Beneficial effects of Extremely Low Frequency (ELF) Sinusoidal Magnetic Field (SMF) exposure on mineral and protein content of mungbean seeds and sprouts

R.M. Nair*, T. Leelapriya, K.S.Dhillip, V.N. Boddepalli and D.R. Ledesma

World Vegetable Center, South Asia, ICRISAT Campus, Patancheru-502 324, Hyderabad, Telengana, India.

ABSTRACT

Five mungbean [Vigna radiata (L.) Wilczek] lines (CN9-5, EC693363, Harsha, KPS-1 and NM 94) were subjected to three different Extremely Low Frequency (ELF) Sinusoidal Magnetic Field (SMF) treatments. Fresh seed lots were exposed to ELF-SMF for 5 hours/day for a total duration of 15 days. Three treatment combinations of ELF-SMF chosen for assessment and comparison were: T1-10Hz, 1500 ± 250 nanoTesla (nT), T2- 50Hz, 1500 ± 250nT and T3 - 100Hz, 1500 ± 250nT. Non-treated seeds were maintained as control (T4). Minerals (iron, calcium, zinc and total phosphorus) and protein contents were determined in both the control and test seed lots and sprout samples raised from them. The sprouting parameters were also recorded. All three ELF-SMF treatments were significant for calcium and total phosphorus content in the test seed samples when compared to control. In the case of sprouts, with respect to minerals, all the ELF-SMF treatments were significant for calcium content when compared to control. With respect to protein, sprouts from EC 693363 line recorded 8.3% increase in protein content in T1 (10Hz) while sprouts from Harsha line recorded 7.2% increase in protein content in T2 (50Hz) compared to their respective controls. No treatment effects were observed for the sprouting parameters.

Key words: ELF, Line, Magnetic treatment, Seed, Sinusoidal.

INTRODUCTION

The influence of magnetic field (both static and time-varying) on seed, plant growth and development is shaping into an exciting area of research. Recently Maffei (2014) reviewed the developments in this field including the possible role of geomagnetic field. The first report on the effect of magnetic field on plants was by Savostin (1930). Krylov and Tarakanova (1960) proposed auxin-like effect on germinating seeds by static magnetic field and termed it as magnetotropism. Increase in seedling growth, seed vigor and also crop yield in seeds treated with static magnetic fields were reported by Pietruszewski (1993). Promotion of cell elongation, Negishi et al., (1999) and ultra structural peculiarities such as a noticeable accumulation of lipid bodies and reduction of phytoferritin in plastids were recorded in pea seedlings treated with static magnetic fields by Belyavskaya (2001). Seeds treated by weak Extremely Low Frequency (ELF) Electromagnetic Field stimulation showed higher activity of enzymes controlling particular stages of seed germination, (Akseyonov et al., 2000) and free radical accumulation (Podleony et al., 2004). Increase in epicotyl length of pea (Pisum sativum L.) was observed when the seeds were subjected to low intensity static magnetic field (Yamashita et al., 2004). Varied effects were reported when seeds were treated with different combinations of frequency, intensity and durations of magnetic field treatments (Vashisth and Nagarajan, 2008). Increase in root length, root surface area and root volume were observed in chickpea (Cicer arietinum L.) after exposure to ELF electromagnetic field (Vashisth and Nagarajan, 2008). Findings of Shine et al., (2011) found increase in germination rate, seedling length, fresh weight, dry weight and vigor indices in soybean (Glycine max) seeds exposed to magnetic fields. Javed et al., (2011) found pretreated corn seeds with different electromagnetic treatments particularly 100 and 150 mT for 10 min significantly alleviated the drought-induced adverse effects on growth by improving photosynthesis, transpiration rate and stomatal conductance. Studies by Radhakrishnan and Kumari (2013) showed seeds of soybean exposed to pulsed magnetic field at frequencies of 10 and 100 Hz increased their germination rates.

