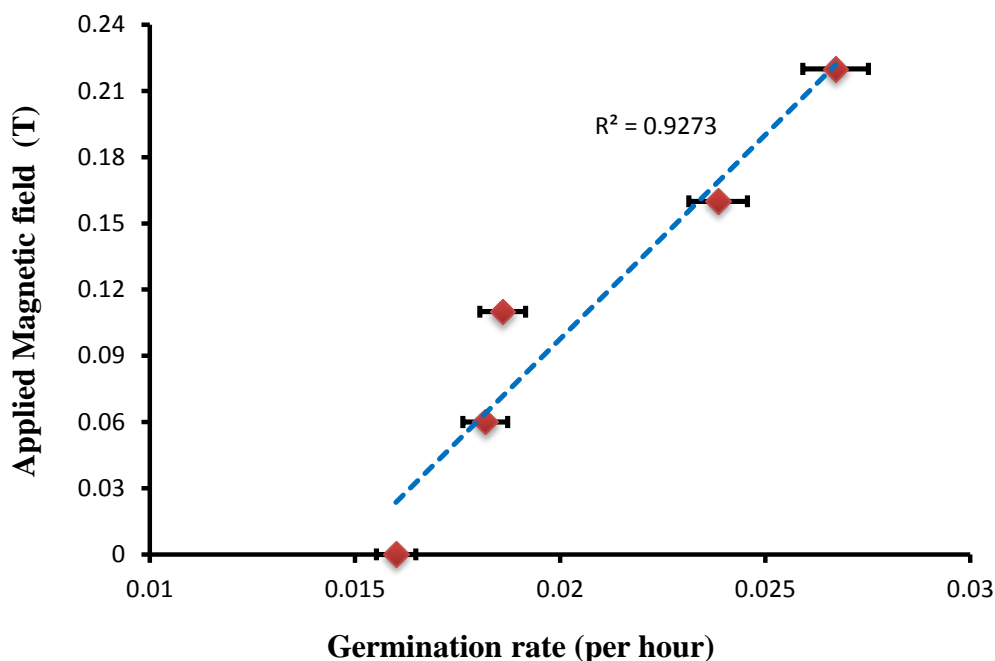
**Figure 5.3(a-e):** Variation of un-germinated seeds with time in the samples.

For each data field, a decaying exponential curve is obtained. Transition time, mean germination time and time taken for first seed to germinate ( $t_0$ ) for various magnetic-field values with 100-minute exposure at 15 °C is shown in Figure 5.4. The germination rate, which is the reciprocal of the transition time (Figure. 5.5), increases linearly with the applied magnetic field given by the equation:  $B = 18.515g(r) - 0.272$ . The magnetic-time constant is calculated as 18.515 Th (tesla hours).



**Figure 5.4:** Variation in the mean germination time, transition time and time taken for the first seed to germinate for the magnetically treated seeds.

Seed germination process is a tri-phasic process. In Phase I, there is rapid initial water uptake. In phase II, there is a plateau phase with little change in water content followed by phase III where an increase in water content coincident with shoot growth occurs (Figure 5.1). Experimental data shows that chickpea seeds soaked more water when they were treated with magnetic field. The experimental data as shown in Figure 5.1 shows that Chickpea seeds fitted well in the equation  $w = C_1 \times \ln(t) \pm C_2$  where  $w$  is seed water content (%) (g water/g dry wt) and justified our proposed water uptake model (equation 3.18). Germinating data of Chickpea seeds (Figure 5.2)



**Figure 5.5 :** Shows that mean germination rate of Chickpea seeds that increases linearly with magnetic field and follows the equation  $B = 18.51 g(r) - 0.272$ .

shows that Chickpea seeds fitted well in the equation  $w = C_1 \times \ln(t) \pm C_2$  where  $w$  is seed water content (%) (g water/g dry wt) and justified our proposed water uptake model (equation 3.18). Germinating data of Chickpea seeds (Figure 5.2) treated with variable magnetic-field and with varying time-exposures fitted well in Re-formulated Malthus-Verhulst equation (equation 3.5)  $N_g(t) = N_k N_i / [N_i + (N_k - N_i) \exp \{-\alpha N_k (t - t_0)\}]$ . It is clear from Figure 5.2 that germination capacity increases with increasing intensity of magnetic field. Pietruszewski and Kania [11] determined germination rate coefficient ( $\alpha_c = .005155$ ,  $\alpha_{D11} = .007625$ ,  $\alpha_{D13} = .007625$ ,  $\alpha_{D21} = .007085$ ,  $\alpha_{D23} = .005855$  for treated wheat seeds with magnetic field at 45mT and 30 mT for different time intervals (for magnetic doses: D11=D13= 12.9 and D21=D23=17.9 kJ m<sup>-3</sup>). On the basis of germination rate- coefficient, Pietruszewski and Kania [11] have shown that higher dose rate i.e. D23 gives higher crop yield and lesser dose rate, i.e. D11 gives lesser yield of the crops. In the present case for time-exposure of magnetic field,  $\alpha$  values are improved from 0 to 0.11 T whereas at higher level of magnetic field a decreasing trend is obtained in  $\alpha$  values. Apparently, it seems that  $\alpha$  values do not signify the definite result, but these values become important for taking its reciprocal  $(K/\alpha) + t_0$ , where  $K$  is some fractional constant. A simple approach to Stochastic model is formulated and verified experimentally (Equation 3.21, Figure 5.3). This model generates a new constant called germinating magnetic constant  $\lambda_{B,T}$ . The germinating magnetic constant

$\lambda_{B,T}$  is important to the sense that it signifies to transition time (by taking its reciprocal and adding in it the initial time of germination (transition time =  $(1/\lambda_{B,T}) + t_0$ ). Transition time is that time during which seed undergoes a transition from un-germinated to germinated state. The trend of the variation in transition time matched well with the trend of variation in mean germination time (Figure 5.4). According to Tseng [12] seed germination process passes through a number of states. Presently, it has been proved theoretically and verified experimentally that there are only two states un-germinated and germinated; transition takes place only in between these two states (Figure 5.4).

Comparative analysis on the hydration pattern showed that when Chickpea seeds are exposed to static magnetic fields of 100 mT for 1 h [13], water uptake was more in phase II and III in magnetically exposed seeds compared to unexposed seeds. If the seeds of chickpea were exposed in batches to static magnetic fields of strength varying from 0 to 250 mT in steps of 50 mT for 1–4 h [14], then results showed that magnetic field enhanced the seed performance like speed of germination, seedling length and seedling dry weight as compared to unexposed control seeds. Among the various combinations of field strength and duration, 50 mT for 2 h, 100 mT for 1 h and 150 mT for 2 h exposures gave best results[14]. The effects of magnetic treatment of irrigation water on snow and Kabuli chickpea were investigated under glasshouse conditions [15]. The results of this study suggest that both magnetic treatment of irrigation water and magnetic treatment of seeds have the potential to improve the early seedling growth and nutrient contents of seedlings.

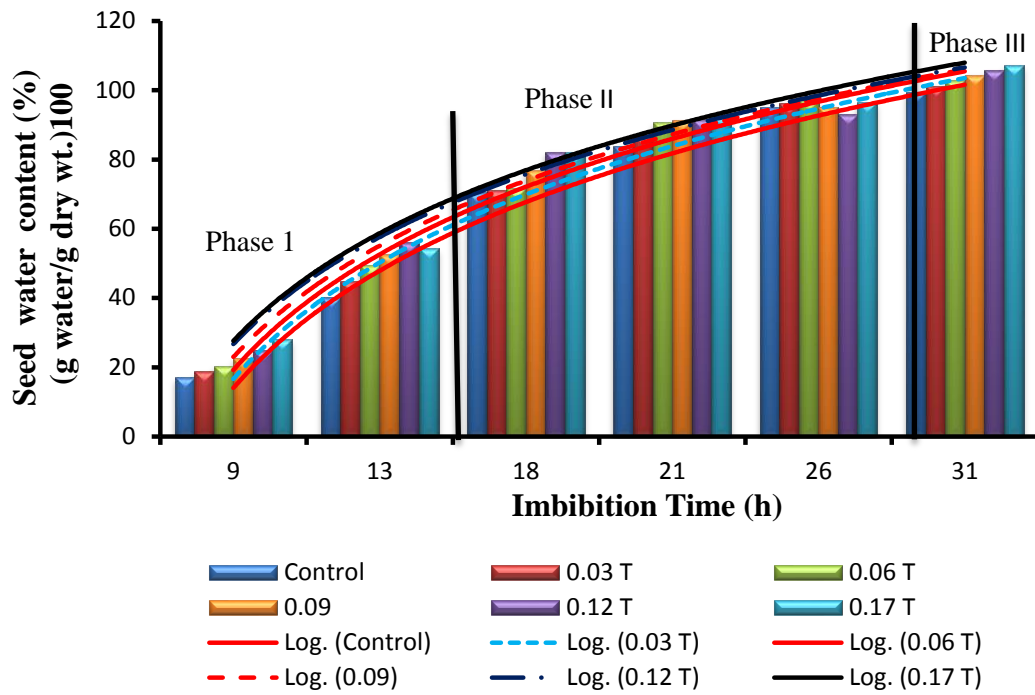
In the present case, it is found that there is continuous improvement in germination time and germination rate with increasing intensity of the magnetic field. There is great improvement in mean germination time, transition time with magnetic treatment (Figure 5.4). Mahajan and Pandey [16, 17] formulated the Magnetic-time model and showed that this model worked well for *Cicer arietinum* L. seeds [16] and *Vigna radiate* seeds (in off season i.e. at 13 °C [17]. Present data (Figure 5.5) proved that magnetic-time model fits to magnetically treated chickpea (*Cicer arietinum* L.) seeds in laboratory conditions at constant temperature of 15 °C. Germinating data showed a linear relation between applied magnetic field and germination rate ( $B = 18.515 \times g(r) - 0.272$ ). Comparing this equation with magnetic time model equation (3.11), magnetic time constant  $\theta_B$  is calculated, which is 18.51 Th (Tehsla-hour). Lesser value of  $\theta_B$  shows the enhanced effect of magnetic field on the germination of Chickpea seed in laboratory conditions.

The exact mechanism behind the effect of static magnetic field (SMF) on living organisms is still unclear. Many explanations were given by the researchers. It has been reported that external magnetic field influences both the activation of ions and polarization of dipoles in living cells [18]. Presently, it is clear that magnetic field influences the water uptake and germination capacity. It is possible that some metal ions may be present within the seed protein which retains the magnetism even after removal of the magnetic field and causes an increase in the water uptake and hence germination capacity.

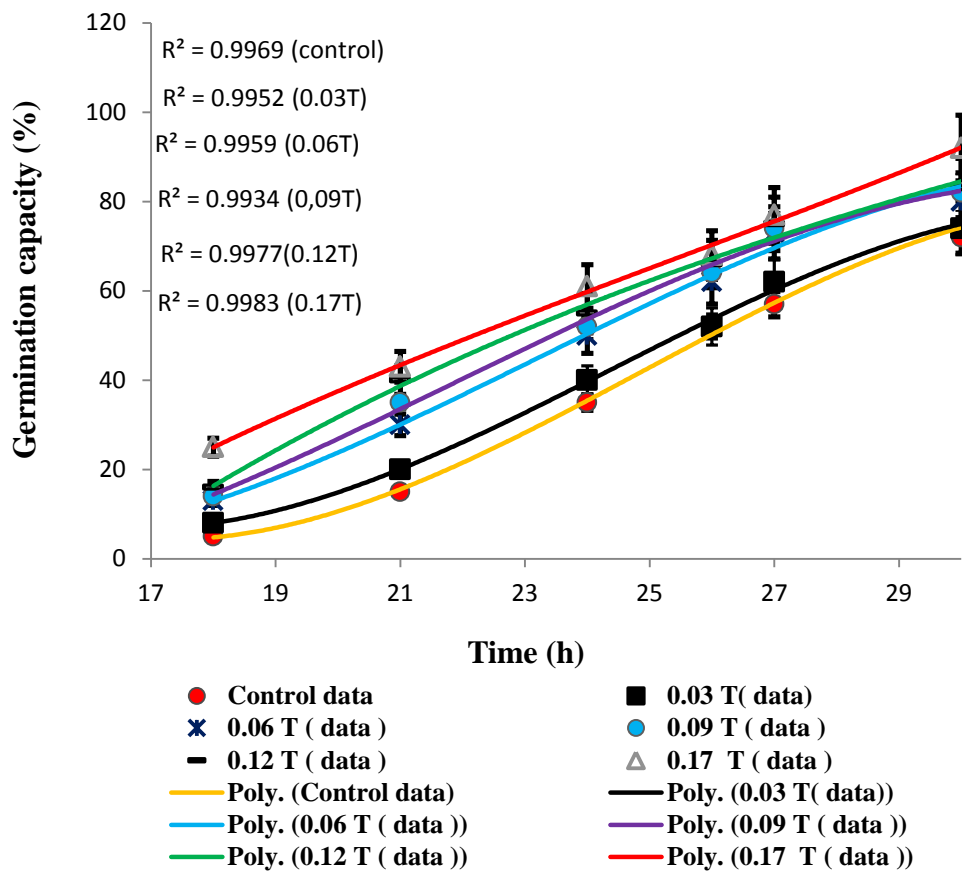
### **5.3 Effect of magnetic field on water uptake and germination capacity of Mung (*Vigna radiata*) seed**

A large section of the poor, particularly women and children of the developing world is facing the problem of persistent hunger and suffering from under-nutrition condition because of widespread poverty. The people of the poor section fulfil major part of protein from cereal grains and pulses. Mung (*Vigna radiata*) is a good supplement having high nutritional value and is commonly consumed pulse in India. To fulfil the growing demand of *Vigna radiata*, one has to adopt some methods other than using pesticides and synthetic fertilizers to increase the production of Mung. One of the promising techniques is treating the *Vigna radiata* with magnetic field before sowing. Mahajan and Pandey [19] worked on *Vigna radiata* by treating it with magnetic field in off season (13 °C) and showed a small enhanced effect on the germination of *Vigna radiata* seed. In order to increase the production of *Vigna radiata* in the best season of its germination, the current work is undertaken where the combined effect of magnetic field and temperature that varies from 26 and 30 °C have been studied. A simple statistical approach (a slightly different from the Stochastic model) is presented, which proves that germinating process is a two-state process and not a multistate process as was assumed in the Stochastic model. When transition takes place from non-germinating to germinating state, mean transition time is calculated. The transition time helps to understand the effect of magnetic field on the germination of *Vigna radiata* seeds. The experiment was performed in India at Khalsa College, Physics laboratory, Patiala, Punjab on 12<sup>th</sup> to 16 May 2013. For the current study, *Vigna radiata* varietie SML 668 seeds was taken as it is very stable and provide higher yield with early maturity. Moreover, this variety is tolerant of yellow mosaic virus (MYMV). In the present research, this variety was treated with magnetic field of 30, 60, 90, 120 and 170 mT at 30 °C. The seed water content as compared to its dry weight is measured at different time intervals. Figure 5.6 shows the continuous increase in water absorption for

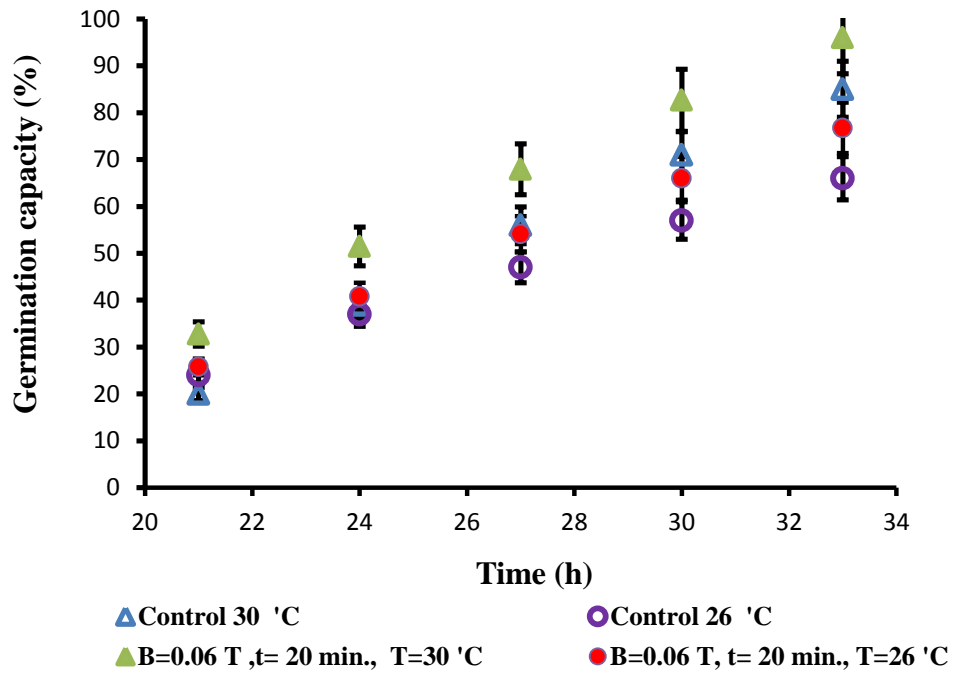
30, 60, 90, 120 and 170 mT field values with 20-minute exposure at 30 °C, satisfying the equation  $w = C_1 \times \ln(t) \pm C_2$  with  $R^2 > 0.99$  for all the curves where  $w$  is the percentage of water uptake relative to seeds dry weight, and  $C_1$  is water uptake coefficient. Germinating data of *Vigna radiata* seed is fitted well in polynomial equations of third order ( $G_c = -0.0434t^3 + 3.2399t^2 - 73.132t + 524.67$ ,  $G_{0.03T} = -0.0409t^3 + 2.9946t^2 - 66.023t + 464.63$ ,  $G_{0.06T} = -0.0266t^3 + 1.8539t^2 - 36.178t + 218.63$ ,  $G_{0.09T} = -0.0226t^3 + 1.478t^2 - 25.485t + 125.83$ ,  $G_{0.12T} = 0.0052t^3 - 0.5533t^2 + 23.117t - 250.69$  and  $G_{0.17T} = 0.0085t^3 - 0.6465t^2 + 21.653t - 204.85$  for magnetic field of 0.03T, 0.09T, 0.12T and 0.17T with 20-minute exposure at 30 °C and is shown in Figure 5.7. Combined effect of magnetic field and temperature on germination capacity is shown in Figure 5.8. Both physical quantities i.e. magnetic field and temperature results in improvement in germination capacity. Experimental data of un-germinated *Vigna radiata* seed versus time is plotted along with the theoretical values calculated using the Re-formulated Stochastic function. It is of exponential nature:  $N = (N_k - N_i) \exp(-(t - t_0))$  for different values of magnetic-intensity for 20-minute exposure at 30 °C and is shown in Figure 5.9. For each data field, a decaying exponential curve is obtained. Transition time, mean germination time and time taken for first seed to germinate for various magnetic-field values with 20-minute exposure at 30 °C is shown in Figure 5.10 respectively. Seed germination process begins with imbibition of water. Imbibition is a tri-phasic process. In Phase I (Figure 5.6), there is rapid initial water uptake. In phase II, there is a plateau with little change in water content followed by an increase in water content coincident with shoot growth (phase III). The data shows that water uptake by the seed can be increased by increasing the intensity of the magnetic field keeping temperature and time-exposure constant. The present experimental data fitted well in the water model equation 3.18,  $w = C_1 \times \ln(t) \pm C_2$  where  $w$  is seed water content (%) (g water/g dry wt). Germinating data of *Vigna radiata* seeds treated with variable magnetic-field and fitted well in polynomial equation of 3<sup>rd</sup> order is shown in Figure 5.7. It shows that germination capacity increases with increasing intensity of magnetic field. A simple approach to Stochastic model is formulated and verified experimentally as given in equation 3.21 and Figure 5.9. This model generates a new constant called germinating magnetic constant  $\lambda_{B,T}$ .



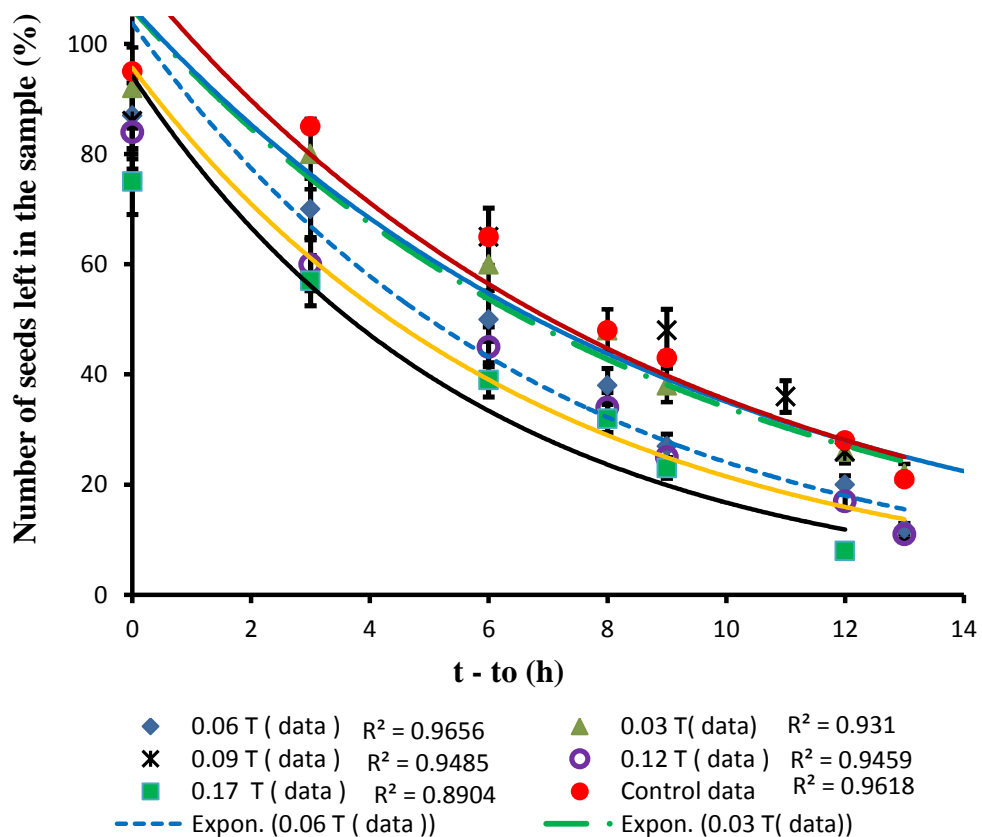
**Figure 5.6:** Variation of absorbed seed water content with the imbibition time for magnetically treated seeds at different field intensities.



