COMPARISON EFFECT OF PULSE-POWER GENERATED ELECTROMAGNETIC FIELD ON THE GROWTH RATE OF GREEN SOYBEAN

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requirements for the award of the degree of
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In the name of Allah, Most Gracious, Most Merciful

This thesis is dedicated

To my beloved parents Zawahir Ismail and Ruhani Mat Hussin for their priceless sacrifices and supports

To my supportive sisters and brothers

To my beloved wife Nurhasyyati Zahri

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ABSTRACT

This research is to investigate and make preliminary comparison on the effect 50 Hz sine waveform of pulsed magnetic field on the growth rate of green soybean with a variety of magnetic field values (600 mG, 100 mG, 70 mG, 20 mG, 8 mG and 3 mG). A circuit consisting of excitation ferrite-core coil, diode, power MOSFET, resistor, function generator and power supply has been designed and developed to generate pulse magnetic field. It has the ability to produce a stable value of magnetic field operating at a frequency of 50 Hz. Selected green soybean seeds were exposed to three types of waveforms, namely sine wave, square wave and sawtooth wave at 50 Hz. In the experiment, 400 seeds of green soybean arranged in a straight line were exposed to magnetic field in the range of 3 to 600 mG. Values of the magnetic field have been determined by the distance between source (excitation ferrite-core coil) and subject (green soybean). The experiment was conducted for a duration of seven days and samples were taken randomly. The experiment was conducted into two different parts: in the first three days the experiment was conducted in the dark and second four successive day of experiment was conducted under daylight. The results of sine wave show that six magnetic field values at root inhibit the germination rate while six magnetic field values at hypocotyls part has sped up growth rate. Moreover, growth rate at leaf part has been sped up but only for 70 mG magnetic field. In the sawtooth experiment, only three magnetic values (20 mG, 8 mG and 3 mG) show speed up progress on growth rate, while others show the sign of decreasing germination and growth rates for root and leaf part. Lastly, for the square wave, all the seeds were exposed to six different magnetic field values (600 mG, 100 mG, 70 mG, 20 mG, 8 mG and 3 mG) and the result show that the germination and growth rates for root, hypocotyls and leaf were inhibited. As a conclusion, the most pronounce effect of different waveform was sine waveform that affect to speed up the growth rate of hypocotyls and leaf.

ABSTRAK

Kajian ini adalah untuk mengkaji dan membuat perbandingan ke atas kesan awal 50 Hz bentuk gelombang sinus denyutan medan magnet kepada kadar pertumbuhan kacang soya hijau dengan pelbagai nilai medan magnet (600 mG, 100 mG, 70 mG, 20 mG, 8 mG dan 3 mG). Sebuah litar yang terdiri daripada gegelung pengujaan berteras ferit, diod, MOSFET kuasa, perintang, penjana fungsi dan bekalan kuasa telah direka dan dibangunkan untuk menjana denyutan medan magnet. Ia mempunyai keupayaan untuk menghasilkan nilai medan magnet yang stabil yang beroperasi pada frekuensi 50 Hz. Benih kacang soya hijau terpilih didedahkan kepada tiga jenis bentuk gelombang iaitu gelombang sinus, gelombang segi empat dan gelombang gerigi pada 50 Hz. Dalam eksperimen, 400 biji kacang soya hijau disusun dalam satu barisan lurus didedahkan kepada medan magnet dalam julat 3 hingga 600 mG. Nilai medan magnet telah ditentukan oleh jarak antara sumber (gegelung pengujaan teras ferit) dan subjek (kacang soya hijau). Eksperimen telah dilakukan selama tujuh hari dan sampel diambil secara rawak. Eksperimen dilakukan dalam dua bahagian yang berbeza: dalam tiga hari pertama eksperimen dilakukan dalam gelap dan empat hari berturut-turut eksperimen dilakukan di siang hari. Keputusan gelombang sinus menunjukkan, 6 nilai medan magnet pada akar menghalang kadar percambahan manakala 6 nilai medan magnet pada bahagian hipokotil telah mempercepatkan kadar pertumbuhan. Selain itu, kadar pertumbuhan pada bahagian daun juga telah dipercepatkan tetapi hanya untuk 70 mG medan magnet. Dalam eksperimen gelombang gergaji, hanya 3 nilai medan magnet (20 mG, 8 mG dan 3 mG) menunjukkan peningkatan kemajuan ke atas kadar pertumbuhan. Manakala yang lain menunjukkan tanda penurunan kadar percambahan dan kadar pertumbuhan untuk bahagian akar dan daun. Akhir sekali untuk gelombang segi empat, kesemua biji yang terdedah kepada 6 nilai medan magnet (600 mG, 100 mG, 70 mG, 20 mG, 8 mG dan 3 mG) yang berbeza dan keputusan menunjukkan kadar percambahan dan pertumbuhan untuk akar, hipokotil dan daun terhalang. Sebagai kesimpulan, kesan sebahagian besar bentuk gelombang yang berbeza adalah bentuk gelombang sinus yang memberi kesan peningkatan kepada kadar pertumbuhan hipokotil dan daun.