It has become of increased importance to understand the behavior of induced magnetic field on seed germination kinetics and plant growth. The germination kinetics of seeds stimulated with a static magnetic field before sowing has been studied. Experimental data shows a linear decrease in mean germination time and maximum time which has been described using the reformulated Malthus-verhulst
equation (Mahajan and Pandey, 2011). Seed germination depends on several physico-chemical factors like temperature, water potential and light. The sensitivity to water absorption in seeds is more when exposed to ELF electromagnetic fields, raising metabolic driving of intracellular water dynamics accompanied by hydrogen bonding and breaking responsible for biological effects. These changes in cell-hydration in seeds depends on the age and environment factors such as temperature and humidity (Ayrapetyan and De, 2014). Lately, Cryptochromes, photolyase-like blue light receptors that can form radical pairs after exposure to blue light has been suggested to be a potential magnetoreceptor based on the proposition that radical pairs are involved in magnetoreception. Given radical-pair mechanism, oxidative stress appears (Yu et al., 2010) with weak magnetic field induction which could affect chemical reactions. It is known that metabolic processes in living organisms are linked by electrons transport. If the membrane permeability and ion transport processes were to be affected, it might be responsible for the acceleration of chlorophyll excitation by light (Repacholi and Greenebaum., 1999). The effect of magnetic field on the function of cryptochrome is under detailed investigation.

The focus of this study was primarily on the effect and causality of Extremely Low Frequency (ELF) sinusoidal Magnetic Field (SMF) treatment on the mineral and protein content of seeds of five mungbean lines [Vigna radiata (L.) Wilczek]. Additionally the effect on the sprouting parameters and nutritional quality of the sprouts from seeds exposed to ELF-SMF were also assessed.

MATERIALS AND METHODS

Controlled Magnetic Field (CMF) enclosures were used for generating the required Magnetic Field exposures.

**Controlled Magnetic Field (CMF) enclosure:** It is a modified four-member coil system (derived from the fundamental equations of a Fanselau-Braunbeck coil system) where the four coils are mounted co-axially and in co-planar fashion to form an enclosure (Fig.1) with the arrangement of the coils (inner set of two rings with a larger radius and a outer set of two rings with a smaller radius) governed by a unique ratio of distance to radius such that this arrangement allows a highly homogenous magnetic field to be generated within the inner set of two rings of the enclosure along the axis of the coil system for a given measure of current (in milli-Ampere).

The CMF enclosures designed and fabricated at Madras Institute of Magnetobiology, Chennai, India were carefully calibrated using high precision magnetometers and current measuring devices in the Magnetic Standardization Lab of the Institute. The high precision measurements involved in calibration derived a coil constant expressed in nano-Tesla (nT) per milli-ampere (mA) of current. The associated hardware for the CMF enclosures is a standard signal generator integrated with a meter assembly. The signal generator delivering the current to the CMF enclosure operates at 110/220V, 50/60 Hz at the primary end and at the secondary end deliver currents in the range of 10 to 100 milli Amperes (mA) at desired waveforms (typically sine, square and ramp) in varying frequencies (between 0.1 Hz to 1KHz) at voltages between 0.2 to 20 volts. The meter to measure the current delivered to the coil from the signal generator is a class 2 type (pre-calibrated) milli-ammeter. The design specifications of the CMF enclosures can be classed as “excellent” for magnetic fields generated in the extremely low frequency (less than 300 Hz) ultra-low intensity range (500 nT to 5000 nT).

**Magnetic Field Exposure:** Mungbean seeds were subjected to SMF’s of 3 different exposure combinations involving frequency and intensity. One Kg of each mungbean seed line (CN9-5, EC693363, Harsha, KPS-1 and NM 94) provided for the experiment by World Vegetable Center (harvested from kharif 2013 season crop grown in Hyderabad) were evenly divided into four parts by weight and they were subjected to 3 different exposure combinations (Test) group with the 4th part serving as Control.

The following exposure combinations were used for the experiment;

- **T1:** 10Hz, 1500nT ± 250nT, Sine wave - A
- **T2:** 50Hz, 1500nT ± 250nT, Sine wave - B
- **T3:** 100Hz, 1500nT ± 250nT, Sine wave – C
- **T4:** Control (Note: For SMF exposure combinations, first parameter denotes the frequency of the magnetic field, the second denotes the strength and the third the wave form of the magnetic field generated within the Controlled Magnetic Field (CMF) enclosures. Three CMF enclosures were used for test group and a 4th one without any exposure served as control.)

![Fig 1: Controlled Magnetic Field (CMF) enclosure](image-url)
Seeds obtained post treatments were analyzed for the nutritional composition after three weeks from the last day of the treatments as well after raising them as sprouts. From each seed line three sub samples (three replicates) were taken for analysis.

**Sprouts:** The design followed was a randomized complete block design with three replications. One hundred seeds per seed line treated for each “Test” and “Control” treatment were sprouted separately in wet germination paper soaked with distilled water and grown at 25°C under dark condition for four days.