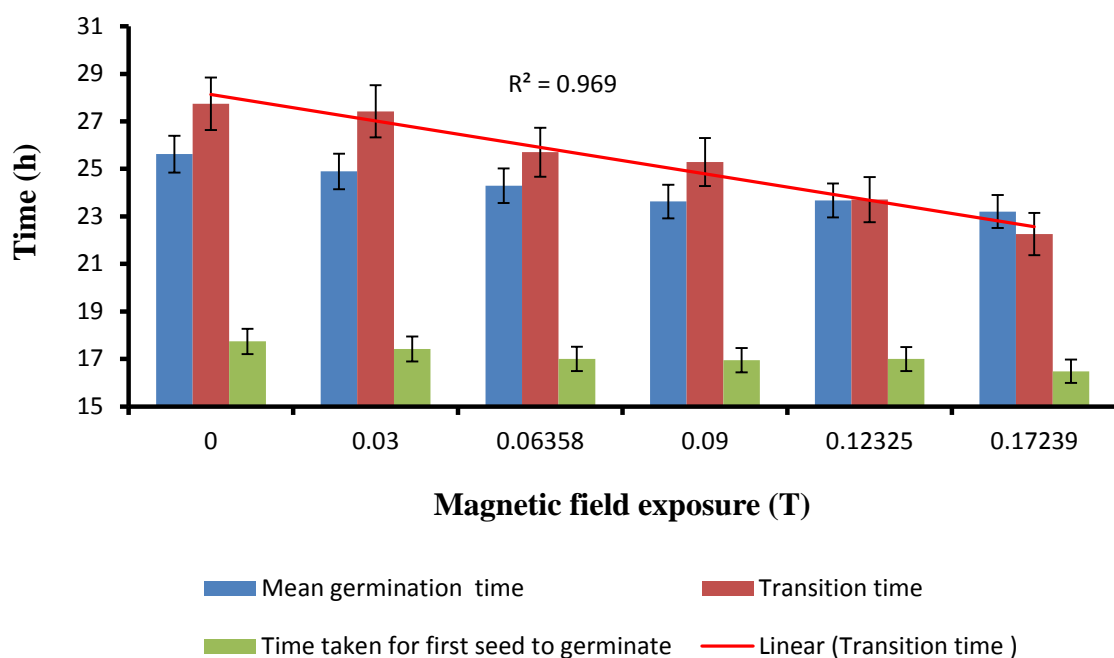
**Figure 5.7:** Showing variation in germination growth capacity for magnetically treated seeds.



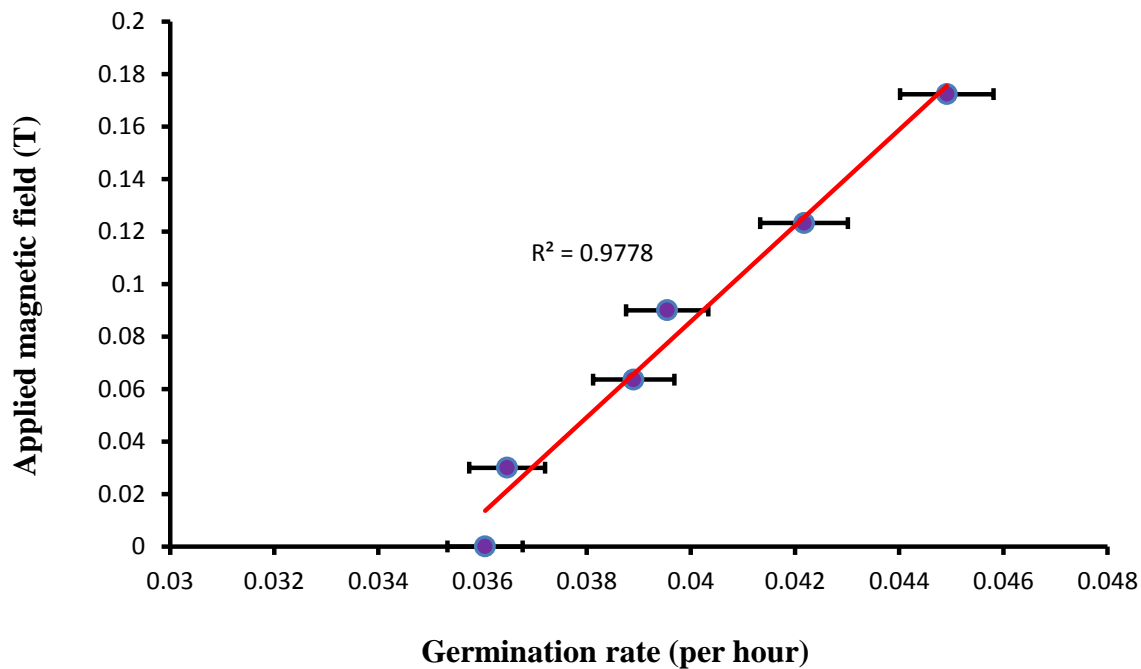
**Figure 5.8:** The graph shows the combined effect of magnetic field and temperature on germination capacity.



**Figure 5.9:** Variation of un-germinated seeds with time in the samples.



**Figure 5.10:** Variation in the mean germination time, transition time and time taken for the first seed to germinate for the magnetically treated seeds.



**Figure 5.11:** Shows that mean germination rate of Mung seeds increases linearly with magnetic field and follows the equation  $B = 18.25g(r) - 0.6443$ .

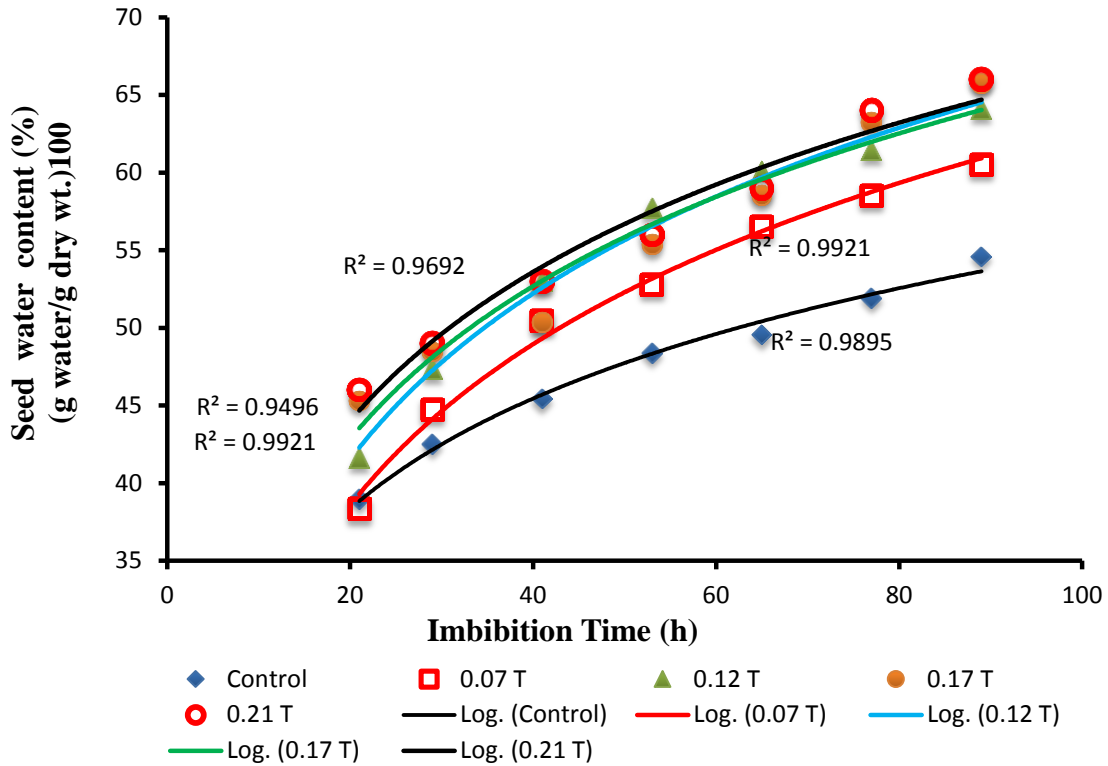
The germinating magnetic constant  $\lambda_{B,T}$  is important to the sense that it signifies to transition time by taking its reciprocal and adding in it the initial time of germination (transition time =  $(1/\lambda_{B,T}) + t_0$ ). Transition time is that time during which seed undergoes a transition from un-germinated to germinated state. The trend of the variation in transition time matched with the trend of variation in mean germination time as shown in Figure 5.10. According to Tseng [12] seed germination process passes through a number of states. Presently, it has been proved theoretically and verified experimentally that there are only two states un-germinated and germinated; transition takes place only in between these two states (Figure 5.9). There is an improvement in mean germination time, transition time and time taken for first seed to germinate with magnetic treatment by increasing the intensity of magnetic field (Figure 5.10). Mahajan and Pandey [16] formulated the Magnetic-time model and showed that this model worked well for *Cicer arietinum* L. seeds and *Vigna radiata* seeds (in off season i.e. at 13 °C) [19]. Figure (5.8) shows that germination capacity can be increased either by increasing temperature or by increasing intensity of magnetic field. Present data shown in Figure 5.11 proved that magnetic-time model fits to magnetically treated *vigna radiata* seeds in its best season of germination (SML 668 varieties of *Vigna radiata* seeds at 30 °C). Germinating data showed a linear relation between applied magnetic field and germination rate ( $B = 18.253 \times g(r) - 0.6443$ ). Comparing this equation with magnetic time model equation 3.11, magnetic time constant  $\theta_B$  is calculated, which is 18.25 Th. Lesser value of  $\theta_B$  shows the better effect of magnetic field upon the germination of *Vigna radiata* seed in its best season of germination.

The role of magnetic fields and their influence on functioning of biological organisms are still a matter of study [1]. Many explanations have been given for it. The forces induced by magnetic fields may affect the process that can change the rate of movement of electrons significantly [20]. An optimal external electromagnetic field could accelerate the activation of plant growth and seed germination [21, 22]. Presently, it is clear that magnetic field influences the water uptake and germination capacity.

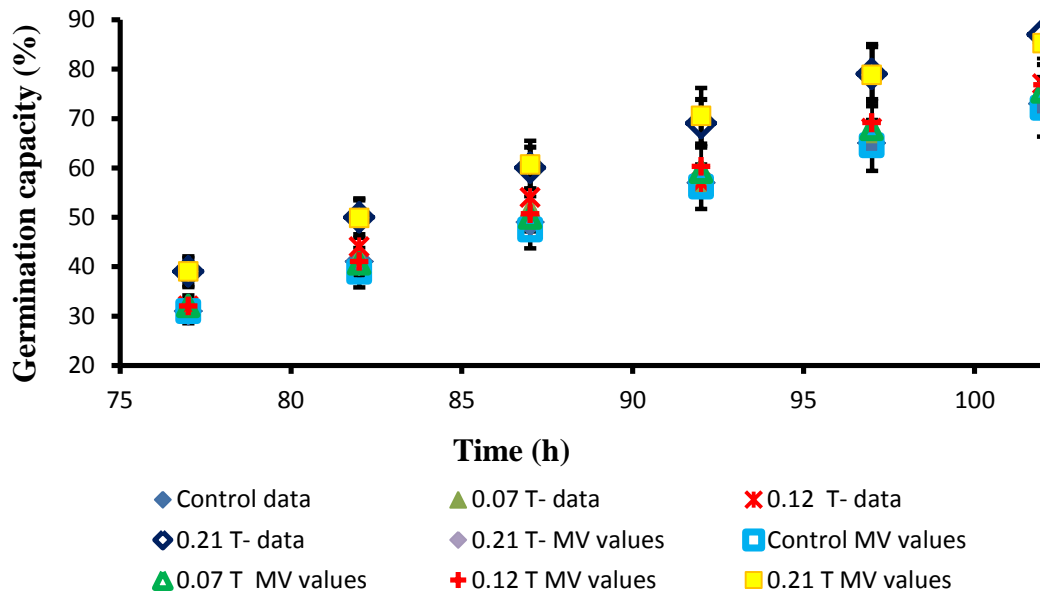
#### **5.4 Effect of Magnetic Treatments On Bitter Gourd (*Momordica Charantia*) Seed**

*Momordica charantia*, also known as bitter gourd, bitter melon and Karela, belongs to the Cucurbitaceae family and is commonly consumed as a food (bitter flavouring) in India. It has been traditionally used to treat diabetes [23]. The bitter gourd variety of *Momordica charantia*

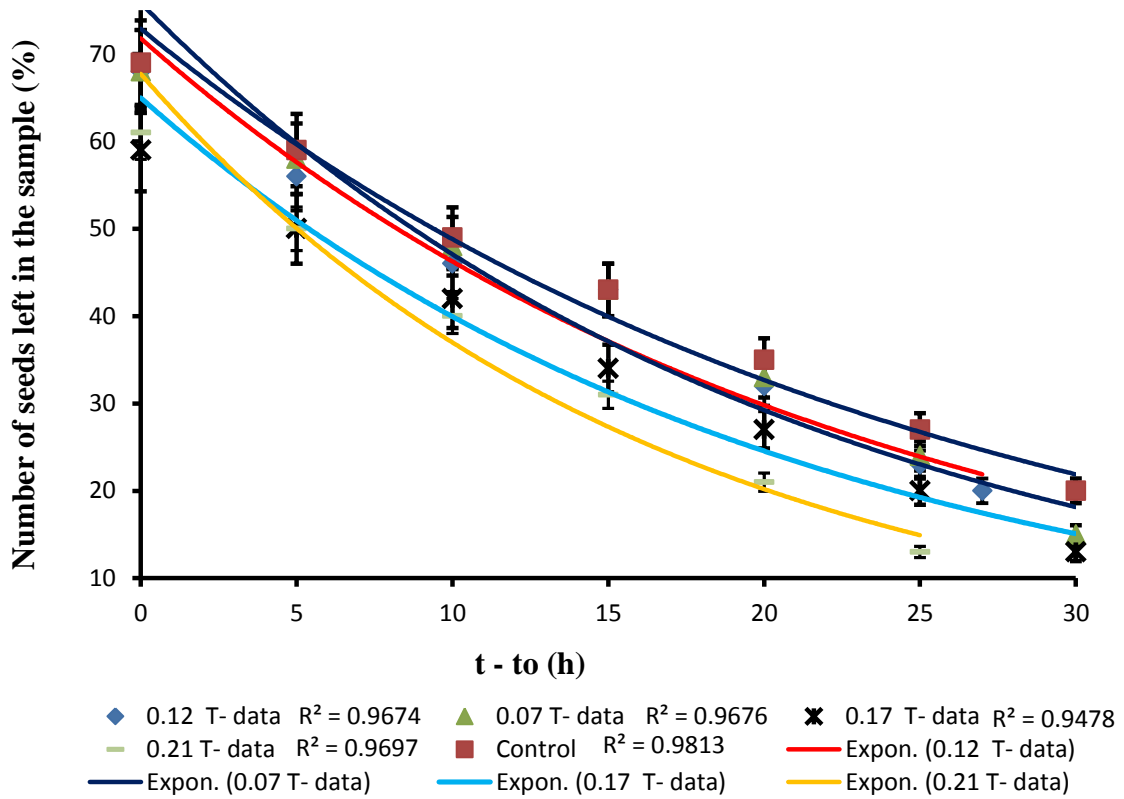
was used to study the effects of magnetic fields on the seed germination parameters. The optimal germination temperature for this variety is 24–27 °C. Three replications of a set of four samples (each sample comprising 40 seeds at 27 °C) were treated with magnetic field of 0.07, 0.12, 0.17 and 0.21 T for 20 minutes. As shown in Figure 5.12 there is an increase in water absorption with an increasing magnetic field. It follows the equation  $w = C_1 \times \ln(t) \pm C_2$ , with  $R^2 > 0.94$  for all curves where  $w$  is the percentage of water uptake by the *Momordica charantia* seeds relative to the dry seed weight and  $C_1$  is the water uptake coefficient. The highest absorption is observed at 0.21 T, as given by the following equations:  $W_{\text{control}} = 10.25 \ln(t) + 7.6401$  ( $R^2 = 0.9895$ ),  $W_{0.21 \text{ T}} = 13.864 \ln(t) + 2.466$  ( $R^2 = 0.9692$ ). The experimental data shown in Figure 5.13 fit well in the re-formulated Malthus-Verhulst equation,  $N_g(t) = N_k N_i / [N_i + (N_k - N_i) \exp\{-\alpha N_k (t - t_0)\}]$ , showing an increasing trend in the germination with an increasing magnetic field. The remaining number of seeds in the sample at any time  $t$  of the exposed lot of seeds fit well in the Stochastic model,  $E[M_1(t)] = M_0 \exp(-\lambda_1 t)$ , for a two-state germinating process. Figure 5.14 supports that seed germination is a two-state process. Conversion from the un-germinated to the germinated state depends on the transition time. The mean germination time, transition time and time taken for the first seed to germinate is slightly improved by the application of a magnetic field, showing a linear trend (Figure 5.15) that further supports the magnetic time model. Aladjadjiyan [24] showed that seeds exhibit paramagnetic behaviour. The magnetic moments of seed particles in an external magnetic-field orient themselves in the direction of the applied field. The impact of the magnetic field on the seeds results in an increase in their energy [24]. This distribution of energy among the seed particles accelerates the metabolism, consequently resulting in better germination. Bathnagar and Deb [25] showed that the coefficient of velocity of germination and the germination capacity are linear functions of the magnetic field. Mahajan and Pandey[16] formulated the magnetic-time model ( $B + H_g = \theta_B g_r$ ) (equation 3.11) and experimentally verified that the germination rate ( $g_r$ ) for a given seed fraction or percentage is a linear function of  $B$  above  $H_g$ , where  $H_g$  is the base value in the units of the magnetic field. *Momordica charantia* supported this model and follows the equation,  $B = 174.02g(r) - 1.815$  (Figure 5.16). The germination rate, which is the reciprocal of the transition time, increases linearly with the applied magnetic field, as given by the following equation:  $B = 174.02g(r) - 1.815$ .



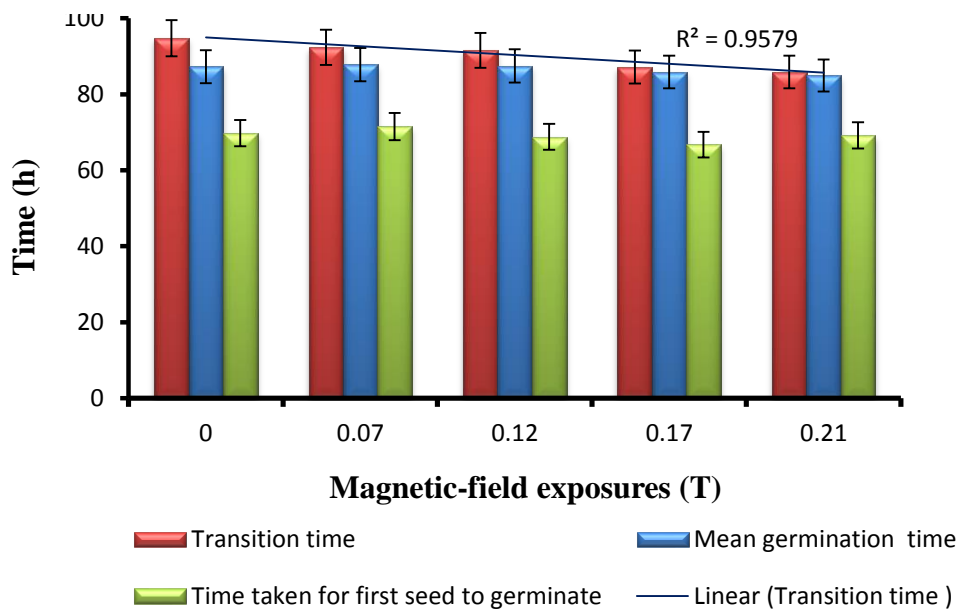
**Figure 5.12:** Variation of absorbed seed water content with the imbibition time for magnetically treated seeds at different field intensities.



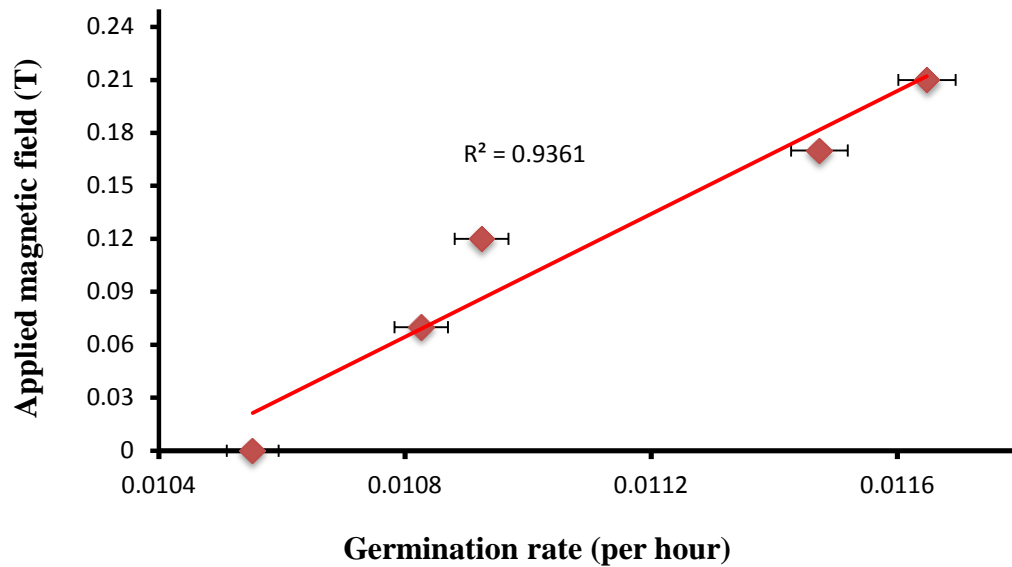
**Figure 5.13:** Showing variation in germination growth capacity for magnetically treated seeds.