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LIST OF ABBREVIATIONS

AMF	-	Alternating Magnetic Field
ANOVA	-	Analysis of Variance
DC	-	Direc Current
DFB	-	Degrees of freedom between
DFW	-	Degrees of freedom within
ELF	-	Extreme Low Frequency
EF	-	Electric Field
MF	-	Magnetic field
MFT	-	Magnetic Field Treatment
EMPT	-	Electromagnetic Pulse Therapy
EMT	-	Electromagnetic Therapy
FEMM	-	Finite Element Method Magnetic
MOSFET	-	Metal Oxide Semiconductor Field Effect Transistor
MSB	-	mean square between
MSW	-	mean square within
PCB	-	Printerd Circuit Board
PEFT	-	Pulsed Electric Field Treatment
PMFT	-	Pulse Magnetic Field Treatment
SMF	-	Static Magnetic Field
SPSS	-	Statistical Package for the Social Sciences

LIST OF SYMBOLS

α	-	Significance Level
mT	-	milli Tesla
T	-	Tesla
mG	-	milli Gauss
μT	-	micro Tesla
nm	-	nanometer
$^\circ$	-	Degree
C	-	Celcius
Hz	-	Hertz
kHz	-	kilo Hertz
MHz	-	Mega Hertz
μs	-	microsecond
s	-	second
h	-	hour
mm	-	milimeter
cm	-	centimeter
m	-	meter
%	-	Percent
V	-	Voltage
V_{pp}	-	Voltage Peak to Peak
kA	-	kilo Ampere
mg	-	mili gram
RH	-	Relative Humidity
H_0	-	Null Hypothesis
H_1	-	Alternative Hypothesis
μ_1	-	mean 1
μ_2	-	mean 2
T	-	Student T-Test
$\bar{x}$	-	sample average x
$\bar{y}$	-	sample average y

$S_x{}^2$	-	sample variance x
$S_y{}^2$	-	sample variance y
n_1	-	number of observation x
n_2	-	number of observation y
F	-	F statistic
β	-	Electromagnetic Field
μ_0	-	Relative Permeability material
i	-	current
N	-	number of turn
π	-	pi
r	-	Radial Distance
X_L	-	Inductive Reactance
L	-	Inductance
ω	-	Omega

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CHAPTER 1

INTRODUCTION

Living matters communicate with many mechanisms, depending on complexity of the biological environment. Intracellular interactions are the mechanisms of communication between cells which closely related to the chemical and electrical signalling. Change in voltage gradients often correlates with morphogenetic events during growth patterning of plants and animals [1]. Human activities that produce an electric field (EF) and a magnetic field (MF) give strength to an effect of natural phenomena on plants. EF is a field of force surrounding a charged particle, while ME is a field of force surrounding a moving charged particle. EF and MF are always related with each other because a charged particle always has an MF and an EF [2].