**Sprout length:** Sprout length was taken from the point below the hypocotyls to the end of the tip of the sprout and it was measured with a ruler.

**Fresh and Dry weight:** The fresh weight of sprouts was determined by using an electronic balance. After taking the fresh weight, seedlings were kept in a hot air oven at 50 ± 5 °C for 48 hours, then the weight of dry matter was recorded.

**Mineral content analysis**

**Fe, Zn and Ca analysis:** Nitric acid – Hydrogen peroxide digestion (OH digestion) method was used for the analysis of Fe, Zn and Ca in both seed and sprout samples of mungbean. Approximately 0.6 g of oven-dried material was weighed to 1 mg into individually labelled 75 mL Pyrex tubes. Masses were recorded direct to database as above. Mungbean samples were prepared with 0.5 g of sucrose to simulate digestion of carbon substrate. It was immediately decanted to 4.5 mL sample tubes as for OH and HA digests and the remainder stored in 30 mL storage tubes (Matthew et al., 2011).

**Total phosphorus and protein analysis:** Approximately 0.5 g of finely ground mungbean seed and sprout samples were weighed and transferred to 250 mL digestion tubes. Fourteen mL of concentrated sulfuric acid containing 0.5% Se (by weight as metal) powder was added to soak the grounded sprouts held in each tube. Sulfuric acid and Se mixture was prepared by dissolving Se powder in concentrated sulfuric acid by heating on a hot plate with occasional mixing by stirring with a glass rod. Five grams of Se powder was added to about 500 mL of sulfuric acid and heated to dissolve the Se powder. The mixture was cooled and the volume made to one liter. After adding the digestion mixture to grounded mungbean sprout materials, the digestion tubes were transferred to block digester, preheated to 370°C temperature. About 2.5 h was needed for completing the digestion, indicated by clear and colorless plant digests (Sahrawat et al., 2002).

**Statistical analysis:** The analysis of variance based on randomized complete block design with 20 factorial treatments (five mungbean lines x four magnetic treatments) and three replications was performed using PROC ANOVA of SAS version 9.4 software; and mean comparison was performed using the Least Square Design at 5% and 1% levels of significance for both seed and sprout analysis.

**RESULTS AND DISCUSSION**

**Seed:** The analysis of variance showed significant variation (P <0.05) among lines for zinc, calcium, total phosphorus and protein content. The treatment effects were significant (P <0.05) for Ca and total phosphorus. The interaction effects were significant (P <0.05) for zinc, calcium, total phosphorus and protein (Table 1).

In the case of EC 693363 and Harsha, the Zn levels recorded for all the three treatments were significantly higher than the control. The highest Zn level for EC 693363 was observed in T3 (100 Hz) while the highest level for Harsha was in T1 (10 Hz). In the case of NM 94 all the treatments resulted in significantly lower Zn levels than the control. However, there was no significant difference between the treatments for KPS-1 and CN9-5 (Table 2).

The Ca levels of CN9-5, EC 693363 and Harsha recorded for all the three treatments (T1, T2 and T3) were significantly higher than the control (T4). NM 94 recorded significantly higher Ca levels for T1 and T2 compared to the control. In KPS-1, T4 recorded highest levels of calcium than T1, T2 and T3 (Table 2).

The total phosphorus levels of EC 693363 and KPS-1 to all the three treatments (T1, T2 and T3) were significantly higher than the control. CN9-5 recorded significantly higher total phosphorus level to treatments T1 and T2 than the control, while in Harsha only T1 was better than the control. However, there was no significant difference between the treatments for NM 94 (Table 2).

| Source                  | DF  | Fe    | Zn    | Ca    | Total P | Protein |
|-------------------------|-----|-------|-------|-------|---------|---------|
| Replications            | 2   | 16.7  | 1.7   | 4898.3| 0.0002  | 2.03*** |
| Lines (L)               | 4   | 90.2*** | 11.9*** | 69711.6*** | 0.0035*** | 10.18*** |
| Treatment (T)           | 3   | 24.7  | 1.7   | 152107.8*** | 0.0020*** | 0.38    |
| Line x treatment (L x T)| 12  | 14.8  | 3.6*** | 67696.2*** | 0.0004*  | 2.01*** |
| Error                   | 38  | 15.0  | 0.8   | 3221.2| 0.0002  | 0.23    |

Table 1: Analysis of variance for mineral nutrient and protein content in mungbean seeds subjected to ELF Sinusoidal Magnetic Fields
In the case of protein content, EC 693363 and Harsha registered significantly higher levels for all the three treatments than the control, while NM 94 recorded significantly lower levels for all the three treatments than the control. T1 and T2 resulted in significantly lower protein levels in CN 9-5 than the control, while T3 was on par. However, there was no significant difference between all the four treatments for KPS-1 (Table 2).