**Figure 5.14:** Variation of un-germinated seeds with time in the samples.

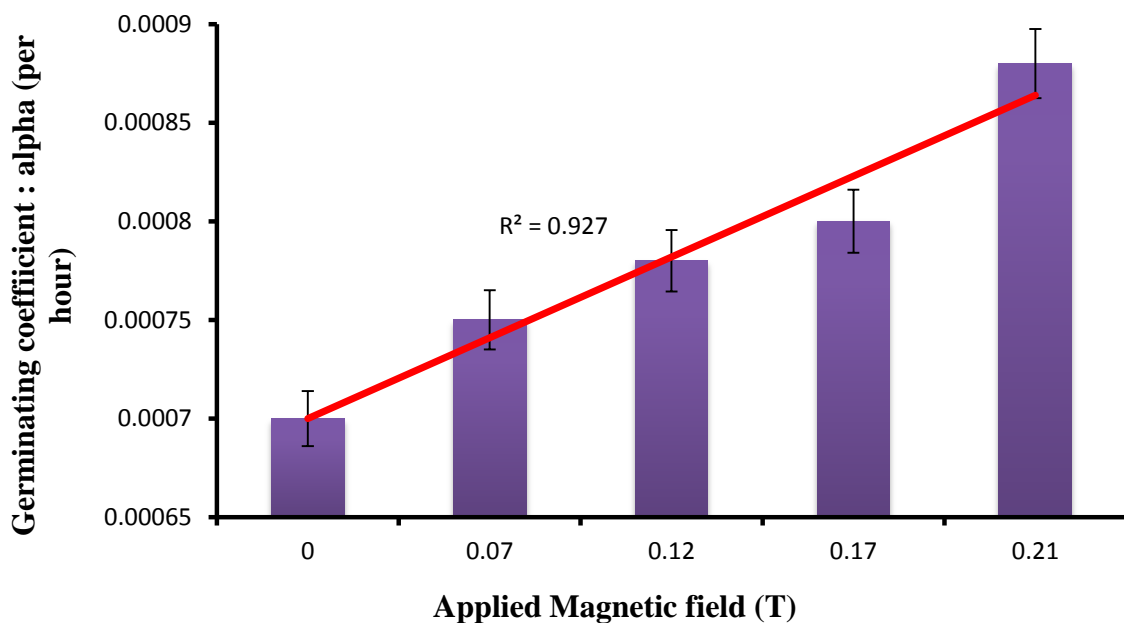


**Figure 5.15:** Variation in the mean germination time, transition time and time taken for the first seed to germinate for the magnetically treated seeds.



**Figure 5.16:** Shows that mean germination rate of Mung seeds increases linearly with magnetic field and follows the equation  $B = 174.02g(r) - 1.815$ .

The *Momordica charantia* seed results as shown in Figure 5.16 further support the magnetic time model [16]. The magnetic-time constant and  $H_g$  are 174.02 Th and 1.815 T, respectively. A high value of the magnetic-time constant signifies a reduced effect of the magnetic field on *Momordica charantia* germination. Aladjadjiyan [22] worked on tobacco seeds (*Nicotiana tabacum* L.) by treating them with a magnetic field of 0.15 T for 10, 20 and



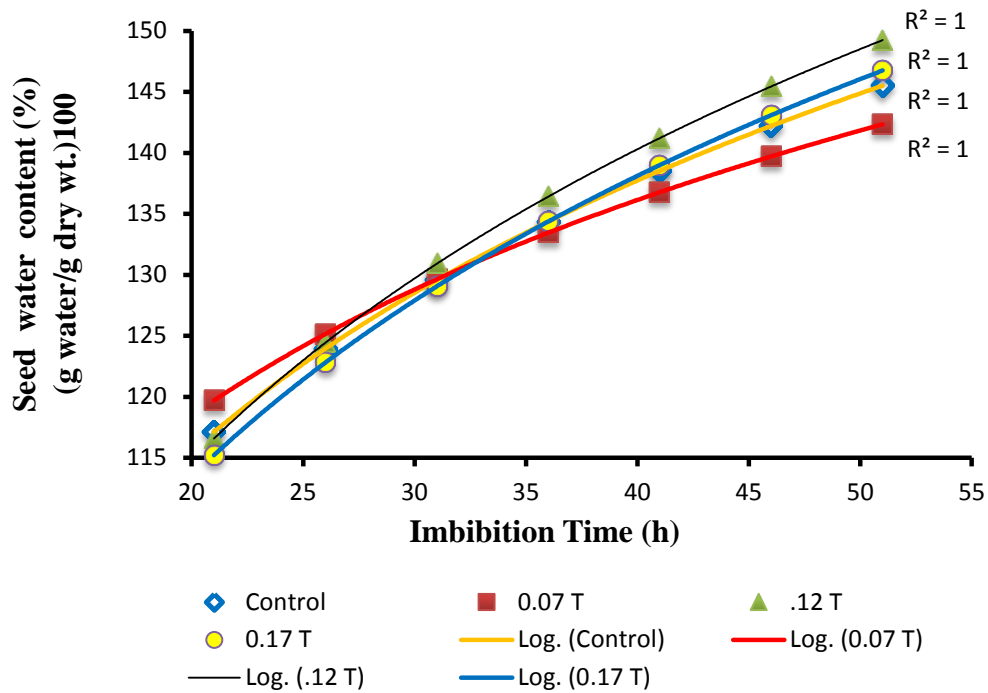
**Figure 5.17:** Variation of germinating coefficient with magnetic field.

30-minute exposures and found a linear increase in the germination capacity (G) with increasing exposure time, as given by the equation's  $G = 0.088t + 0.215$  and  $G = 0.0745t + 0.3$  for non-soaked and preliminarily soaked seeds, respectively. Aladjadjiyan [22] explained that the magnetically treated seeds stimulate the process of germination because mitochondria possess paramagnetic properties (similar to those found in chloroplasts). Using the reformulated Malthus-Verhulst equation, the germinating coefficients are calculated for the magnetically treated seeds. There is almost a linear increase in the value of the germinating coefficient with the applied magnetic fields (Figure 5.17). The exact mechanism of the static magnetic field (SMF) on living organisms is still unclear. Sharaf El-Deen [26] showed that nutrition value could be enhanced by MF treatment. Magnetic-field pre-treatment of seeds was reported to increased lipid oxidation and ascorbic acid contents in cucumber (*Cucumis sativus*) [27]. Presently, it is clear that magnetic field influences the water uptake and germination capacity.

### 5.5 Effect of Magnetic Treatments on Ash Gourd (*Benincasa hispida*) Seed

The white gourd also called as winter melon, winter gourd, or ash gourd, is eaten like a vegetable. It is the only member of the genus *Benincasa*. In India, it is called petha. The plant resembles with pumpkin [28]. The static and variable magnetic fields treatments before sowing has shown a progressive effect on the germination yield, growth speed and germination rate [16, 17, 29-32]. However, the detail study on low field treatment has not been done systematically. Ash gourd, a medicinal plant, is studied here to explore its behaviour in the presence of static magnetic fields. Hybrid variety *Pumpkin VNR P-6* of Ash's gourd is used for the present research. Seeds are obtained from VNR Seeds Pvt. Ltd. Ratnagiri arcade, first floor, opp. Rajkumar college, Raipur, 492001, India. The experiment has been performed on 30<sup>th</sup> May 2013 at constant temperature of 30 °C. For magnetic treatments, three replications of a set of four samples (each sample comprising 40 seeds at 30 °C) were placed in the plastic container to expose to a magnetic field of 0.07, 0.12 and 0.17 T for 20 minutes between the pole pieces of the electromagnet. Magnetically treated seeds have shown a change in water absorption as compared to control by the following equations:  $W_{\text{control}} = 31.999\ln(t) + 19.694$  ( $R^2 = 1$ ),  $W_{0.07\text{ T}} = 25.514\ln(t) + 42.02$  ( $R^2 = 1$ ) and  $W_{0.12\text{ T}} = 36.814\ln(t) + 4.4942$  ( $R^2 = 1$ ) as shown in Figure 5.18. For the magnetically treated seeds, the reformulated Malthus-Verhulst equation and experimental data show a decrease in the seed germination capacity as compared to the control (Figure 5.19) at 0.12 and 0.17 T.

As shown in Figure 5.20 the number of un germinated seeds remaining in the sample decreases exponentially with time. The trend of the exponential curve differs with the change in the magnetic dose. There is no appreciable change in the mean germination time, but transition time showed an improvement at 0.07 T as compared to other field values



**Figure 5.18:** Variation of absorbed seed water content with the imbibition time for magnetically treated seeds at different field intensities.

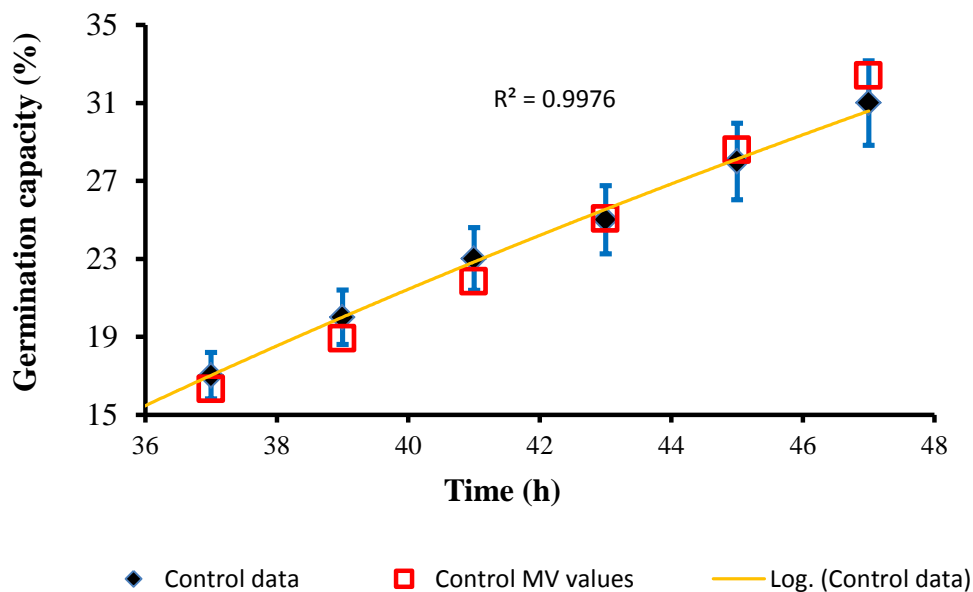


Figure 5.19a

(Figure 5.21). The experimental data shown in Figure 5.19 fit well in the re-formulated Malthus-Verhulst equation,  $N_g(t) = N_k N_i / [N_i + (N_k - N_i) \exp \{-\alpha N_k (t - t_0)\}]$  (equation 3.5), showing an increasing trend in the germination with an magnetic field of 0.07 T where as some retardation is observed in germination at 0.12 T.

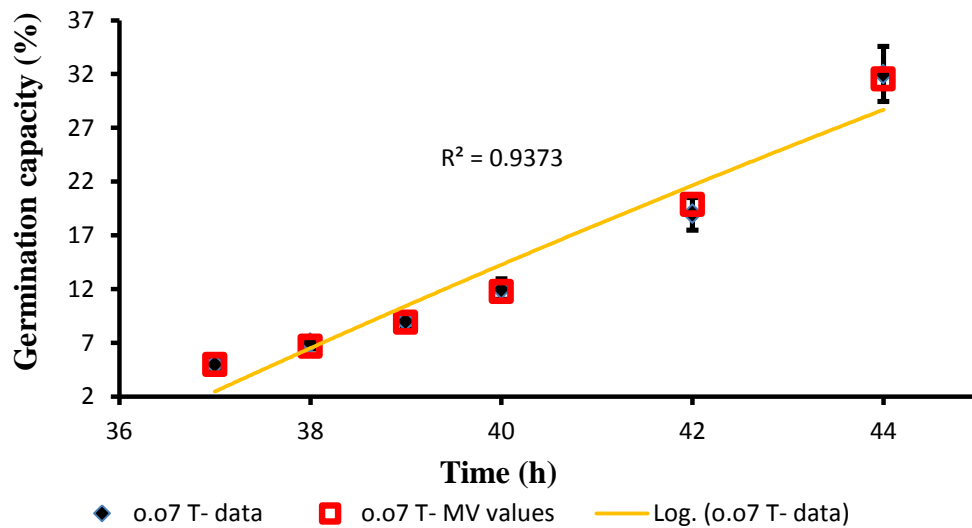


Figure 5.19b

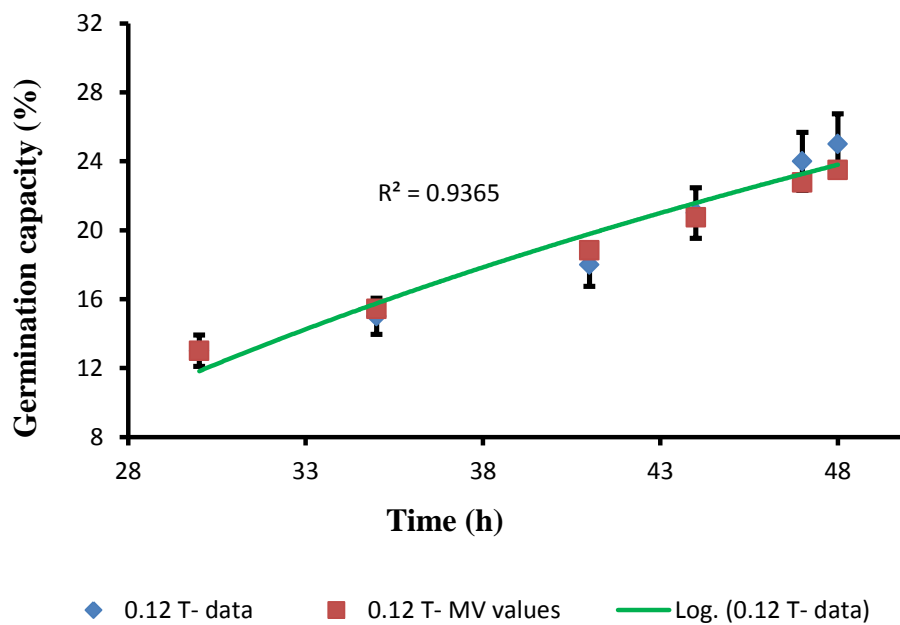


Figure 5.19c

The number of seeds remaining in the sample at any time  $t$  of the different samples exposed to different doses of the magnetic-field fit well in the Stochastic model,  $E[M_1(t)] = M_0 \exp(-\lambda_1 t)$ , for a two-state germinating process (Figure 5.20). Figure 5.20 supports that seed germination is a two state process.

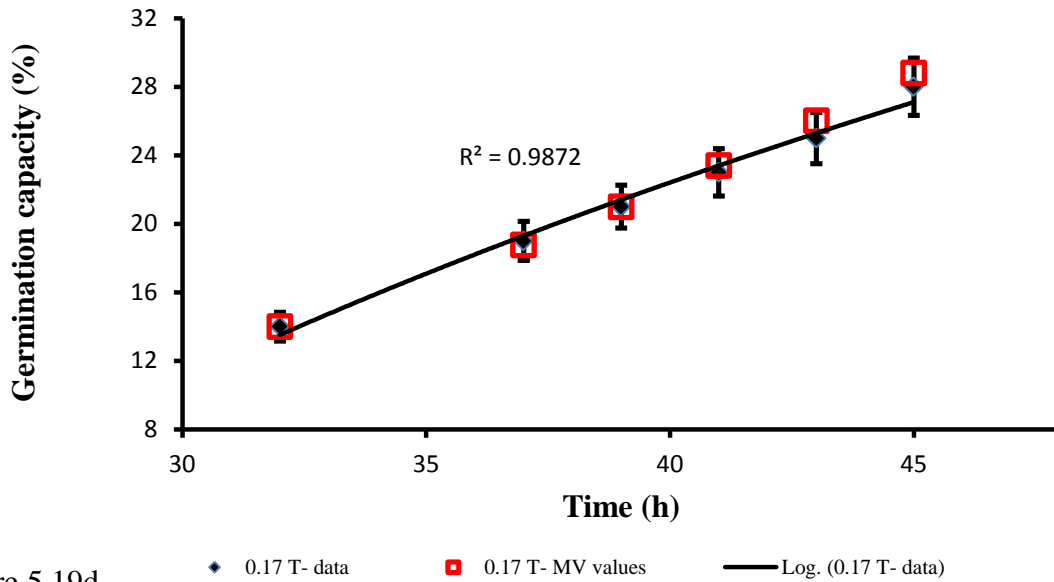


Figure 5.19d

**Figure 5.19(a-d):** Showing variation in germination growth capacity for magnetically treated seeds.

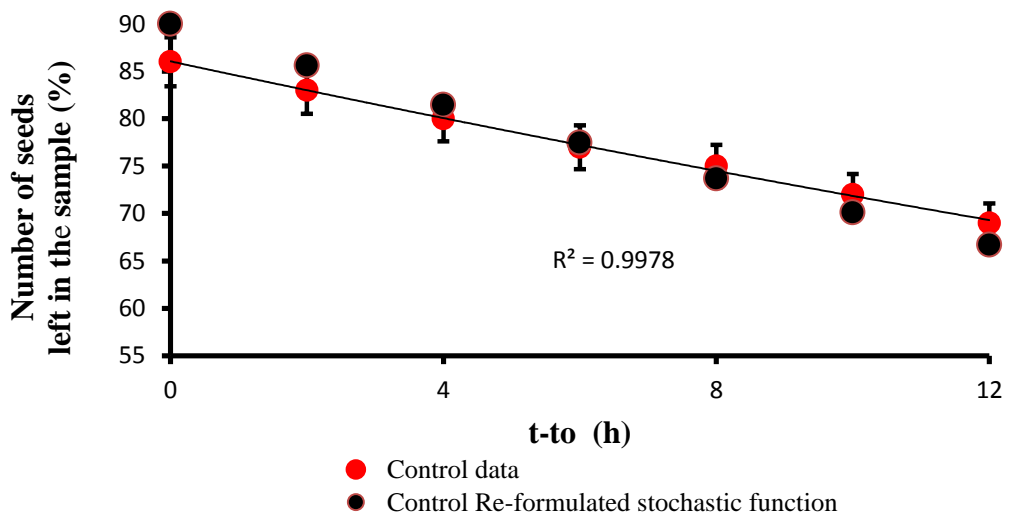


Figure 5.20a

Using the re-formulated Malthus-Verhulst equation, the germinating coefficients are calculated for the magnetically treated seeds ( $\alpha_{\text{control}} = 0.0009\text{h}^{-1}$ ,  $\alpha_{0.07\text{ T}} = 0.0031\text{ h}^{-1}$ ,  $\alpha_{0.12\text{ T}} = 0.0004\text{ h}^{-1}$  and  $\alpha_{0.17\text{ T}} = 0.0007\text{h}^{-1}$ ). There is an improvement in the value of  $\alpha$  (germinating coefficient) at 0.07 T and a declination in the  $\alpha$  value is found at 0.12 T.