The variety of intensities of MF and EF are used in several applications including electronic equipment, food sterilization, medical diagnostics, medical therapies and levitation. For direct biological applications, high intensity MF and EF have been used due to their damage effects on biological samples. Moreover, beneficial effect on living organisms had been reported by using weak MF and EF. As a way of regulating the biological activity of these systems, knowledge on the mechanisms of the MF and EF action on various biological systems may effectively use [2, 3].

Investigations into the effect of MF on plants and seeds have been done since the late 1900s recommended that the growth and yield to plants would be improved more than chemical fertilizers and thus it contributes to the improvement on the crop productivity and protection. Other than that, a few countries have developed magnetic technologies that were environmentally friendly and non-polluting to the soil and were reasonably priced to farmers [4]. An affordable physical and potentially a safe method has been reported by using MF treatment of seeds to speed up the release of seeds from dormant state, to improve seed germination, plant growth and plant yield. Moreover, MF also affects in an increase in seed water uptake, enzymatic activity of seeds, essential nutrient uptake into leaves, chlorophyll pigment content, protection against heat stress and pathogens without adversely affecting the environment [4, 5, 6, 7, 8, 9]. Base on scientific debate, potential health risk cannot still be ruled out, even if the mechanistic, animal, and in vitro toxicology literature fail to demonstrate any consistent pattern across studies. Up to date, the scientific community is actively working to clarify all the existing controversies about this matter [10].

1.1 Problem Statement

Investigations into the effect of MF on plants have been performed by many researchers. Their investigations have covered a variety of aspects, for example physical considerations, such as the weight of fruits, length of shoot, the length of root, the length of leaf, the length of hypocotyls and etc. Moreover, they have also investigated the physiological changes in plants, such as nutrient element uptake, electroporation, cell volume changes due to water uptake and etc [11,12,13, 14, 15, 16,17]. Most experiments have been conducted in a condition of extreme low frequency (ELF), static MF or alternating MF [11, 12, 18, 19, 20].

In this research, the pulsed generator MF was developed to be a simple circuit and it could be compatible with use of a variety of ferrite-core coils. The important consideration is the limitation of a MF produced by the coil, so specific components will be placed in the circuit to stabilise the drive of the current to the coil. Also, the selected coils can pick-up three types of waveform square, triangle and sinusoidal waves.

Because of limitation of the experiment process, in the research, the selected subjects must have a short grow up duration. The selected subject is green soybean and considerations are genetics, size and weight of seeds; there are all important and may become the main factors affecting the results of the experiment. Moreover, orientation of green soybean position when exposed to a pulse MF should be considered in the design of experiment.

The main purpose of this research is to observe green soybean growth rate due to the exposure of MF intensities with a variety of waveforms.

1.2 Research Objectives

The target of this research is to compare effect of a variety of pulsed MF intensities on the green soybean plants with three types of waveform. Below are the research objectives:

- Design and fabricate a pulsed generator magnetic device that can control frequency in a certain range to get the necessary MF for the treatment.
- Choose suitable green soybean seeds and create suitable experimental methods.
- Implement the pulsed magnetic device to the green soybean seeds and observe the effect of MF exposure to the green soybean seeds.

1.3 Research Scopes

The scope of this research is to design a pulsed magnetic generator which can drive current to an excitation coil. In details, the generator was built with a circuit drive current and with a power supply to power up it. A function generator was used to pump in pulses to the designed circuit so that current could have been induced into the excitation coil to produce pulsed MF. A device called Gauss meter was used to measure the generated MF by the excitation coil.