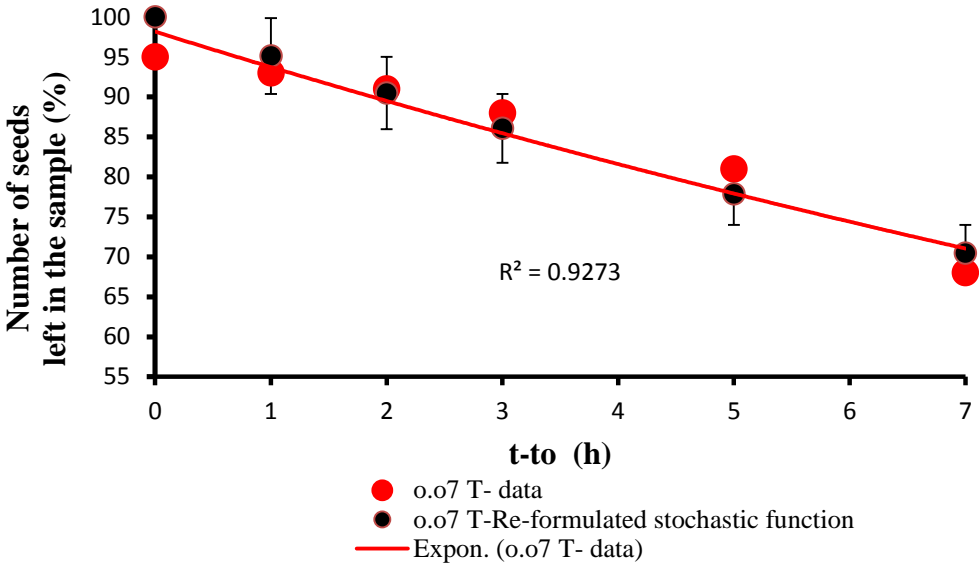


Figure 5.20b

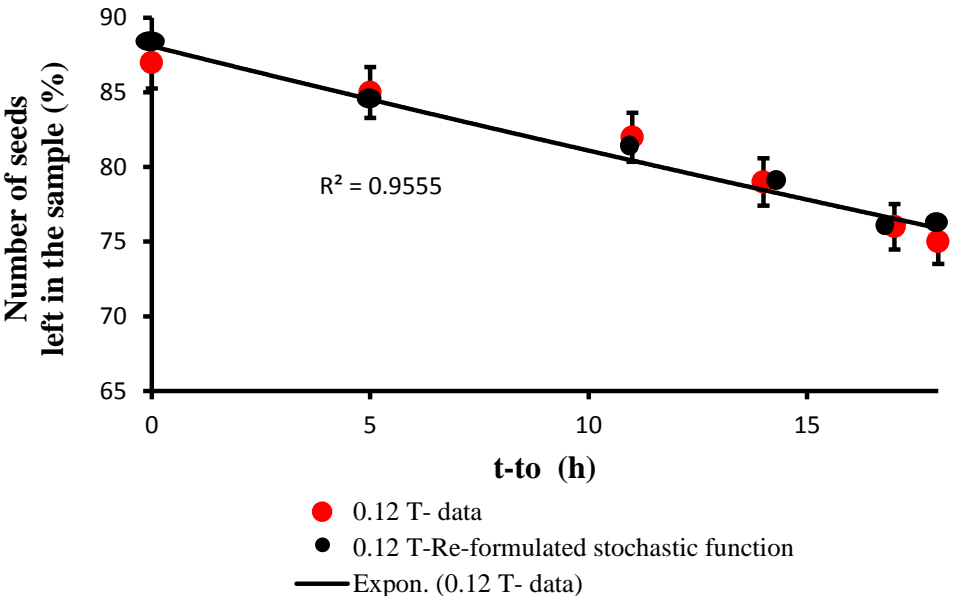


Figure 5.20c

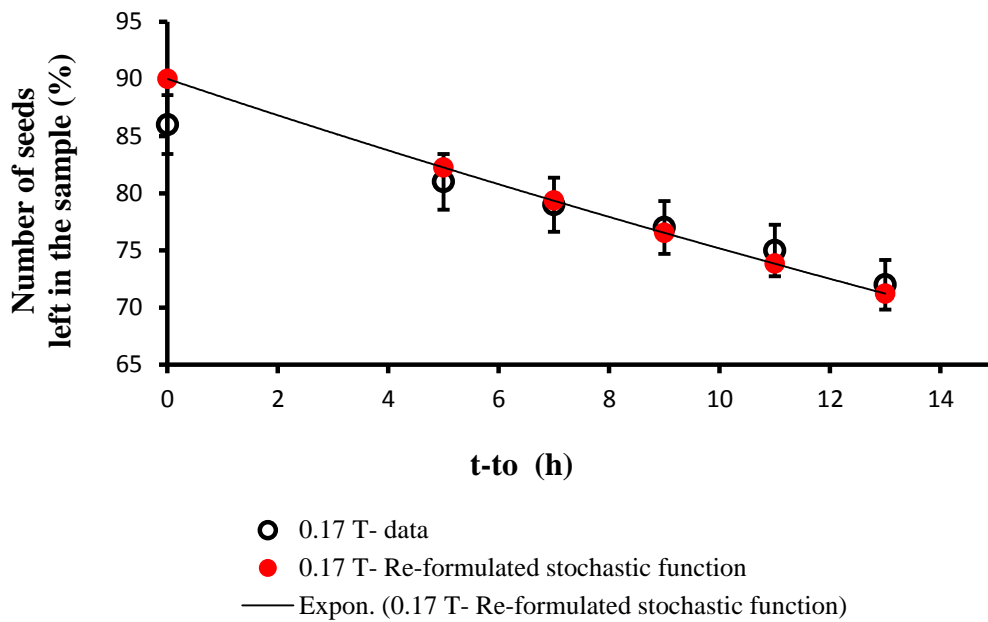
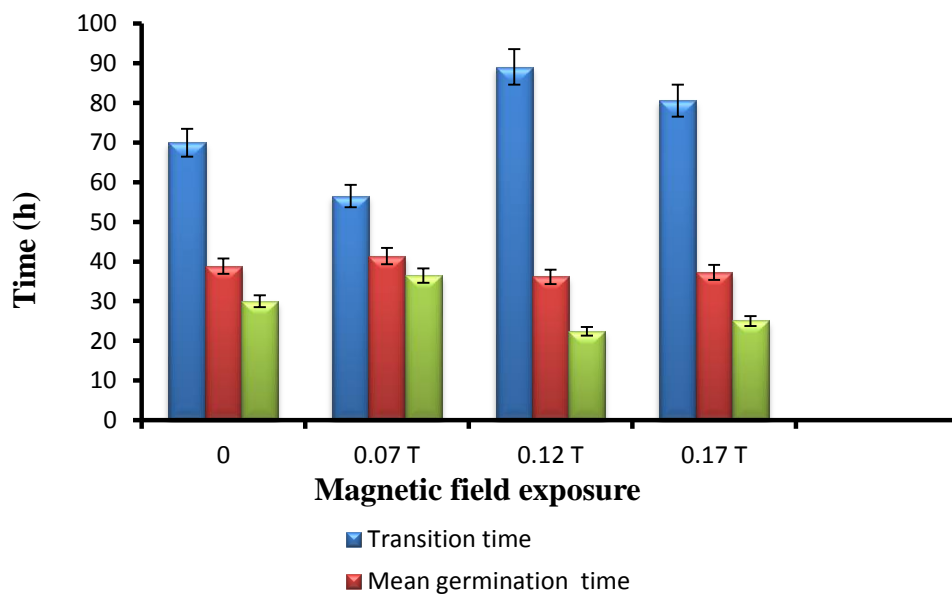


Figure 5.20 d

**Figure 5.20 (a-d):** Variation of un-germinated seeds with time in the samples.

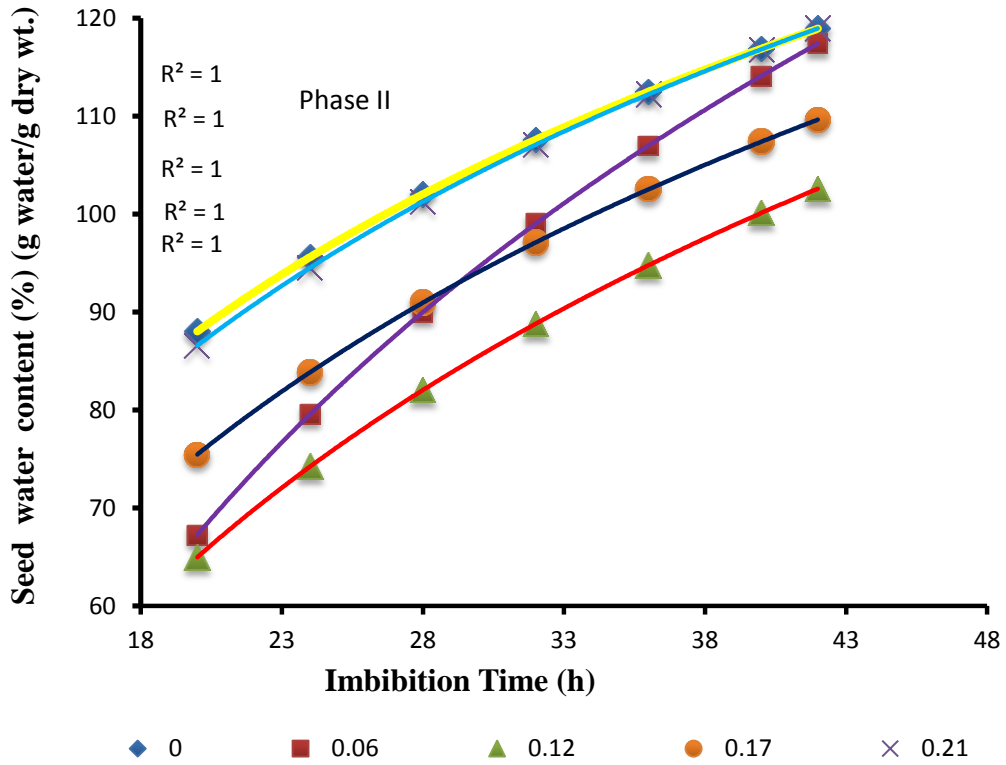


**Figure 5.21:** Variation in the mean germination time, transition time and time taken for the first seed to germinate for the magnetically treated seeds.

Transition time is calculated by taking the reciprocal of transition constant and adding initial time of germination in it. The transition time value is improved only for lower value of magnetic fields, i.e. at 0.07 T. For higher magnetic treatment the transition time declined, which results poor germination at higher value of magnetic dose (Figure 5.21).

## 5.6 Effect of Magnetic Treatments on Okra (*Abelmoschus esculentus* L.) Seed

Okra requires a long, warm and humid growing period. It can be successfully grown in hot humid areas. It is sensitive to frost and extremely low temperatures. For normal growth and development, a temperature between 24°C and 28°C is preferred [33]. For seed germination optimum soil moisture and a temperature between 25°C and 35°C is needed with fastest germination observed at 35°C. Beyond this range, the germination will be delayed, and weak seeds may not even germinate [33]. The seed water content as compared to its dry weight is measured at different time intervals. Figure 5.22 shows a continuous increase in water absorption with time for all field values (0.07, 0.12, 0.17 and 0.21 T) with 20-minute exposure at 30 °C. Water uptake data satisfying the equation  $w = C_1 \times \ln(t) \pm C_2$  with  $R^2 = 1$  (for all the curves), where  $w$  is the percentage of water uptake relative to seeds dry weight and  $C_1$  is water uptake coefficient. Germinating data of Okra seeds is fitted well in Re-formulated Malthus-Verhulst equation  $N_g(t) = N_k N_i / [N_i + (N_k - N_i) \exp \{-\alpha N_k (t - t_0)\}]$  (equation 3.5) for magnetic field of 0.07, 0.12, 0.17 and 0.21 T with 20-minute exposure at 30 °C and is shown in Figure 5.23. Using Re-formulated Malthus-Verhulst, the germination rate- coefficient was determined ( $\alpha_{\text{control}} = 0.0025 \text{ h}^{-1}$ ,  $\alpha_{0.07 \text{ T}} = 0.002 \text{ h}^{-1}$ ,  $\alpha_{0.12 \text{ T}} = 0.0023 \text{ h}^{-1}$ ,  $\alpha_{0.17 \text{ T}} = 0.0014 \text{ h}^{-1}$ ,  $\alpha_{0.21 \text{ T}} = 0.002 \text{ h}^{-1}$ ) by minimizing the residual sum of squares and executing the best possible fit for the growth model for the data. Experimental data of un-germinated okra seeds versus time is plotted along with the theoretical values which were calculated using the Re-formulated stochastic function:  $N = (N_k - N_i) \exp(-\lambda_{B,T}(t - t_0))$  (equation 3.21) for different values of magnetic- intensities for 20-minute exposure at 30 °C and is shown in Figure 5.24. For each data field, a decaying exponential curve is obtained. Transition time, mean germination time and time taken for first seed to germinate for various magnetic-field values with 20-minute exposure at 30 °C is shown in Figure 5.25.



**Figure 5.22:** Variation of absorbed seed water content with the imbibition time for magnetically treated seeds at different field intensities.

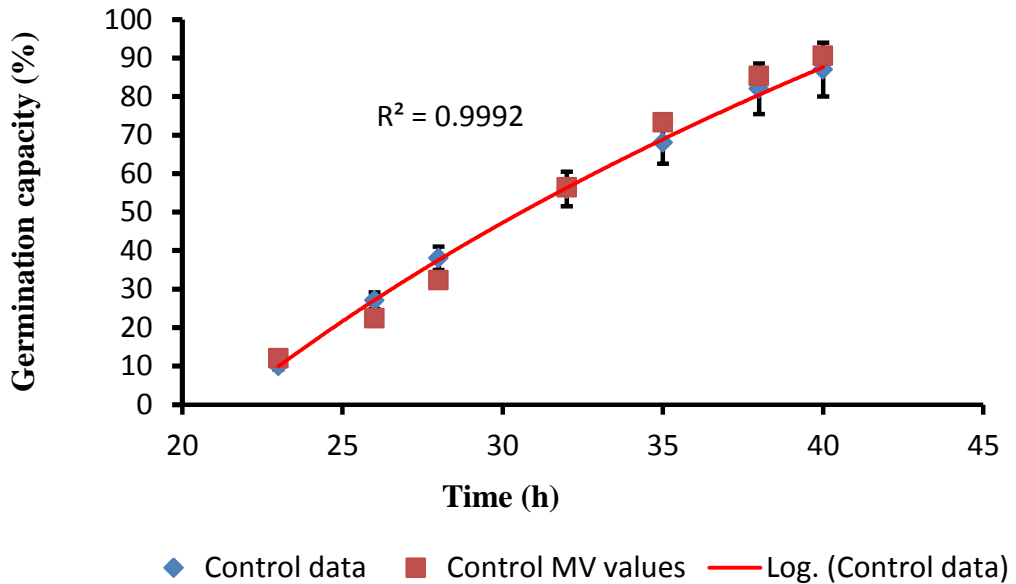


Figure 5.23a

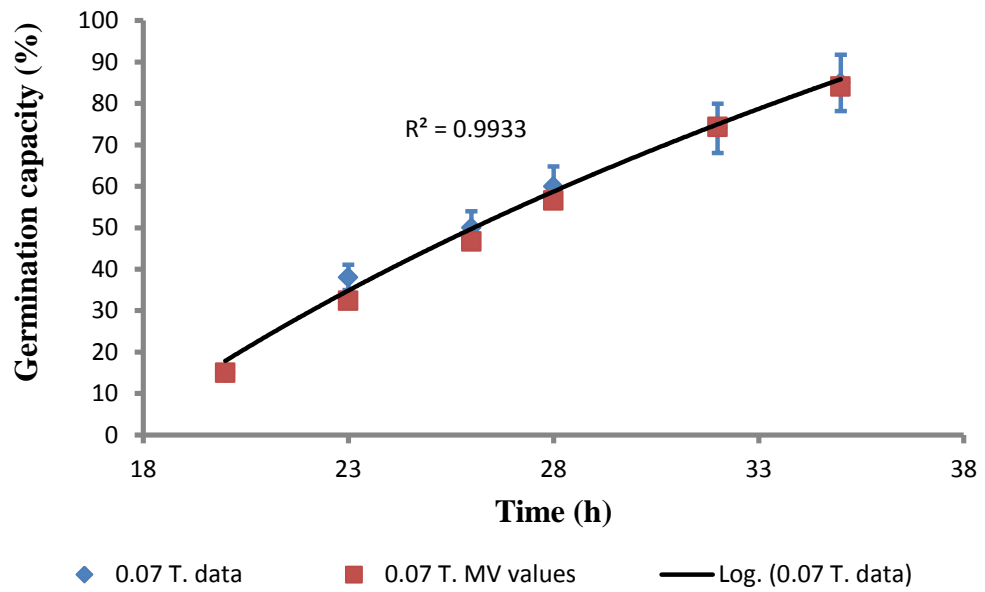


Figure 5.23b

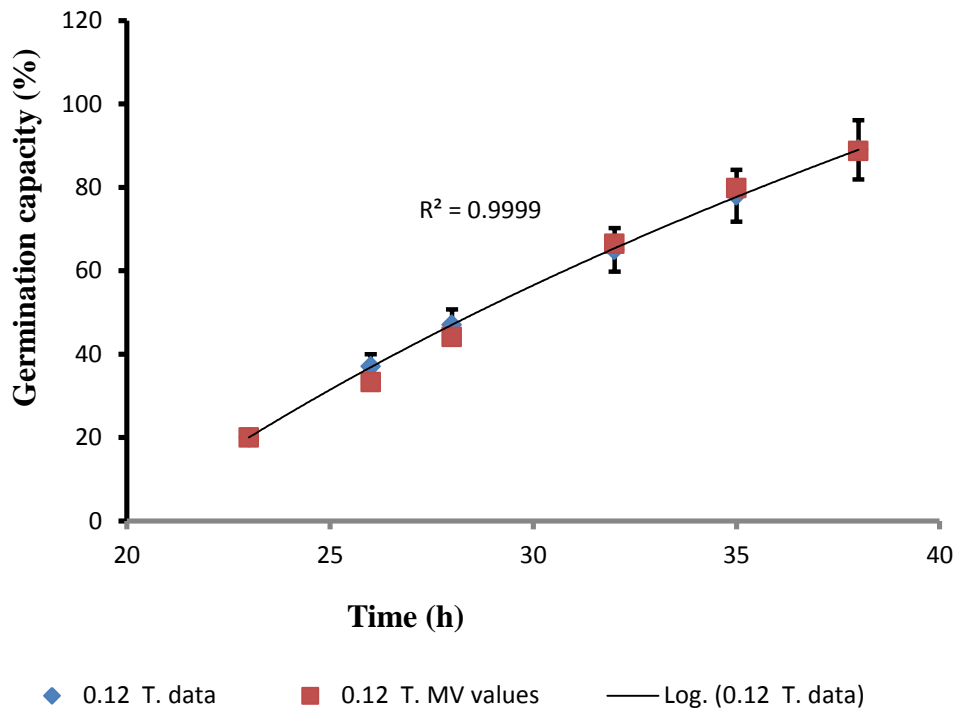


Figure 5.23c

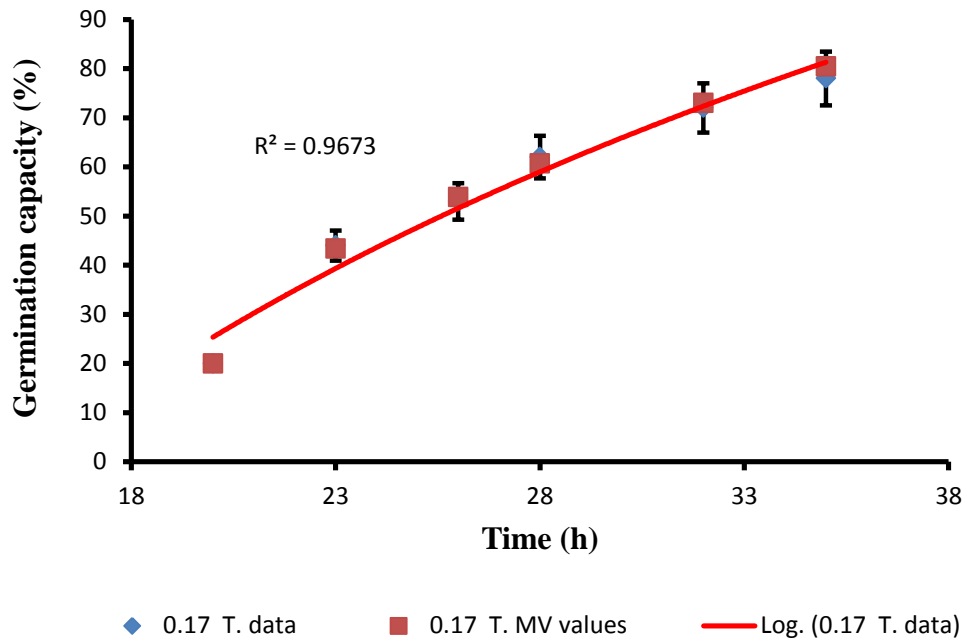


Figure 5.23d

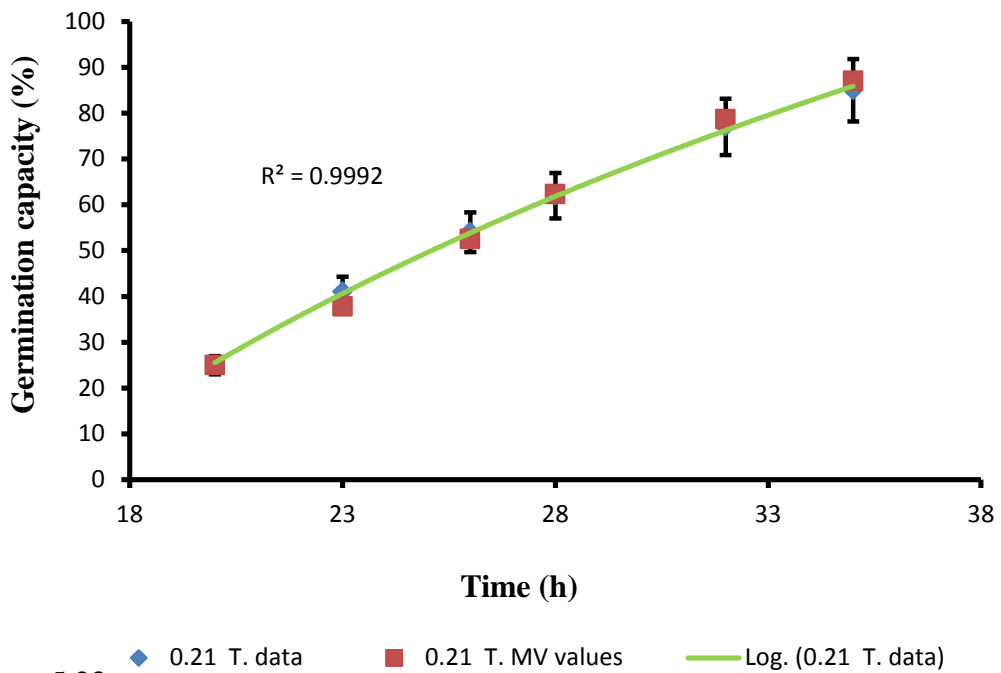


Figure 5.23e

**Figure 5.23 (a-e):** Showing variation in germination growth capacity for magnetically treated seeds.

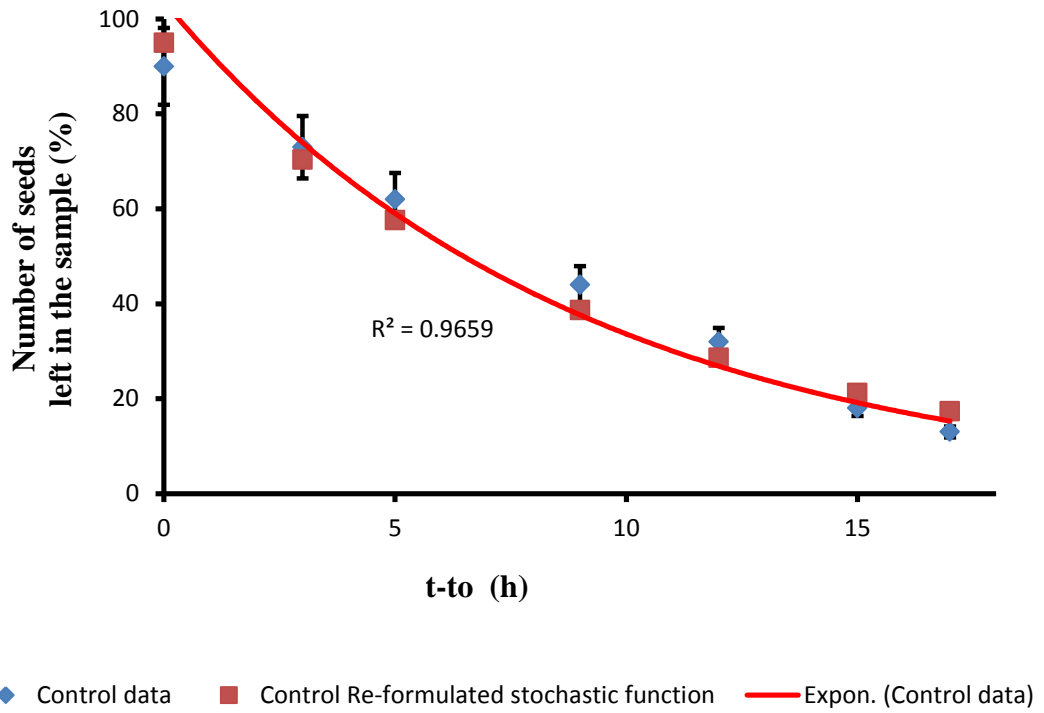


Figure 5.24a

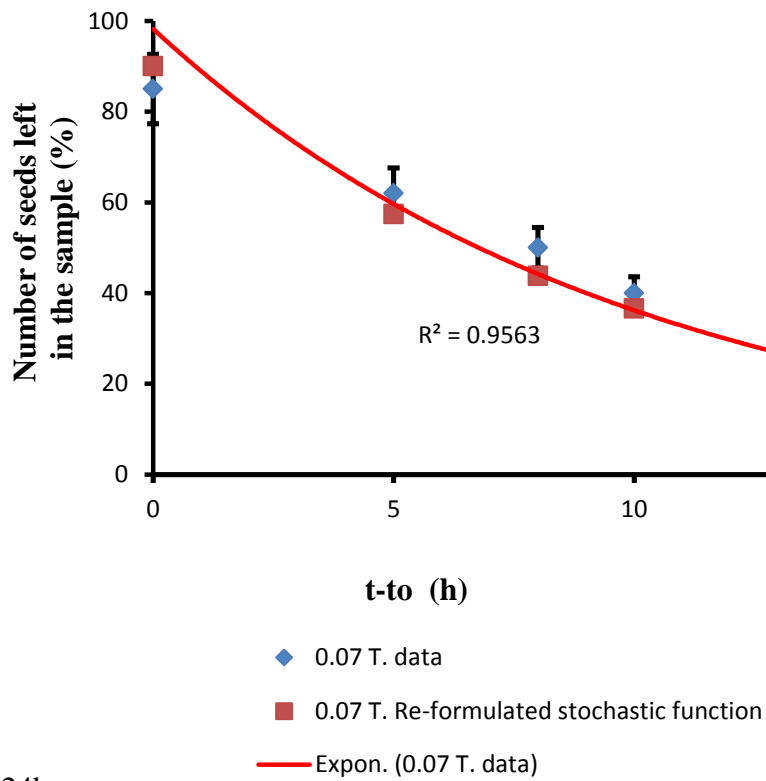


Figure 5.24b

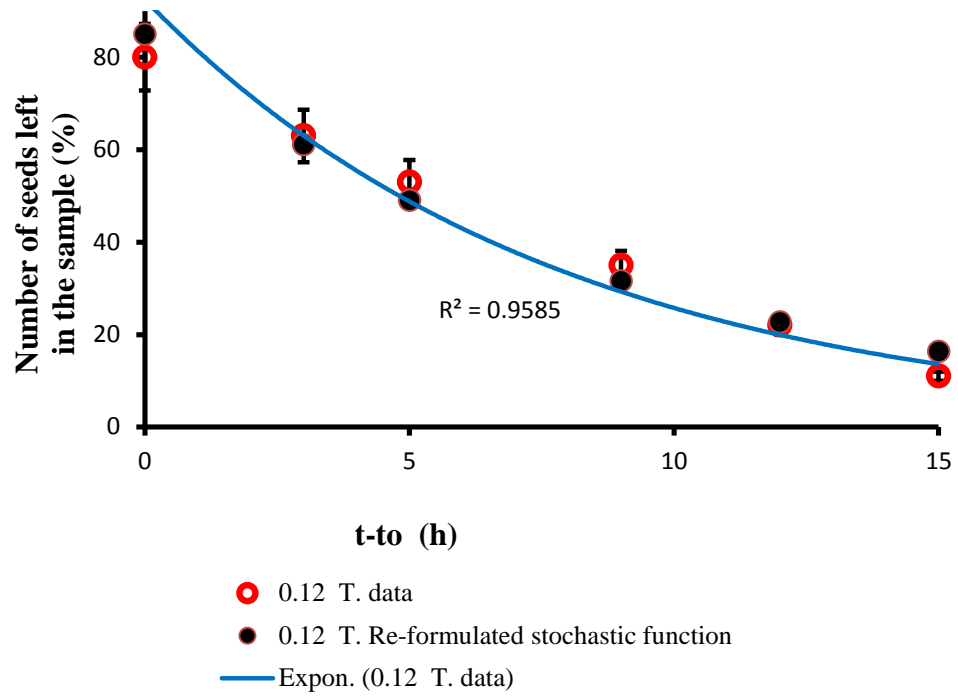


Figure 5.24c

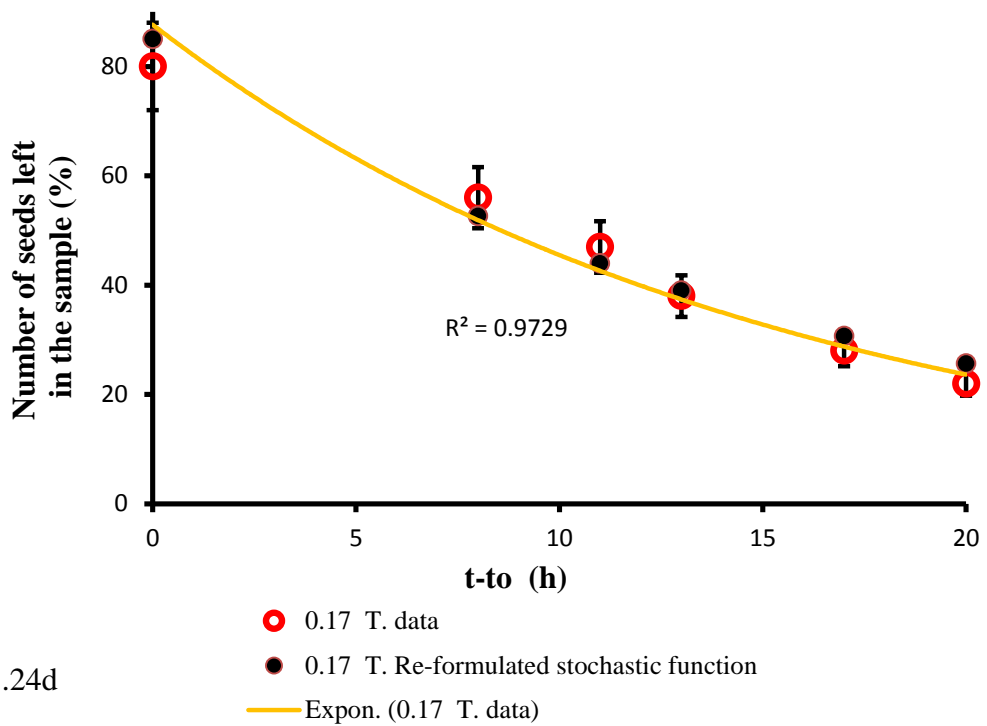


Figure 5.24d

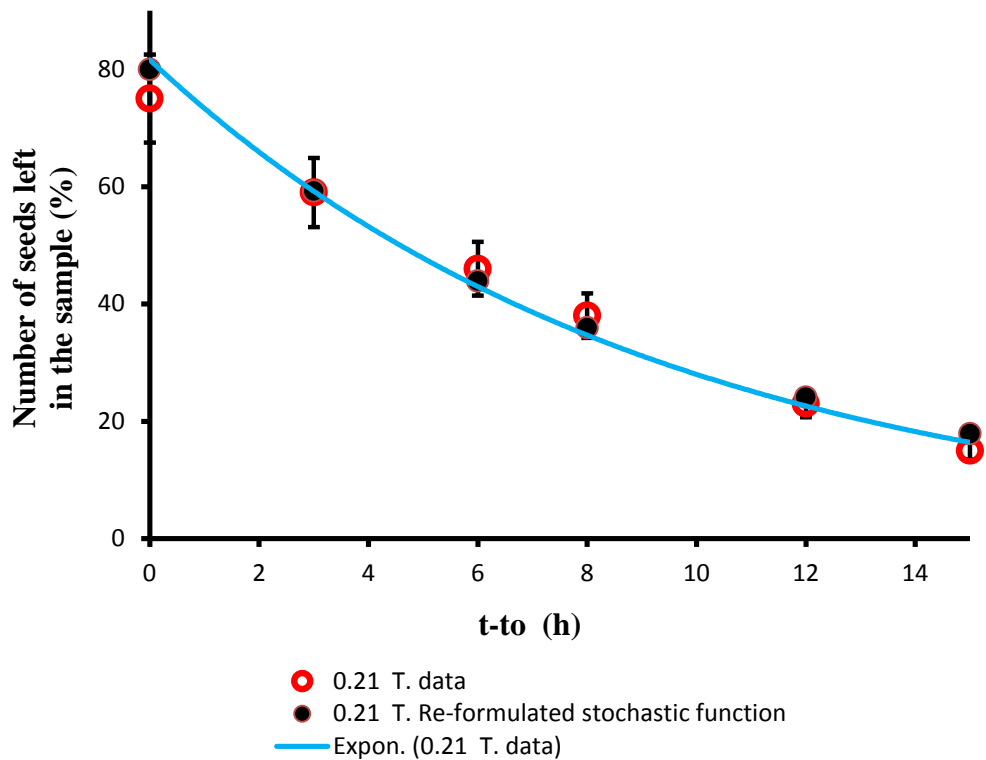
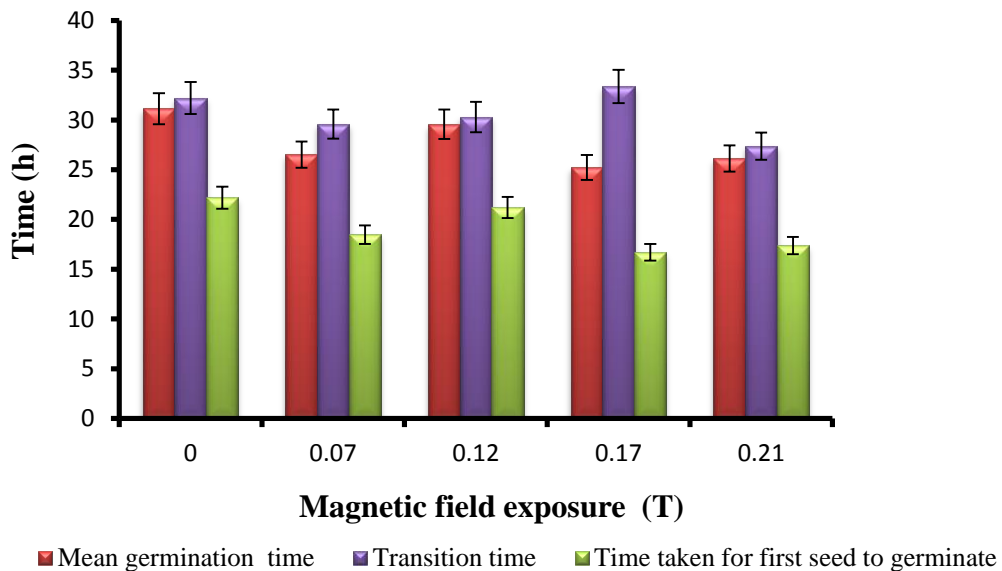


Figure 5.24e

**Figure 5.24 (a-e):** Variation of un-germinated seeds with time in the samples.



**Figure 5.25:** Variation in the mean germination time, transition time and time taken for the first seed to germinate for the magnetically treated seeds.

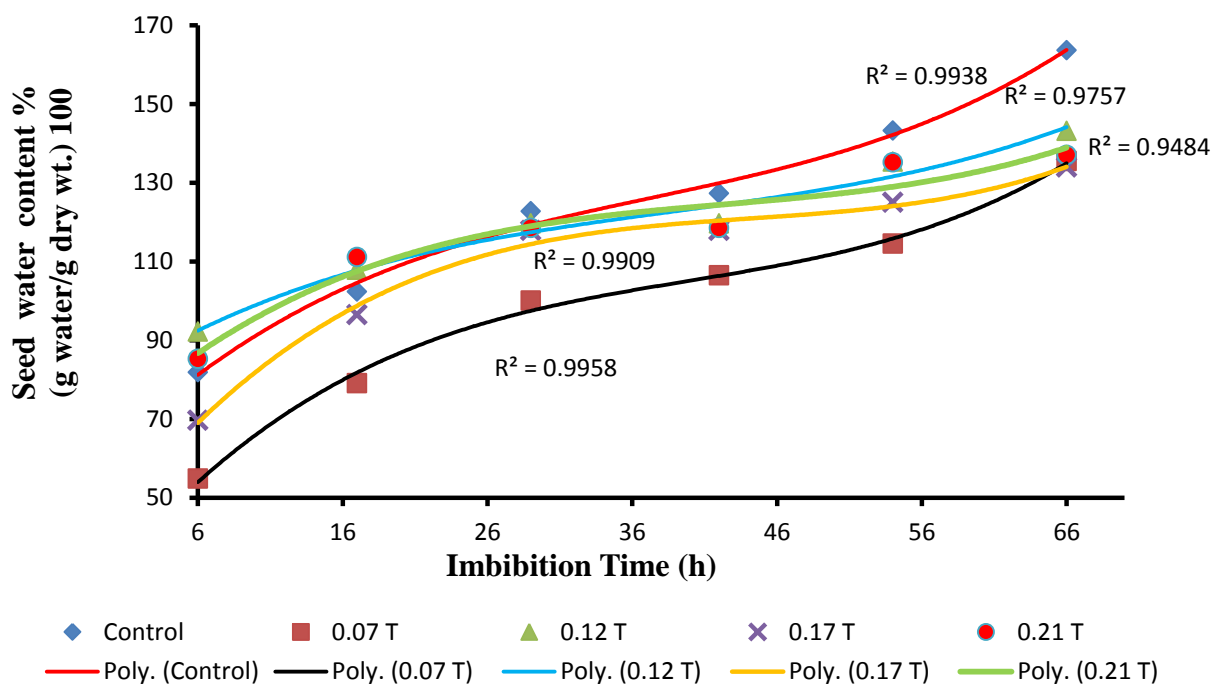
Seed germination process begins with imbibition of water which is tri-phasic process. In Phase I, there is rapid initial water uptake. In phase II (Figure 5.22), there is a plateau with little change in water content followed by an increase in water content which coincides with shoot growth (phase III). Okra seeds upon treatment with magnetic field soaked less water. After 28 h from the start of imbibition, i.e. in phase II, Okra seeds (treated with 0.12 mT for 20-minute exposure) soaked 20% less water as compared to control. The present experimental data (Figure 5.22) fitted well in the equation  $w = C_1 \times \ln(t) \pm C_2$  where  $w$  is seed water content (%) (g water/g dry wt). Experimental data of water uptake exactly justifies to Mahajan and Pandey's water uptake model (3.18). Germinating data of Okra seeds (Figure 5.23) treated with variable magnetic-field fitted well in Re-formulated Malthus-Verhulst equation  $N_g(t) = N_k N_i / [N_i + (N_k - N_i) \exp \{-\alpha N_k (t - t_0)\}]$  (equation 3.5). It is clear from Figure 5.23 that germination capacity is slightly improved at all field values. Using Re-formulated Malthus-Verhulst formula, the germination rate-coefficient was determined by minimizing the residual sum of squares and executing the best possible fit for the growth model for the data. In the present case, no improvement in  $\alpha$  values by varying magnetic field is observed where the results are in coincidence with water absorption trends and there is a decrease in water absorption at all field values. A simple approach to Stochastic model is verified experimentally (Equation 3.21, Figure 5.24) and is used to find a constant called germinating magnetic constant  $\lambda_{B,T}$ . The germinating magnetic constant  $\lambda_{B,T}$  is important to the sense that it signifies transition time (by taking its reciprocal and adding in it the initial time of germination (transition time =  $(1/\lambda_{B,T}) + t_0$ ). Transition time is that time during which seed undergoes a transition from un-germinated to germinated state. The trend of the variation in transition time matched at all field values (Figure 5.25) except at 0.17 T. There is small improvement in mean germination time, transition time and time taken for first seed to germinate (Figure 5.25) with magnetic treatment. Maximum improvement in mean germination time is observed at 0.17 T (5.7h relative to control) and minimum at 0.12 T (1.4 h). The exact mechanism behind the effect of static magnetic field (SMF) on living organisms is still unclear. The role of magnetic fields and their influence on functioning of biological organisms are still insufficiently understood [1]. Magnetic field alters the cation uptake capacity and has a positive effect on plant nutrient uptake [34]. It has been reported that static magnetic fields affect the diffusion of biological particles in solutions by inducing Lorentz force [18]. Presently, it is clear that magnetic field influences the water uptake and germination capacity. Therefore, some metal ion may be attached to the seed protein which

retains the magnetism even after the removal of magnetic field. This alters the water uptake and hence germination capacity.

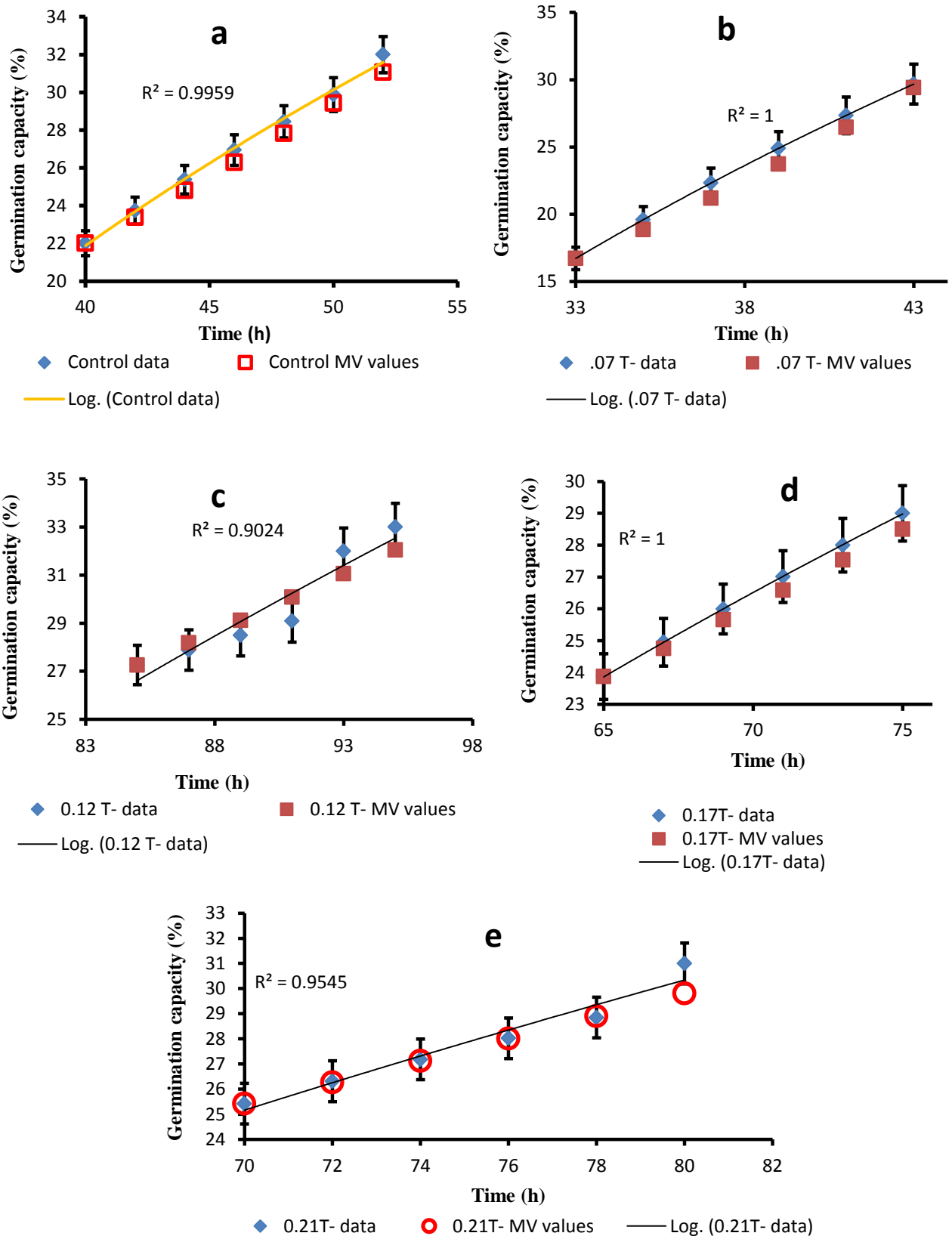
### 5.7 Effect of Magnetic Treatment on Water Uptake and Germination Capacity of Spinach (*Spinacia oleracea* L.) Seed