The research scopes can be divided into two, experiment on circuit testing and experiment on treatment of exposing samples. For circuit testing, the developed hardware was tested on a few aspects such as the ability to generate MF, the MF magnitude and the sensing field. Meanwhile, experiment of exposing pulsed MF to the samples involves three stages. First stage is the selection of samples, criteria includes subject grow up rate and easy handling. Next stage is to design an experimental setup, which suitable with samples, so it will be easy to handle sample and collect data. The last stage is data analysis. Data collected being analysed by software and results will identify if further repetition experiment is needed.

1.4 Organisation of Thesis

Chapter 1 discusses the general history of treatment in the field of agriculture. This chapter also elaborates on the problem statement, research objectives and scope of this research.

Chapter 2 presents the literature review of magnetic treatment. Types of treatment and the recent investigations into the effect the EF and MF due to exposure of plant cells to the MF were described. This chapter also includes previous studies regarding the MF generator and the magnetic source, induction coil.

Chapter 3 describes the criteria of coil selection, the circuit design, the procedures of experiment and the biostatistician data analysis.

Chapter 4 discusses the results of the experiments and the data analysis in terms of sine, square and sawtooth waves.

Chapter 5 presents the conclusions and the recommendations for future work.

only. Sine wave, square wave and sawtooth experiments gave results of the inhibited germination and growth rates at root and leaf parts, as exception, there was one group of samples exposed to the sine wave MF resulted with a speed up growth rate for the leaf part.

5.2 Contribution to Treatment

This research provides a significant contribution in the agricultural field. The MF treatment for plant cells was performed. First,6 different values of magnetic field (600 mG, 100 mG, 70 mG, 20 mG, 8 mG and 3 mG), which could give different results were investigated. The results showed that the MF treatments could be used at a specific part such as root, hypocotyls or leaf. Results from experiments showed that sine wave had inhibit effect on root and leaf, but hypocotyls exposed to all the magnetic levels slightly effect with a speed up growth rate. Only 70 mG MF gave a slightly effect, to speed up the growth rate of the leaf.

Second contribution is to test square wave and sawtooth wave as the waveforms to the induced coil. Square wave experiments showed that it was suitable to slow down or inhibit the germination and growth rates for seeds and plant, in the test conditions around 50 Hz of all the tested 6 MF levels in this research. Sawtooth experiments showed a different result, where a speed up growth rate in20 mG, 8 mG or 3 mG exposed MF for the hypocotyls. Sawtooth experiment also inhibited the germination and growth rates for the exposed sample of root and leaf parts.

The third contribution is explored into the 50 Hz frequency, that it is not commonly implemented in Malaysia. The emitting frequency was in the range of 50-60 Hz, which was produced by an electrical equipment whereby inductions of the MF occurred in the electrical line. From the research, we can predict that a slightly exposure to an MF will cause side effects, either good or bad, on the animal and plant cells.

5.3 Recommendation for future work

This research can be improved further, especially the hardware part and the experimental procedures. For hardware development, circuit drive current can be redesign and rebuilt again for a more stable current and an easy to do experiment. The experimental procedures can be improved on the repetition rate of the treatments. Experiments can be conducted 3 or 5 times with a larger number of samples, which more than 400 samples, to get an average result. By doing so, it will give closely results near to the accurate results that a better data analysis can be produced. It is recommended to have a variety of seeds as samples, such as corn seeds, cucumber seeds, peanuts seeds and etc to enhance the subject samples.