Extensive literature survey revealed that no reports are available about the effects of germination of spinach seeds by giving magnetic treatments. The present study was undertaken to explore the germination effects of spinach seed in the environment of magnetic fields. In the present research, it is found that on being treated with magnetic field, there is an increase over the yield of spinach (*Spinacia oleracea* L.). The results showed that the magnetic field stimulates to spinach seed positively at its lower values. At a higher value of magnetic field, the germination yield of spinach becomes negative. The seed water content as compared to its dry weight is measured at different time intervals. Figure 5.26 shows a continuous increase in water absorption with time for all field values (0.07, 0.12, 0.17 and 0.21 T) with 20-minute exposure at 29 °C; Water uptake curves are satisfying the equation  $w_{\text{control}} = 0.0007t^3 - 0.0735t^2 + 3.5397t + 62.464$ ,  $w_{0.07\text{ T}} = 0.0008t^3 - 0.0944t^2 + 4.3661t + 30.957$  (3<sup>rd</sup> order polynomial). Germinating data of Spinach seeds is fitted well in Re-formulated Malthus-Verhulst equation  $N_g(t) = N_k N_i / [N_i + (N_k - N_i) \exp \{-\alpha N_k (t - t_0)\}]$  (equation 3.5) for magnetic field 0.07, 0.12, 0.17 and 0.21 T with 20-minute exposure at 29 °C, is shown in Figure 5.27. Using Re-formulated Malthus-Verhulst, the germination rate-coefficient was determined ( $\alpha_{\text{control}} = 0.00039\text{ h}^{-1}$ ,  $\alpha_{0.07\text{ T}} = 0.00073\text{ h}^{-1}$ ,  $\alpha_{0.12\text{ T}} = 0.00023\text{ h}^{-1}$ ,  $\alpha_{0.17\text{ T}} = 0.00024\text{ h}^{-1}$ ,  $\alpha_{0.21\text{ T}} = 0.00022\text{ h}^{-1}$ ) by minimizing the residual sum of squares and executing the best possible fit for the growth model for the data. Experimental data of un-germinated spinach seeds versus time is plotted against different values of magnetic-intensities for 20-minute exposure at 29 °C (Figure 5.28). For each data field, a decaying exponential curve is obtained which falls in the category of good fitting. Transition time, mean germination time and time taken for first seed to germinate for various magnetic-field values with 20-minute exposure at 29 °C is shown in Figure 5.29. Spinach seeds upon treatment with magnetic field of 0.07 T with 20-minute exposure soaked less water. After 6 h when imbibition starts, Spinach seeds soaked 27% less water in phase I and 21% less water in phase II (42 h) as compared to control. At other magnetic treatments,

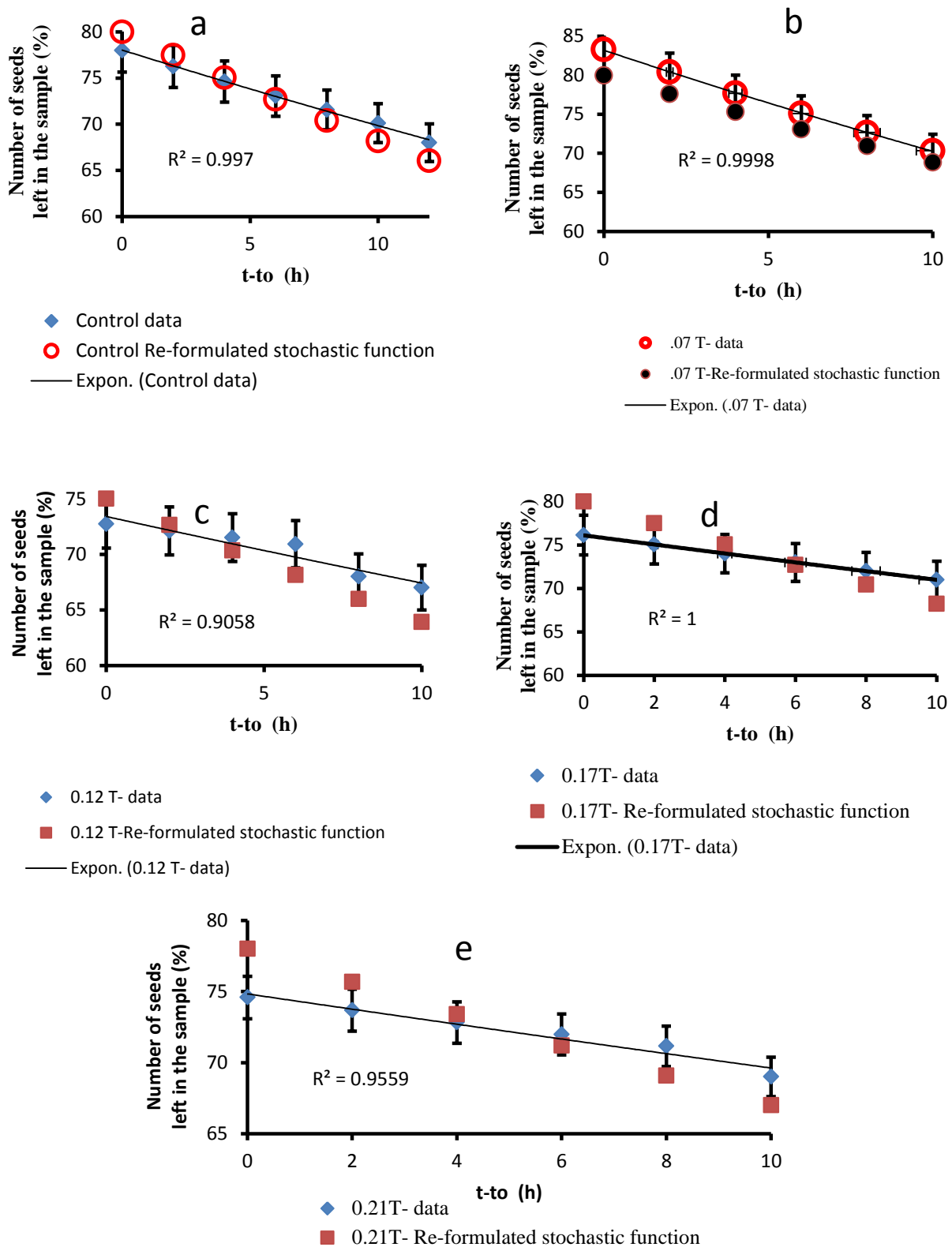
there is no appreciable change in water absorption. The present experimental data as shown in Figure 5.26 of water uptake fitted well in the polynomial equations of the form  $w_{\text{control}} = at^3 - bt^2 + ct + d$ . where  $a$ ,  $b$ ,  $c$  and  $d$  are some constants whose value depends on the value of physical parameters, which affects the germination. So a new model is required to justify water uptake equation  $w_{\text{control}} = at^3 - bt^2 + ct + d$ . Germinating data of Spinach seeds as shown in Figure 5.27 treated with variable magnetic-field fitted well in Re-formulated Malthus-Verhulst equation  $N_g(t) = N_k N_i / [N_i + (N_k - N_i) \exp \{-\alpha N_k (t-t_0)\}]$  (equation 3.5). It is clear from Figure 5.27 that germination capacity is maximum at 0.07 T and minimum at 0.12 T. The results signify, less water absorption that leads to better germination and vice-versa. Using Re-formulated Malthus-Verhulst equation, the germination rate-coefficient was determined by minimizing the residual sum of squares and executing the best possible fit for the growth model for the data. In the present case,  $\alpha$  value is very much improved for 0.07 T so it leads to improvement in the early germination parameters whereas with the higher dose of magnetic treatment, alpha value becomes poor which results weak early germination parameters. A simple approach to Stochastic model is verified experimentally (Equation 3.21, Figure 5.28) and is used to find a constant called germinating



**Figure 5.26:** Variation of absorbed seed water content with the imbibition time for magnetically treated seeds at different field intensities.

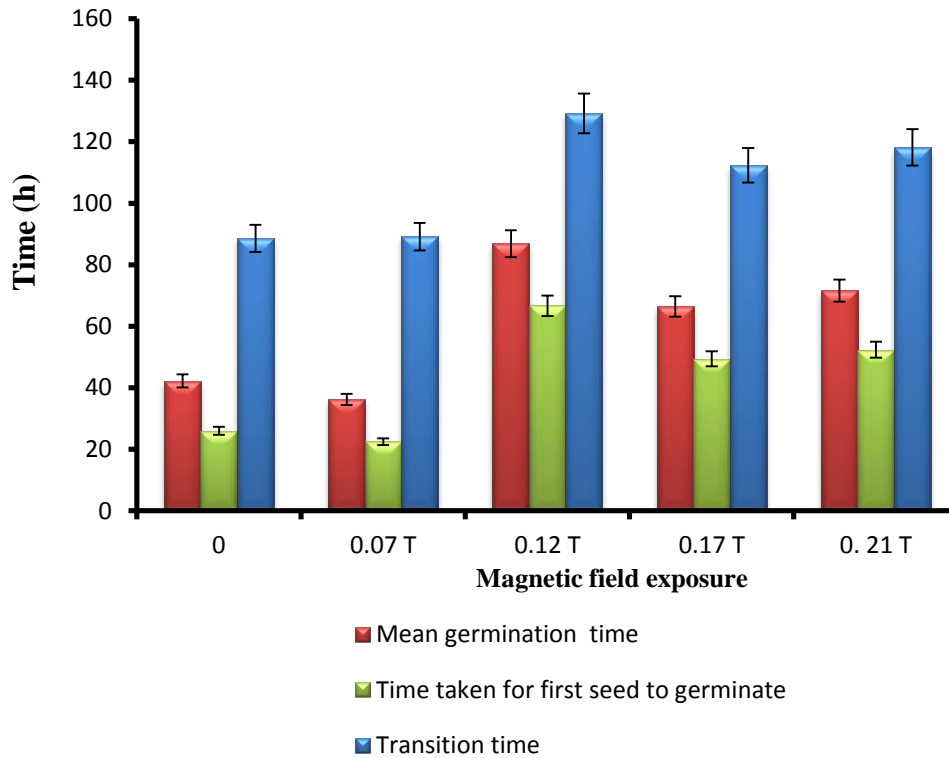


**Figure 5.27( a-e):** Showing variation in germination growth capacity for magnetically treated seeds.



**Figure 5.28 (a-e):** Variation of un-germinated seeds with time in the samples.

magnetic constant  $\lambda_{B,T}$ . Magnetic constant  $\lambda_{B,T}$  signifies transition time by taking its reciprocal and adding in it the initial time of germination (transition time =  $(1/\lambda_{B,T}) + t_0$ ).

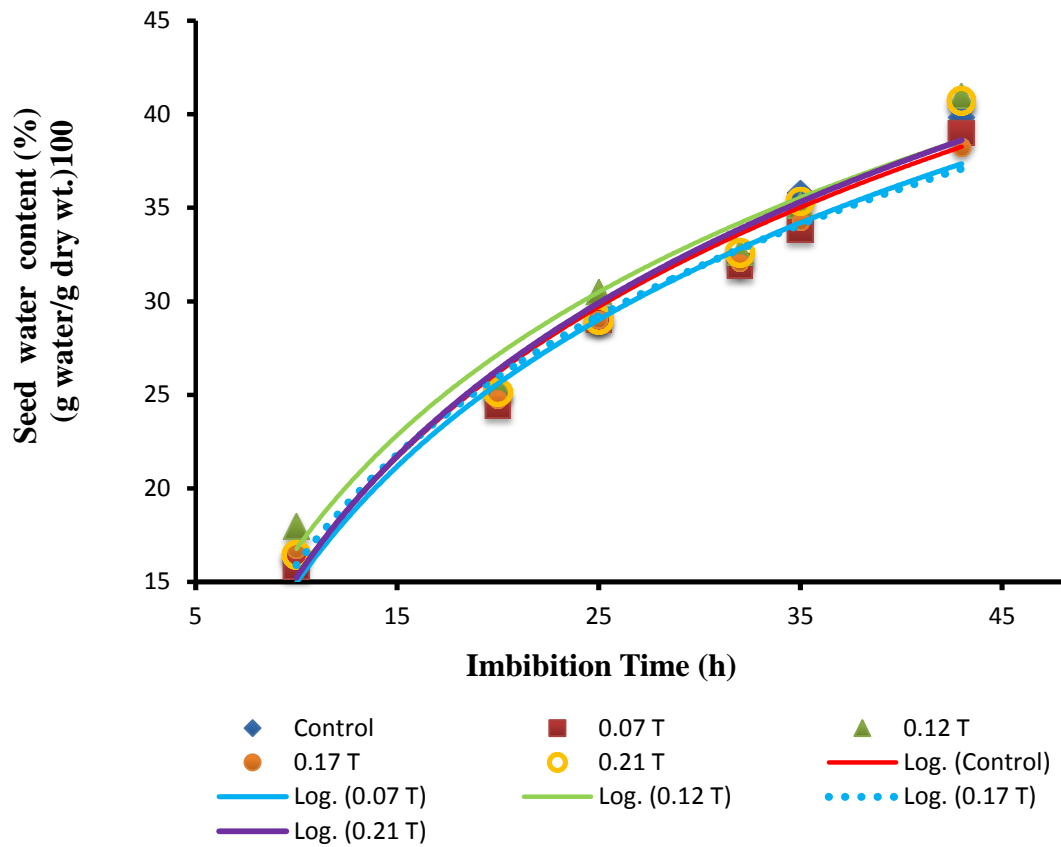


**Figure 5.29:** The variation in the mean germination time, transition time and time taken for the first seed to germinate for the magnetically treated seeds.

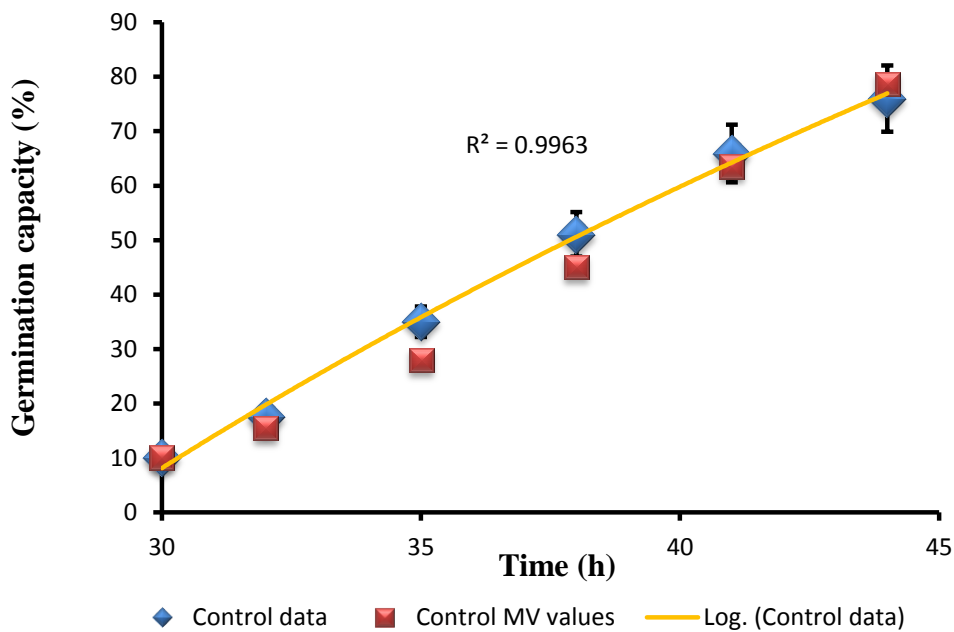
Transition time is that time during which seed undergoes a transition from un-germinated to germinated state. The trend of the variation in transition time matched well at all field values having the trend of variation in mean germination time (Figure 5.29). There is an improvement in mean germination time, transition time and time taken for first seed to germinate (Figure 5.29) with 0.07 T for 20 minute magnetic treatment. Higher value of magnetic dose ( $> 0.07$  T) gives retardation to germination process. Presently, it is clear that magnetic field influences the water uptake and germination capacity. The exact mechanism behind the effect of static magnetic field (SMF) on living organisms is still unclear. Magnetic field alters the cation uptake capacity and has a positive effect on plant nutrient uptake [34].

## 5.8 Effect of magnetic field on germination and water uptake of maize (*Zea mays* L.) seed

Maize is one of the main fodder crops of the Punjab state. It has the higher yield than any other cereal. With the increasing demand of poultry feed in India, the demand of maize is also going up. Chemical treatments are found to be effective for enhancing the growth and yield, but might be detrimental at later stages of development [35]. The effect of magnetic-field treatment on biological systems has been studied by various researchers for enhancing germination, vigour as well as growth at later stages of development [35]. To study the effect of magnetic field on the germination of Maize, hybrid maize seeds P-55 were obtained from Proline seeds company (India) Pvt. Ltd. and was used in the present research. The seed water content as compared to its dry weight is measured at different time intervals. Figure (5.30) shows a continuous increase in water absorption with time for all field values (0.07, 0.12, 0.17 and 0.21 T) with 30-minute exposure at 31 °C. Water uptake curves satisfy the equation  $w = C_1 \times \ln(t) \pm C_2$  with  $R^2 > 0.96$  for all the curves, where  $w$  is the percentage of water uptake relative to seeds dry weight, and  $C_1$  is water uptake coefficient. Maximum water uptake is observed at 0.12 T. At the start of water uptake (phase I), dry maize seeds imbibe water; take up oxygen and as a result increase its seed mass. In this phase at any time  $t = 30$  h as shown in Figure 5.30, percentage increase in water uptake relative to dry weight of seed as compared to control is 0.45 unit. In phase II, there is a metabolic plateau with low water absorption. Phase II (Figure 5.30) shows that percentage increase in water uptake relative to dry weight of seed as compared to control for 0.12 T at 31 °C with 30-minute exposure is 1.15 unit (at any instant  $t = 43$  h). Germinating data of Okra seeds is fitted well in Re-formulated Malthus-Verhulst equation  $N_g(t) = N_k N_i / [N_i + (N_k - N_i) \exp \{-\alpha N_k (t - t_0)\}]$  for magnetic field 0.07, 0.12, 0.17 and 0.21 T with 30-minute exposure at 31 °C, is shown in Figure 5.31. Using Re-formulated Malthus-Verhulst, the germination rate- coefficient was determined ( $\alpha_{\text{control}} = 0.0025 \text{ h}^{-1}$ ,  $\alpha_{0.07 \text{ T}} = 0.0022 \text{ h}^{-1}$ ,  $\alpha_{0.12 \text{ T}} = 0.005 \text{ h}^{-1}$ ,  $\alpha_{0.17 \text{ T}} = 0.005 \text{ h}^{-1}$ ,  $\alpha_{0.21 \text{ T}} = 0.003 \text{ h}^{-1}$ ) by minimizing the residual sum of squares and executing the best possible fit for the growth model for the data. Experimental data of un-germinated maize seeds versus time is plotted along with the theoretical values calculated using the Re-formulated Stochastic function:  $N = (N_k - N_i) \exp(-\lambda_{B,T} (t - t_0))$  for different values of magnetic- intensities for 30-minute exposure at 31 °C (Figure 5.32). For each data field, a decaying exponential curve is obtained. Transition time, mean germination time and time taken for first seed to germinate for various magnetic field values with 30 minute exposure at 31 °C is shown in Figure (5.33).



**Figure 5.30:** Variation of absorbed seed water content with the imbibition time for magnetically treated seeds at different field intensities.



**Figure 5.31 a**

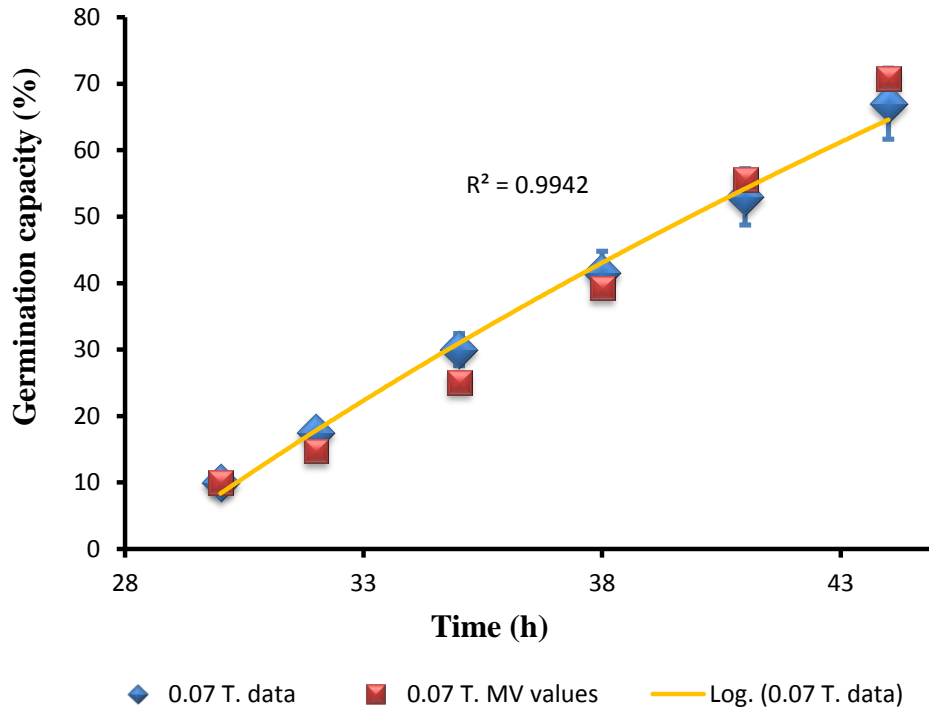


Figure 5.31 b

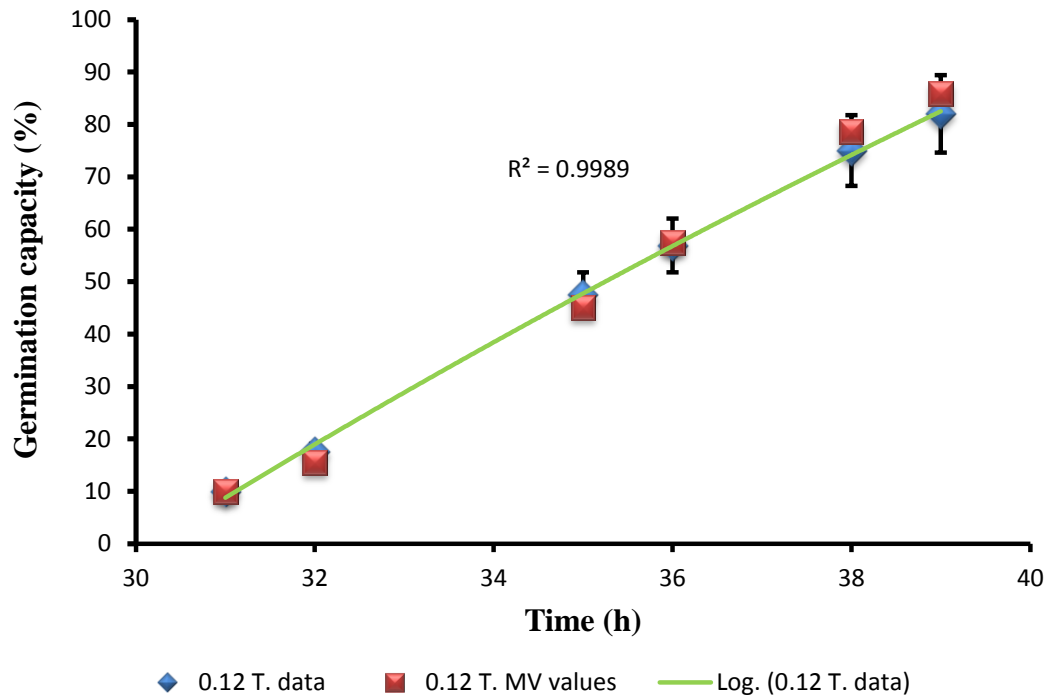


Figure 5.31 c

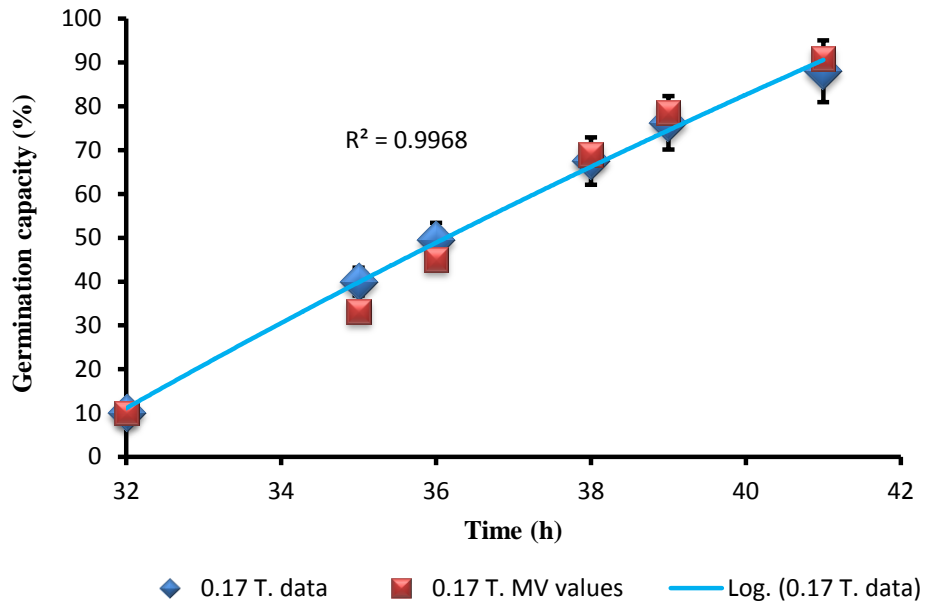


Figure 5.31 d

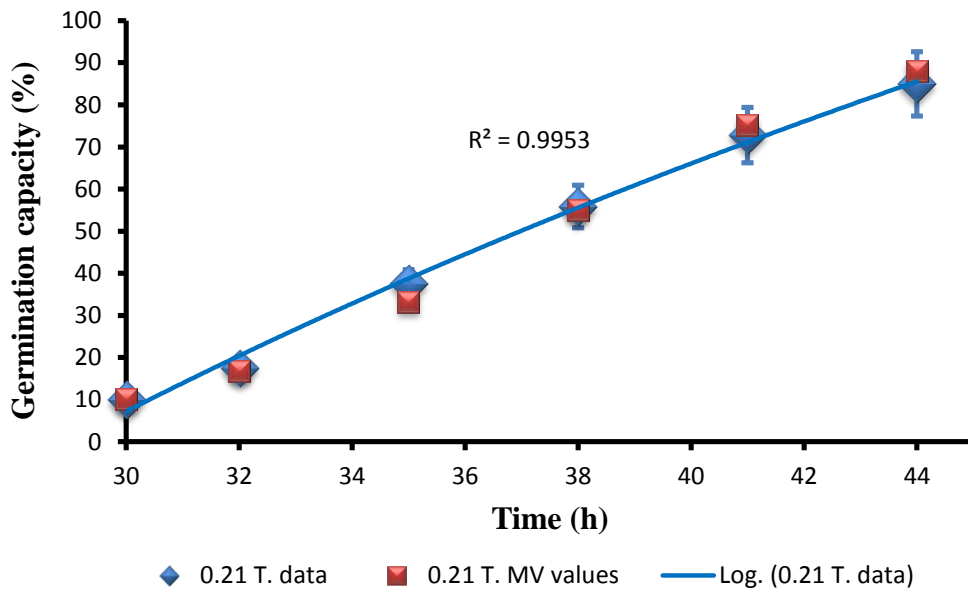


Figure 5.31 e

**Figure 5.31(a-e) :** Showing variation in germination growth capacity for magnetically treated seeds.

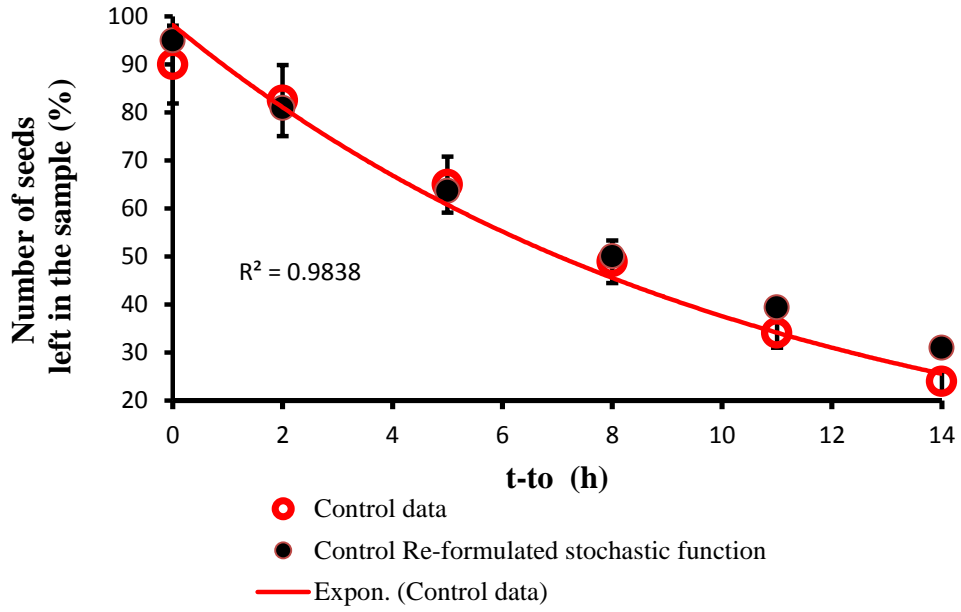


Figure 5.32 a

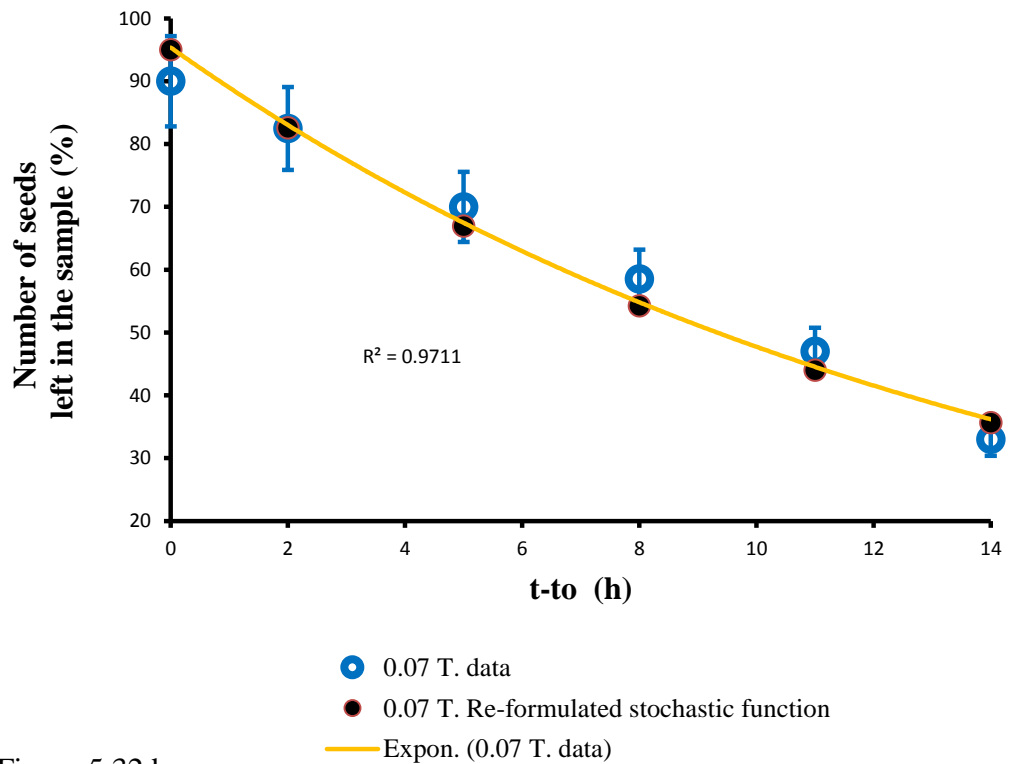


Figure 5.32 b

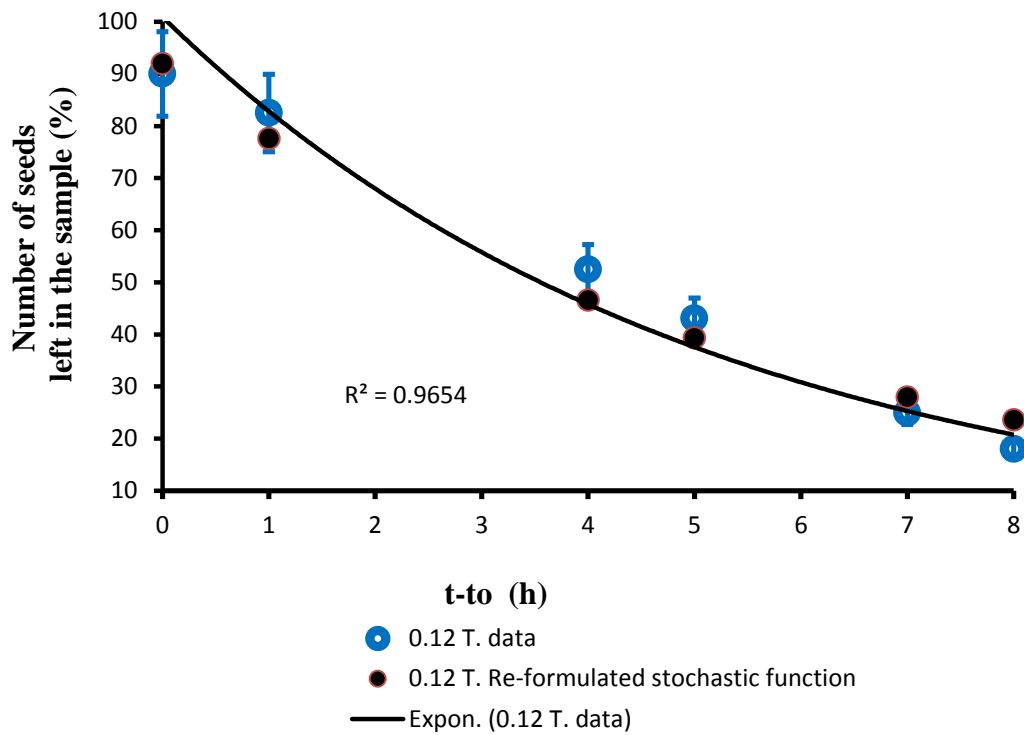


Figure 5.32 c

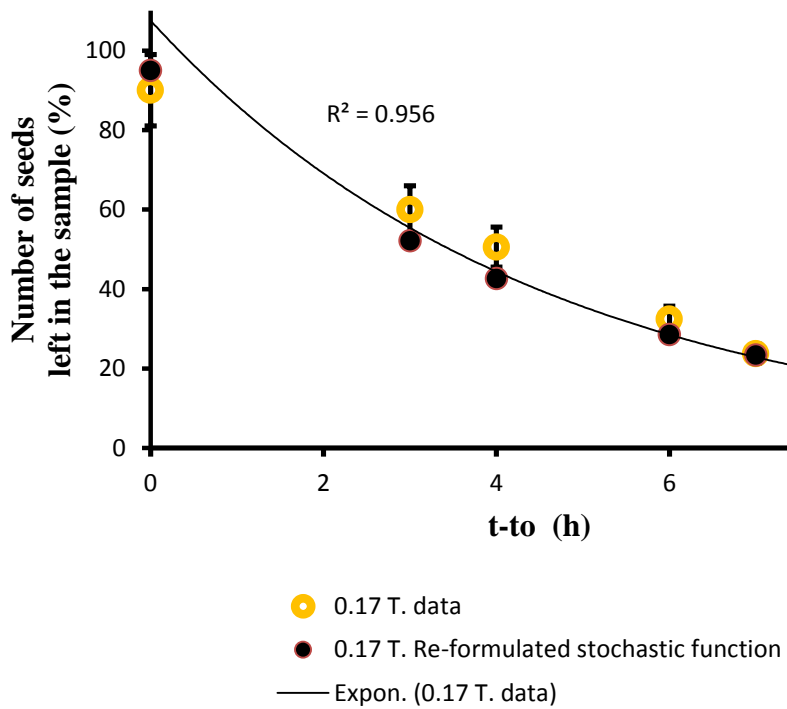


Figure 5.32 d

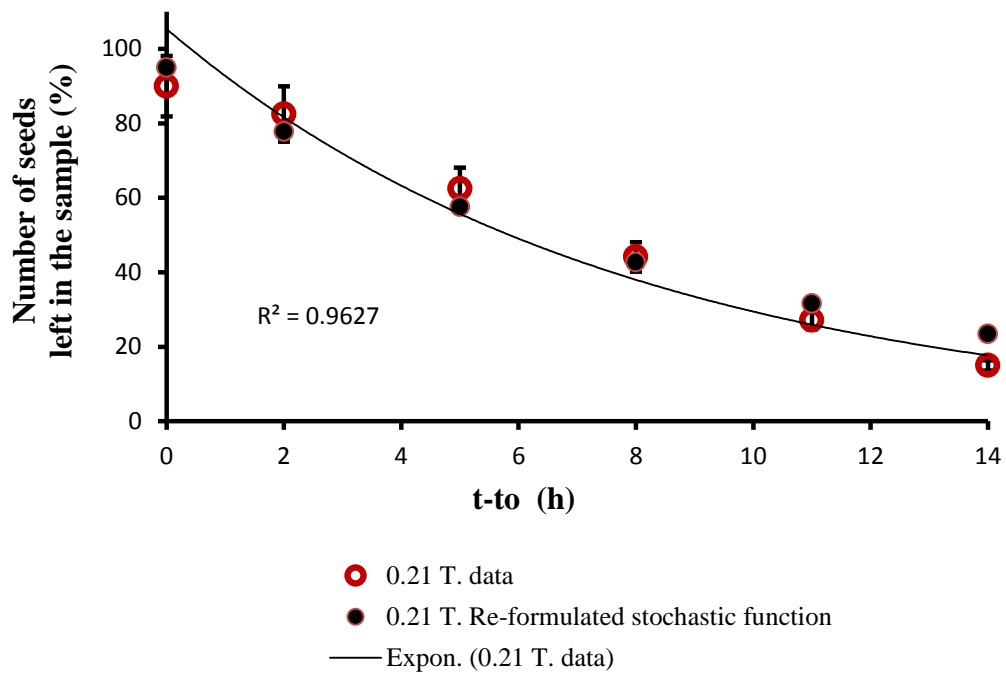
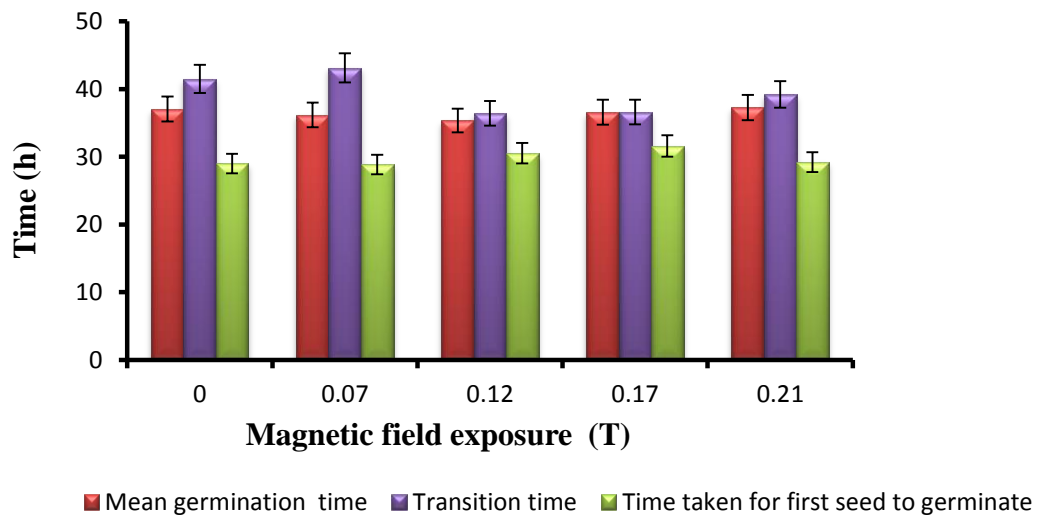


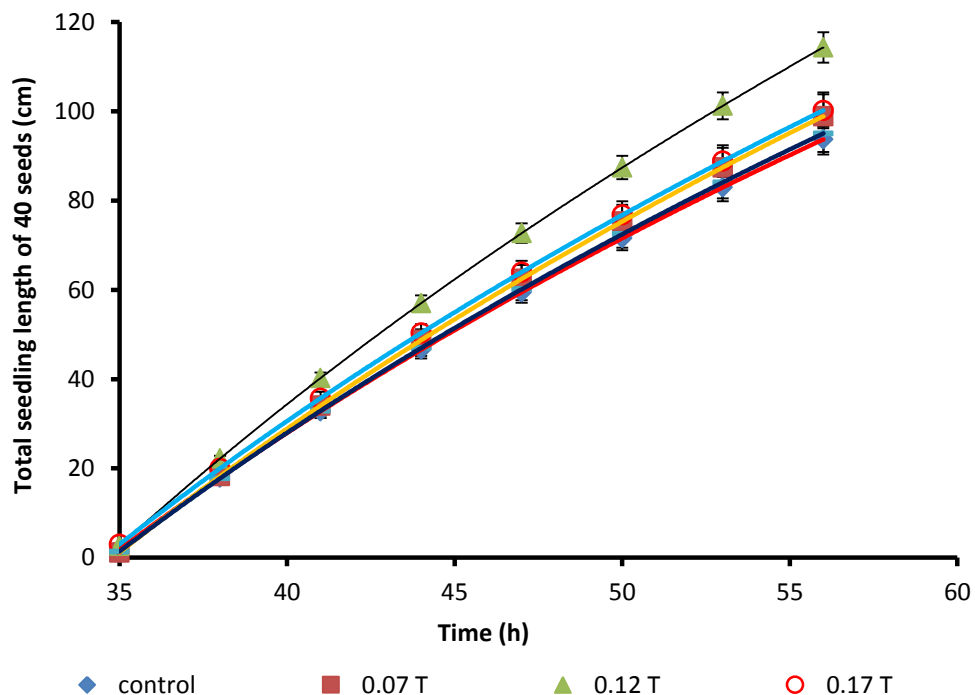
Figure 5.32 e

**Figure 5.32 (a-e):** Variation of un-germinated seeds with time in the samples.



**Figure 5.33:** Variation in the mean germination time, transition time and time taken for the first seed to germinate for the magnetically treated seeds.

Seedling length of 40 seeds (in total) is measured and is shown in Figure 5.34. Maize seeds upon treatment with magnetic field soaked slightly more water. It implies that effect of magnetic field on the germination of maize seed is very small. The present experimental data (Figure 5.30) fitted well in the equation  $w = C_1 \times \ln(t) \pm C_2$  where  $w$  is % seed water content. The data justifies to Mahajan and Pandey water uptake model (3.18). Germinating data of Maize seeds (Figure 5.31) treated with variable magnetic-field fitted well in Re-formulated Malthus-Verhulst equation  $N_g(t) = N_k N_i / [N_i + (N_k - N_i) \exp \{-\alpha N_k (t - t_o)\}]$  (equation 3.5). It is clear from Figure 5.31 that germination capacity is maximum at 0.12 mT. The result is in coincidence with the water absorption curves at 0.12 T. Using Re-formulated Malthus-Verhulst the germination rate- coefficient was determined by minimizing the residual sum of squares and executing the best possible fit for the growth model for the data. In the present case  $\alpha$  values are improved by magnetic-field treatments, especially at 0.12 and 0.17 T. A simple approach to Stochastic model is verified experimentally (Equation 3.21, Figure 5.32) and is used to find a constant called germinating magnetic constant  $\lambda_{B,T}$ . The germinating magnetic constant  $\lambda_{B,T}$  is in turn used to find the value of transition time (equation 3.25). The trend of the variation in transition time matched at all field values from the trend of variation in mean germination time as shown in Figure 5.33. Presently, it has been proved theoretically (equation 3.21) and verified experimentally (Figure 5.32) that there



**Figure 5.34:** Variation of total seedling length of 40 seeds with time.

are only two states; un-germinated and germinated and transition takes place between these two states only. As shown in Figure 5.33 that there is small improvement in mean germination time, transition time and time taken for first seed to germinate with magnetic treatment specially at 0.12 and 0.17 T. Maximum improvement in mean germination time is observed at 0.12 T (1.7h relative to control) and minimum at 0.07 T (0.8 h). Flórez [3] also studied the effect of exposure of maize seeds to stationary magnetic fields (125 or 250 mT for different periods of time) and showed improvement in mean germination time and the time required to obtain 10, 25, 50, 75 and 90% of seeds to germinate. Seedling length of 40 seeds (in total) (Fig. 5) have shown a logarithmic trend with equations:  $L_{\text{control}} = 195.49 \ln(t) - 693.2$ ,  $L_{0.07 \text{ T}} = 207.99 \ln(t) - 738.35$ ,  $L_{0.12 \text{ T}} = 237.6 \ln(t) - 842.11$ ,  $L_{0.17 \text{ T}} = 206.88 \ln(t) - 732.55$ ,  $L_{0.21 \text{ T}} = 199.35 \ln(t) - 707.4$  ( the data fitting coefficient for all curves:  $R^2 > 0.99$ ). Maximum improvement in seedling length is obtained at 0.12 and 0.17 T. The result of seedling length variation is coinciding with the variation in rate of water uptake statistics. Biological stimulation and chemical properties of fruit serum plays an important role in optimizing crops yield [36, 37]. Chemical treatments are often used to enhance seed vigour and plant growth by influencing the biochemical processes. However, the main advantage of using magnetic stimulation methods over traditional chemical processes is the absence of toxic residues.