REFERENCES

1. Levin, M. Bioelectromagnetics in morphogenesis. *Bioelectromagnetics*, 2003. 24(5): 295–315.
2. Cakmak, T., Cakmak, Z. E., Dumlupinar, R. and Tekinay, T. Analysis of apoplastic and symplastic antioxidant system in shallot leaves: Impacts of weak static electric and magnetic field. *Journal of Plant Physiology*, 2012. 169(11): 1066–1073.
3. Cakmak, T., Dumlupinar, R. and Erdal, S. Acceleration of germination and early growth of wheat and bean seedlings grown under various magnetic field and osmotic conditions. *Bioelectromagnetics*, 2010. 31(2): 120–129.
4. De Souza, A., GarcÃa, D., Sueiro, L. and Gilart, F. Improvement of the seed germination, growth and yield of onion plants by extremely low frequency non-uniform magnetic fields. *Scientia Horticulturae*, 2014. 176: 63–69.
5. Yao, Y., Li, Y., Yang, Y. and Li, C. Effect of seed pretreatment by magnetic field on the sensitivity of cucumber (Cucumis sativus) seedlings to ultraviolet-B radiation. *Environmental and Experimental Botany*, 2005. 54(3): 286–294.
6. Joseph, S., Anawar, H. M., Storer, P., Blackwell, P., Chia, C., Lin, Y., Munroe, P., Donne, S., Horvat, J., Wang, J. and Solaiman, Z. M. Effects of Enriched Biochars Containing Magnetic Iron Nanoparticles on Mycorrhizal Colonisation, Plant Growth, Nutrient Uptake and Soil Quality Improvement. *Pedosphere*, 2015. 25(5): 749–760.
7. Han, Z., Zeng, X. A., Yu, S. J., Zhang, B. S. and Chen, X. D. Effects of pulsed electric fields (PEF) treatment on physicochemical properties of potato starch. *Innovative Food Science and Emerging Technologies*, 2009. 10(4): 481–485.
8. Reina, F. G., Pascual, L. A. and Fundora, l. A. Influence of a stationary magnetic field on water relations in lettuce seeds. Part II: Experimental results. *Bioelectromagnetics*, 2001. 22(8): 596–602.
9. Markkanen, A., Juutilainen, J., Lang, S., Pelkonen, J., Rytomaa, T. and Naarala, J. Effects of 50Hz magnetic field on cell cycle kinetics and the colony forming ability of budding yeast exposed to ultraviolet radiation.

Bioelectromagnetics, 2001. 22(5): 345–350.

10. Marino, C., Galloni, P. and Merla, C. Biological Effects of Electromagnetic Fields. *Reference Module in Materials Science and Materials Engineering*. Elsevier.

11. 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*, 2010. 167(2): 149–156.

12. Esitken, 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 and Plant Science*, 2004. 54(3): 135–139.

13. Belyavskaya, N. A. Biological effects due to weak magnetic field on plants. *Advances in Space Research*, 2004. 34(7): 1566–1574.

14. Minorsky, P. V. Do geomagnetic variations affect plant function? *Journal of Atmospheric and Solar-Terrestrial Physics*, 2007. 69(14): 1770–1774.

15. Florez, M., Carbonell, M. V. and Martinez, E. Exposure of maize seeds to stationary magnetic fields: Effects on germination and early growth. *Environmental and Experimental Botany*, 2007. 59(1): 68–75.

16. Hong-Mei, W. Impact of Magnetic Field on Mung Bean Ultraweak Luminescence. *Image and Signal Processing, 2009. CISP '09. 2nd International Congress on*. 1–3.

17. Weaver, J. C. Electroporation of cells and tissues. *Plasma Science, IEEE Transactions on*, 2000. 28(1): 24–33.

18. Ben-Izhak Monselise, E., Parola, A. H. and Kost, D. Low-frequency electromagnetic fields induce a stress effect upon higher plants, as evident by the universal stress signal, alanine. *Biochemical and Biophysical Research Communications*, 2003. 302(2): 427–434.

19. A., A. Study of the influence of magnetic field on some biological characteristics of Zea mais. *Journal of Central European Agriculture*, 2002. 3(2): 89–94.

20. Yano, A., Hidaka, E., Fujiwara, K. and Iimoto, M. Induction of primary root curvature in radish seedlings in a static magnetic field. *Bioelectromagnetics*, 2001. 22(3): 194–199.