## References

- [1] Belyavskaya N., Biological effects due to weak magnetic field on plants, *Advances in Space Research*, **34**, 7, 1566-1574, 2004.
- [2] Marks N., and Szecówka P., Impact of variable magnetic field stimulation on growth of aboveground parts of potato plants, *Int. Agrophys*, **24**, 165-170, 2010.
- [3] Florez M., Carbonell M. V., and Martínez E., Exposure of maize seeds to stationary magnetic fields: Effects on germination and early growth, *Environmental and Experimental Botany*, **59**, 1, 68-75, 2007.
- [4] Aladjadjiyan A., Study of the influence of magnetic field on some biological characteristics of *Zea mays*, *Journal of Central European Agriculture*, **3**, 2, 89-94, 2002.
- [5] Lev-Yadun S., Gopher A., and Abbo S., The cradle of agriculture, *Science*, **288**, 5471, 1602-1603, 2000.
- [6] Jukanti A., Gaur P., Gowda C. *et al.*, Nutritional quality and health benefits of chickpea (*Cicer arietinum* L.): a review, *British Journal of Nutrition*, **108**, S1, S11-S26, 2012.
- [7] Frimpong A., Sinha A., Tar'an B. *et al.*, Genotype and growing environment influence chickpea (*Cicer arietinum* L.) seed composition, *Journal of the Science of Food and Agriculture*, **89**, 12, 2052-2063, 2009.

- [8] Pande S., Siddique K., Kishore G. *et al.*, Ascochyta blight of chickpea (*Cicer arietinum* L.): a review of biology, pathogenicity, and disease management, *Crop and Pasture Science*, **56**, 4, 317-332, 2005.
- [9] Wilson C., and Tisdell C., Why farmers continue to use pesticides despite environmental, health and sustainability costs, *Ecological Economics*, **39**, 3, 449-462, 2001.
- [10] Arshad M., Bakhsh A., and Ghafoor A., Path coefficient analysis in chickpea (*Cicer arietinum* L.) under rainfed conditions, *Pakistan Journal of Botany*, **36**, 1, 75-82, 2004.
- [11] Pietruszewski S., and Kania K., Effect of magnetic field on germination and yield of wheat, *International Agrophysics*, **24**, 297-302., 2010.
- [12] Tseng S., and Hsu J. P., A Stochastic Analysis of Seed Germination, *Botanical Bulletin of Academia Sinica*, **30**, 201-205., 1989.
- [13] Vashisth A., Joshi D. K., and Singh R., Characterization of water uptake and distribution in chickpea (*Cicer arietinum* L.) seeds during germination by NMR spectroscopy, *African Journal of Biotechnology*, **11**, 59, 12286-12297., 2012.
- [14] Vashisth A., and Nagarajan S., Exposure of seeds to static magnetic field enhances germination and early growth characteristics in chickpea (*Cicer arietinum* L.), *Bioelectromagnetics*, **29**, 7, 571–8, 2008.
- [15] Grewal H. S., and Maheshwari B. L., Magnetic treatment of irrigation water and snow pea and chickpea seeds enhances early growth and nutrient contents of seedlings, *Bioelectromagnetics*, **32**, 1, 58-65, 2011.
- [16] Mahajan T. S., and Pandey O. P., Magnetic-time model for seed germination, *African Journal of Biotechnology*, **11**, 88, 15415-15421, 2012.
- [17] Mahajan T. S., and Pandey O. P., Magnetic-time Model at off Season Germination, *International Agrophysics*, **28**, 1, Accepted In Press doi: 10.2478, 2014.
- [18] Dhawi F., Al-Khayri J. M., and Hassan E., Static magnetic field influence on elements composition in date palm (*Phoenix dactylifera* L.), *Res J Agric Biol Sci*, **5**, 161-166, 2009.
- [19] Mahajan T. S., and Pandey O. P., Magnetic-time Model at off Season Germination, *International Agrophysics*, **Accepted**, 2013.
- [20] Goodman R., and Blank M., Insights into electromagnetic interaction mechanisms, *Journal of cellular physiology*, **192**, 1, 16-22, 2002.
- [21] Moon J.-D., and Chung H.-S., Acceleration of germination of tomato seed by applying AC electric and magnetic fields, *Journal of Electrostatics*, **48**, 2, 103-114, 2000.
- [22] Aladjadjian A., and Ylieva T., Influence of stationary magnetic field on the early stages of the development of tobacco seeds (*Nicotiana Tabacum* L.). *Journal of Central European Agriculture*, **4**, 2, 131–137, 2003.
- [23] Lana D. P., and Julia W. M. "Momordica Charantia: Boston Healing Landscape Project," Boston University School of Medicine, or Boston Medical Center.2012.
- [24] Aladjadjian A., Influence of stationary magnetic field on lentil seeds, *Int. Agrophys*, **24**, 321-324, 2010.
- [25] Bhatnagar D., and Dev A. R., Some effect of pregermination exposure of wheat seeds to magnetic field. II. Effects on some physiological processes, *Seed Research*, **6**, 1, 14-22, 1978.
- [26] Sharaf El-Deen S., Improvement of some characters of edible mushroom with magnetic field, *Bull NRC Egypt*, **28**, 709-717, 2003.
- [27] Yao Y., Li Y., Yang Y. *et al.*, Effect of seed pretreatment by magnetic field on the sensitivity of cucumber (*Cucumis sativus*) seedlings to ultraviolet-B radiation, *Environmental and Experimental Botany*, **54**, 3, 286-294, 2005.

- [28] Morton J. F., *The wax gourd, a year-round Florida vegetable with unusual keeping quality*: State horticultural society, 1971.
- [29] Martínez E., Flórez M., Maqueda R. *et al.*, Pea (*Pisum sativum*, L.) and lentil (*Lens culinaris*, Medik) growth stimulation due to exposure to 125 and 250 mT stationary fields, *Polish Journal of Environmental Studies*, **18**, 4, 657-663, 2009.
- [30] Martinez E., Carbonell M. V., and Amaya J. M., A static magnetic field of 125 mT stimulates the initial growth stages of barley (*Hordeum vulgare* L.), *Electromagnetic Biology and Medicine*, **19**, 3, 271-277, 2000.
- [31] Martínez E., Carbonell M., Flórez M. *et al.*, Germination of tomato seeds (*Lycopersicon esculentum* L) under magnetic field, *International Agrophysics*, **23**, 1, 45-49, 2009.
- [32] Mahajan T. S., and Pandey O. P., Re-formulation of Malthus-Verhulst equation for black gram (*Cicer arietinum* L.) seeds pre-treated with magnetic field, *International Agrophysics*, **25**, 4, 355-359, 2011.
- [33] Government\_of\_India M. E. F., *Series of crop specific biology documents Biology of Okra*, Department of Biotechnology : Ministry of science & Technology Government of india., 2013.
- [34] Eşitken A., and Turan M., Alternating magnetic field effects on yield and plant nutrient element composition of strawberry (*Fragaria x ananassa* cv. Camarosa), *Acta Agriculturae Scandinavica, Section B-Soil & Plant Science*, **54**, 3, 135-139, 2004.
- [35] Jamil Y., Iqbal M., Perveen T. *et al.*, Enhancement in growth and yield of mushroom using magnetic field treatment, *International Agrophysics*, **26**, 375-380, 2012.
- [36] Sleper D., Pathan M., Camps-Raga B. *et al.*, Experimental analysis of corn seed germination enhancement under the application of electromagnetic and magnetic fields, *Proceeding of the European Electromagnetics (EUROEM 2008), Lausanne, Switzerland*, 2008.
- [37] Singh G., Tarsikka P., and Singh H., Effect of ionic and non-ionic salts on viscosity and electrical conductivity of orange and tomato fruit serum, *journal of food science and technology-mysore*, **45**, 4, 368-370, 2008.

## Chapter 6

# Conclusions and Future Scope

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### Overview

This chapter describes the conclusions drawn from the work presented on the electric and magnetic-field exposure of seeds. Apart from this, the future scope of the developed models and requirement of more work on different seeds has been given.

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## 6. CONCLUSIONS

### 6.1 Electric exposure

Application of electric fields on the seed provides means for sensing those processes which are responsible for seed germination. The effect of electric treatment depends upon the strength of external stimulus, which invokes inductive effect, i.e. the effect that persists even after the field has been removed. The effect of the field manifests more if it is of some resonating value. At the resonating level, the field acts as maximum stimulus and changes the seed germination parameters. It is found that low electric field improves the early germination parameters. However, higher electric field gives retardation to germination yield. Seeds are dielectric. When they are, exposed to the electric field then field inside the seed gets modified. Present experimental data of seed germination and water uptake on different electrically treated seed species [Chickpea (*Cicer arietinum* L.), Mung bean (*Vigna Radiata*), Bitter Gourd (*Momordica Charantia*), Spinach (*Spinacia oleracea* L.), White gourd (*Benincasa hispida*), Okra (*Abelmoschus esculentus* L.) and Maize (*Zea mays* L.)] show a change in water uptake and germination capacity. The change in water uptake and germination capacity of electrically treated seeds can be explained with ferroelectric nature of seed. When the seeds are taken out after the electrical exposure then they retain some polarization where a small magnitude of electric dipole moment is left inside the seed even upon removal of the electric field (Ferro-electricity). Water is a polar molecule. A dipole-dipole interaction (interaction between water dipoles and electrically stressed dipoles inside the seed) leads to either delay in water absorption or increased in water absorption. The results obtained in the present research indicate that the internal energy of the seed responds more when there is an appropriate combination of the electric field and exposure time. The conclusion drawn from the present study of electric field treatment of all the studied seeds are given in Table 6.1.

**Table 6.1:** Effect of electric field on different seed species

Seed	Effect of electric exposure
Chickpea	<ul style="list-style-type: none"> <li>✚ The pre-sowing electric field treatment on chickpea seed introduces delay in water uptake.</li> <li>✚ Around 470 V/cm 15 minutes electric field exposure at 13 °C to chickpea seed is critical as at this value, there is the maximum delay in water absorption. This delay increases mean germination time, transition time and time taken for first seed to germinate.</li> <li>✚ The coefficient of water uptake is maximum at 470 V/cm (15 minutes exposure). It improves the post germination factors like root length and shoot length of 28-day old plant.</li> <li>✚ Seeds exhibit ferroelectric properties.</li> <li>✚ Dipole-dipole interactions are responsible for delay or acceleration in water absorption.</li> <li>✚ Ferroelectric effect of the seeds decreases linearly with an increase in temperature.</li> </ul>
Mung	<ul style="list-style-type: none"> <li>➤ Stimulating field resonated to Mung (<i>Vigna radiate</i>) to a greater extent that lie between 300 to 700 V/cm for 20-minute exposure time.</li> <li>➤ Above 1000 V/cm some retarding trend in germination time, transition time, water uptake, and germination capacity is observed.</li> </ul>
Bitter-gourd	<ul style="list-style-type: none"> <li>• The electric field stimulates Bitter gourd seeds positively at lower levels and has a retarding effect on germination at higher levels.</li> <li>• In the off-season, electrically treated seeds (500 V/cm) provided the same amount of germination (approximately) as the control seeds in their best season.</li> </ul>
Ash-gourd	<ul style="list-style-type: none"> <li>✚ Pre-treatment to seeds of Ash gourd with the electric field alters the water uptake, transition time and mean germination time.</li> </ul>

Okra	<ul style="list-style-type: none"> <li>✚ Lower level of the electric field responded positively to seed germination parameters as compared to a higher level of the electric field.</li> <li>❖ Pre-treatment to okra seeds with the electric field alters the water uptake, transition time and mean germination time.</li> <li>❖ Lower level of the electric field responded positively to seed germination parameters as compared to a higher level of the electric field.</li> </ul>
Spinach	<ul style="list-style-type: none"> <li>✓ With applying electric field water absorption increases but more water absorption retards to germination.</li> <li>✓ Mean germination time become almost doubled as compared to control at 1000V/cm and 20 minute electrical treatment.</li> </ul>
Maize	<ul style="list-style-type: none"> <li>○ Stimulating field resonated to maize to a greater extent at 500 V for 20-minute exposure time.</li> </ul>

## 6.2 Magnetic Exposure

By analysing the seed germination data and water uptake, it is observed that the effect of magnetic treatment on seed manifests itself by inducing magnetization into the seed, which persists even after the removal of the field called residual magnetisation. Magnetically treated seeds showed a change in water uptake and germination capacity. On the basis of the magnetic model investigated seeds can be classified into two classes.

- (1) Those seeds which obey to magnetic time model.
- (2) Those seeds which do not obey to magnetic time model.

The seeds that obey to magnetic time model are ‘Chickpea (*Cicer arietinum* L.), Mung bean (*Vigna Radiata*) and Bitter Gourd (*Momordica Charantia*)]. These types of seeds give continuous response to the magnetic field towards germination capacity and water uptake. Therefore, they are more sensitive to the magnetic field. On the other hand, the type of seeds like ‘Spinach (*Spinacia oleracea* L.), White gourd (*Benincasa hispida*), Okra (*Abelmoschus esculentus* L.) and Maize (*Zea mays* L.)’ which do not give a continuous response towards

germination are sensitive to some levels of magnetic field. The conclusion drawn from the present study of magnetic field treatment of all the studied seeds are given in Table 6.2.

**Table 6.2:** Effect of magnetic field on different seed species.

Seed	Effect of magnetic exposure
Chickpea	<ul style="list-style-type: none"> <li>➤ Germinating data showed a linear relation between applied magnetic field and germination rate (<math>B = 18.515 g(r) - 0.2727</math>).</li> <li>➤ Magnetic-time model worked well for <i>Cicer arietinum</i> L. seeds.</li> </ul>
Mung	<ul style="list-style-type: none"> <li>✚ There is great improvement in mean germination time, transition time and time taken for first seed to germinate.</li> <li>✚ Magnetic-time model works well for <i>Vigna radiata</i> seeds (<math>B = 18.253 \times g(r) - 0.6443</math>).</li> </ul>
Bitter-gourd	<ul style="list-style-type: none"> <li>❖ The pre-treated <i>Momordica charantia</i> seeds also support the magnetic-time model (<math>B = 174.02g(r) - 1.815</math>).</li> <li>❖ Germinating data showed a linear relation between applied magnetic field and germination rate.</li> </ul>
Ash-gourd	<ul style="list-style-type: none"> <li>• The behaviour of a magnetic field on seed germination is similar to that of electric field, showing a positive stimulation on germination at lower values and retarding effect at higher values.</li> </ul>
Okra	<ul style="list-style-type: none"> <li>➤ Maximum dip in water uptake by the Okra seed is observed at 0.12 T and minimum is at 0.21 T.</li> <li>➤ There is improvement in mean germination time, transition time and time taken for first seed to germinate with magnetic treatment. Maximum improvement is observed at 0.17 T and minimum at 0.12 T.</li> </ul>
Spinach	<ul style="list-style-type: none"> <li>❖ Maximum dip in water uptake by the <i>Spinacia oleracea</i> L. seed is observed at 0.07 T.</li> <li>❖ There is improvement in mean germination time, transition time and</li> </ul>

Maize	<p>time taken for first seed to germinate with magnetic treatment. Maximum improvement in mean germination time is observed at 0.07 T.</p> <p>.</p> <ul style="list-style-type: none"> <li>✚ Magnetically treated Maize seeds soaked little bit more water as compared to control. It implies that effect of magnetic field on the germination of maize seed is very small. Maximum increase in water uptake by the maize seed is observed at 0.12 T.</li> <li>✚ There is small improvement in mean germination time, transition time and time taken for first seed to germinate with magnetic treatment (0.12 to 0.17 T) maximum improvement in mean germination time is observed at 0.12 T and minimum at 0.07 T.</li> </ul>
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### 6.3 Overall Summary

In 1865, James Clerk Maxwell proposed four Maxwell's equations governing the dynamics of electric fields, magnetic fields and electric charges. It showed that magnetic interactions and motion of electric charges were intrinsically coupled to each other. These equations reflect the unified nature of magnetism and electricity. Equivalence of the equations of electrostatics and magnetostatics in polarizable media explains similarities in the behaviour of ferroelectrics and ferromagnets. If in some material, magnetism and ferroelectricity coexist, then that material is called multiferroics. These materials are very rare in nature because magnetism and ferroelectricity are of contrasting origin [1]. As a consequence, simultaneous occurrence of ferromagnetism and ferroelectricity is hard to be achieved, especially at room temperature [2]. Seed contains amino acid and proteins. It is found that one-third of all proteins and enzymes contain transition metals such as iron, copper, zinc, manganese, molybdenum and cobalt, which, due to their properties (density, small atomic radius, electromagnetic interaction and electrostatic forces) are associated to metalloproteins [3]. Metalloprotein is a generic term for a protein that contains a metal ion. Metal ions are bonded to specific proteins or enzymes that exert their effects on many metabolic processes. Metal ions, play an important role in biological activity, especially in seed germination when the seeds are treated with magnetic field. The seeds retain some magnetism called residual magnetism. The reason for acquiring residual magnetism may be due to the presence of metalloproteins. Electric dipoles can be induced by magnetism [1]. These electric dipoles formed inside the seed interacts with the

water dipole present outside the seed. Dipole-dipole interaction takes place, which changes the water uptake and hence the germination capacity. Present data showed a change in water uptake and germination capacity of all magnetically treated seed species. On the other hand, seed also contains nitrogen (amino group) with a lone pair also. Therefore, seeds are also dielectric. When they are treated with electric field before sowing, they retain some electric dipole moments called residual polarization. This causes a change in water uptake and germination capacity, because of interaction of residual polarization and water dipoles. This proved that seeds are ferroelectric. Hence ferroelectric and ferromagnetic are coexisting in the seed. This study opens a new path to think over it where it demonstrates that seeds are multiferroics in nature.

Botanist and agriculture scientist are using mean germination time of a seed sample. The limitation of using mean germination time was that we have to specify the number of seeds in a sample. Mean germination time is a function of number of seeds in a sample. Presently, a transition time parameter has been introduced. The plus point of using transition time is that it signifies to mean germination time, which is also independent from the number of seeds in a sample. It only depends upon the nature of decaying (exponential) curve. The germination data obtained experimentally is analysed using reformulated MV function. It was thought that germination coefficient  $\alpha$  of MV function signifies to germination yield. This thought was corrected by pointing out that  $\alpha$  value does not signify any definite result as such. Moreover, this value became important for taking its reciprocal and adding some initial time into it. Newly formulated magnetic time model was tested upon a number of seed species. It is found that Chickpea (*Cicer arietinum* L.), Mung bean (*Vigna Radiata*) and Bitter Gourd (*Momordica Charantia*) justified to magnetic time model. These seeds have given a linear improvement with applied magnetic field. Whereas, some other seeds were sensitive to some specific levels of magnetic field. The formulated water uptake model worked well for almost all seed species. A simple statistical approach which is slightly different from the Stochastic model is presented and applied to all different seed species. It is shown that germinating process is a two-state process and not a multistate process as was assumed in the Stochastic model. This model generates a new constant called germinating magnetic constant  $\lambda_{B,T}$  for magnetic field and germinating electric constant  $\lambda_{E,T}$  for electric field. This germinating constant is important to know where it measures numerically the effect of electric and magnetic field on seed germination. Moreover, it also defines the transition time.

## 6.4 Future Scope

Understanding of highly complex fundamental mechanisms and interactions of electric and magnetic fields with biological systems is still incomplete and requires hard work to understand the mechanism. There is a scope to find why some seeds have shown linear response to germination yield with continuous improvement in germination time, whereas, some other seeds do not. It is found that seeds under investigation were sensitive to some level of the electric field. There is further scope to investigate the seed microscopically to know the seed element which resonates or stimulates at some particular field level. In the present research, the seeds were tested under low electric field around 0 to 1200 V/cm. Moreover, its response of the higher field above 1200V/cm, is still to be investigated. Presently, the seeds were exposed to the electric and magnetic field in dry conditions before sowing. There is still a potential to investigate it under wet conditions. Presently, the seeds were pre-treated with the electric and magnetic field, there is another thrust area of research when the fields would be exposed during germination. Presently, seven seed species have been investigated under electric and magnetic field. The work can be extended to many other seeds also.

## References

- [1] Cheong S.-W., and Mostovoy M., Multiferroics: a magnetic twist for ferroelectricity, *Nature materials*, **6**, 1, 13-20, 2007.
- [2] Hill N. A., Why are there so few magnetic ferroelectrics?, *The Journal of Physical Chemistry B*, **104**, 29, 6694-6709, 2000.
- [3] Sussulini A., Garcia J. S., Mesko M. F. *et al.*, Evaluation of soybean seed protein extraction focusing on metalloprotein analysis, *Microchimica Acta*, **158**, 1-2, 173-180, 2007.