21. Leong, S. Y., Oey, I. and Burritt, D. J. Pulsed electric field improves the bioprotective capacity of purÃ©es for different coloured carrot cultivars

against H2O2-induced oxidative damage. *Food Chemistry*, 2016. 196: 654–664.

22. Hajnorouzi, A., Vaezzadeh, M., Ghanati, F., jamnezhad, H. and Nahidian, B. Growth promotion and a decrease of oxidative stress in maize seedlings by a combination of geomagnetic and weak electromagnetic fields. *Journal of Plant Physiology*, 2011. 168(10): 1123–1128.

23. Sakhnini, L. Influence of Ca2+ in biological stimulating effects of AC magnetic fields on germination of bean seeds. *Journal of Magnetism and Magnetic Materials*, 2007. 310(2, Part 3): e1032–e1034.

24. Poinapen, D., Brown, D. C. W. 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. *Journal of Plant Physiology*, 2013. 170(14): 1251–1258.

25. Smith, S. D. and Mays, R. Effect of pulsed magnetic fields on root development in plant cuttings: Preliminary observations. 1984, vol. 12. 567–573.

26. Kotnik, T., Kramar, P., Pucihar, G., Miklavcic, D. and Tarek, M. Cell membrane electroporation- Part 1: The phenomenon. *Electrical Insulation Magazine, IEEE*, 2012. 28(5): 14–23.

27. Weaver, J. C., Smith, K. C., Esser, A. T., Son, R. S. and Gowrishankar, T. R. A brief overview of electroporation pulse strength duration space: A region where additional intracellular effects are expected. *Bioelectrochemistry*, 2012. 87(0): 236–243.

28. de Gier, J. Permeability barriers formed by membrane lipids. *Bioelectrochemistry and Bioenergetics*, 1992. 27(1): 1–10.

29. Deamer DW, B. J. Permeability of lipid bilayers to water and ionic solutes. 1986, vol. 40. 167–188.

30. Jansen, M. and Blume, A. A comparative study of diffusive and osmotic water permeation across bilayers composed of phospholipids with different head groups and fatty acyl chains. *Biophysical Journal*, 1995. 68(3): 997–1008.

31. Knight, H. *Calcium Signaling during Abiotic Stress in Plants*, Academic Press, vol. Volume 195. 1999, 269–324.

32. Funk, R. H. W., Monsees, T. and ozkucur, N. Electromagnetic effects From cell biology to medicine. *Progress in Histochemistry and Cytochemistry*, 2009.

43(4): 177–264.

33. Okumura, T., Muramoto, Y. and Shimizu, N. Acceleration of plant growth by D.C. electric field. *Solid Dielectrics (ICSD), 2010 10th IEEE International Conference on*. 1–4.

34. Guderjan, M., Topfl, S., Angersbach, A. and Knorr, D. Impact of pulsed electric field treatment on the recovery and quality of plant oils. *Journal of Food Engineering*, 2005. 67(3): 281–287.

35. Nechitailo, G. and Gordeev, A. Effect of artificial electric fields on plants grown under microgravity conditions. *Advances in Space Research*, 2001. 28(4): 629–631.

36. Fincan, M. and Dejmek, P. In situ visualization of the effect of a pulsed electric field on plant tissue. *Journal of Food Engineering*, 2002. 55(3): 223–230.

37. Marino, A. A., Hart, F. X. and Reichmanis, M. Weak Electric Fields Affect Plant Development. *Biomedical Engineering, IEEE Transactions on*, 1983. BME-30(12): 833–834.

38. Hong, J., Chen, R., Zeng, X.-A. and Han, Z. Effect of pulsed electric fields assisted acetylation on morphological, structural and functional characteristics of potato starch. *Food Chemistry*, 2016. 192: 15–24.

39. Chi, H., Xu, K., Wu, X., Chen, Q., Xue, D., Song, C., Zhang, W. and Wang, P. Effect of acetylation on the properties of corn starch. *Food Chemistry*, 2008. 106(3): 923–928.

40. Wiktor, A., Sledz, M., Nowacka, M., Rybak, K., Chudoba, T., Lojkowski, W. and Witrowa-Rajchert, D. The impact of pulsed electric field treatment on selected bioactive compound content and color of plant tissue. *Innovative Food Science and Emerging Technologies*, 2015. 30: 69–78.

41. Klevanik, A. Magnetic-field effects on primary reactions in Photosystem I. *Biochimica et Biophysica Acta (BBA) - Bioenergetics*, 1996. 1275(3): 237–243.

42. Vaezzadeh, M., Noruzifar, E., Faezeh, G., Salehkotahi, M. and Mehdian, R. Excitation of plant growth in dormant temperature by steady magnetic field. *Journal of Magnetism and Magnetic Materials*, 2006. 302(1): 105–108.

43. Bilalis, D., Katsenios, N., Efthimiadou, A., Efthimiadis, P. and Karkanis, A. Pulsed electromagnetic fields effect in oregano rooting and vegetative propagation: A potential new organic method. *Acta Agriculturae Scandinavica, Section B Soil and Plant Science*, 2011. 62(1): 94–99.

44. Radhakrishnan, R. and Ranjitha Kumari, B. D. Pulsed magnetic field: A contemporary approach offers to enhance plant growth and yield of soybean. *Plant Physiology and Biochemistry*, 2012. 51: 139–144.

45. Iqbal, M., ul Haq, Z., Malik, A., Ayoub, C. M., Jamil, Y. and Nisar, J. Pre-sowing seed magnetic field stimulation: A good option to enhance bitter gourd germination, seedling growth and yield characteristics. *Biocatalysis and Agricultural Biotechnology*, 2016. 5: 30–37.

46. Shine, M., Guruprasad, K. and Anand, A. Enhancement of germination, growth, and photosynthesis in soybean by pre-treatment of seeds with magnetic field. *Bioelectromagnetics*, 2011. 32(6): 474–484.

47. Souza, A. D., Garci, D., Sueiro, L., Gilart, F., Porras, E. and Licea, L. Pre-sowing magnetic treatments of tomato seeds increase the growth and yield of plants. *Bioelectromagnetics*, 2006. 27(4): 247–257.

48. Anand, A., Nagarajan, S., Verma, A. P. S., Joshi, D. K., Pathak, P. C. and Bhardwaj, J. Pre-treatment of seeds with static magnetic field ameliorates soil water stress in seedlings of maize (Zea mays L.). *Indian Journal of Biochemistry and Biophysics*, 2012. 49: 63–70.

49. Iqbal, M., Haq, Z., Jamil, Y. and Ahmad, M. Effect of presowing magnetic treatment on properties of pea. *International Agrophysics*, 2012. 26(1): 25–31.

50. Muraji, M., Asai, T. and Tatebe, W. Primary root growth rate of Zea mays seedlings grown in an alternating magnetic field of different frequencies. *Bioelectrochemistry and Bioenergetics*, 1998. 44(2): 271–273.

51. Huang, H.-H. and Wang, S.-R. The effects of inverter magnetic fields on early seed germination of mung beans. *Bioelectromagnetics*, 2008. 29(8): 649–657.

52. Stange, B. C., Rowland, R. E., Rapley, B. I. and Podd, J. V. ELF magnetic fields increase amino acid uptake into Vicia faba L. Roots and Alter Ion movement across the plasma membrane. *Bioelectromagnetics*, 2002. 23(5): 347–354.

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

54. Zar, J. H. *Biostatistical Analysis*. 4th ed. Upper Saddle River, N.J.: Prentice Hall. 1999.

55. Triola, M. M. and Triola, M. F. *Biostatistics for the Biological and Health*

Sciences. Pearson international ed. New York: Pearson Education. 2006.