The results obtained in this study have shown positive impact of magnetic field exposure in protein and mineral content. Phosphorus and calcium were higher in all Magnetic Field (MF) treatments. According to Esitken and Turan (2004), MF has an effect on plant nutrient element uptake. Increase in the MF strength to 0.384 T increased concentration of N, K, Ca, Mg, Fe, Mn and Zn in strawberry plant leaves compared to control. The higher nutrient content concentration in EC 693363 increased in the range of 44 to 52% for the three treatments over the control treatment. All the other four lines showed no significant difference in the Ca levels among lines for Fe, Zn, total phosphorus and protein content (Table 3). KPS-1 and CN9-5 registered the highest Fe and Zn concentrations compared to the other lines. In the case of total Phosphorus content, Harsha recorded the highest value (Table 4b).

In the case of protein content, EC 693363 recorded significantly (P<0.001) higher Ca levels in response to T1, T2 and T3 compared to the control. The Ca concentration in EC 693363 increased in the range of 44 to 52% for the three treatments over the control treatment. All the other four lines showed no significant difference in the Ca levels among lines for Fe, Zn, total phosphorus and protein content (Table 3).

**Sprounts**

**Sprouting parameters:** No significant variation for the sprouting parameters was observed among the treatments as well as for the interaction between line and treatment (Table 3). Significant variation (P<0.05) was observed among lines for fresh and dry weight of sprouts and sprout length. KPS-1 and Harsha recorded significantly higher fresh weights compared to the other lines. NM 94 recorded lowest dry weight of sprouts than other lines. KPS-1 recorded the highest values for sprout length compared to the other lines. The mean values recorded for all the traits for the different treatments is presented in Table 4a and the mean values of the five mungbean lines recorded are presented in Table 4b.

**Mineral nutrient and protein content:** Significant (P<0.001) variation among treatments was recorded only for Ca content. Significant variation (P<0.001) was observed among lines for Fe, Zn, total phosphorus and protein content (Table 3). KPS-1 and CN9-5 registered the highest Fe and Zn concentrations compared to the other lines. In the case of total Phosphorus content, Harsha recorded the highest value (Table 4b).

**Line versus treatment interaction** was significant (P<0.05) for both calcium and protein content (Table 5 and 6). EC 693363 recorded significantly (P<0.05) higher Ca levels in response to T1, T2 and T3 compared to the control. The Ca concentration in EC 693363 increased in the range of 44 to 52% for the three treatments over the control treatment. All the other four lines showed no significant difference in the Ca levels among lines for the different treatments (Table 5).

In the case of EC 693363, all the three treatments resulted in significantly (P<0.05) higher protein content compared to the control. Harsha recorded significantly higher protein content for T2 and T3 treatments compared to T1 and control. Sprouts from EC 693363 recorded 8.3% increase in protein content compared to the control in response to T1 (10Hz), while sprouts from Harsha recorded 7.2% increase in protein content in response to T2 (50Hz) compared to the control. CN 9-5 and KPS-1 recorded no significant difference between the treatments for protein content while in NM 94, T2 resulted in decreasing the protein level compared to the other treatments (Table 6).

Protein and DNA are important biomolecules responsible for carrying out path ways for plant growth.
Table 3: Analysis of variance for sprouting parameters, mineral nutrient and protein content in mungbean sprouts from seeds subjected to ELF Sinusoidal Magnetic Fields

| Source                        | DF | Mean squares | Fresh weight | Dry weight | Sprouting % | Length (cm) | Fe (ppm) | Zn (ppm) | Ca (ppm) | Total Phosphorus (%) | Total Protein of sprouts (g) | Error |
|-------------------------------|----|--------------|--------------|------------|-------------|-------------|----------|----------|----------|----------------------|-----------------------------|--------|
| Replications                  | 2  | 0.64         | 167.35**     | 7.55       | 11.17       | 38          | 7.63     | 0.11     | 5.72     | 13822.00             | 0.0009                     |        |
| Lines (L)                     | 4  | 1.40***      | 1.04***      | 0.25       | 0.21        | 38          | 7.63     | 0.11     | 5.72     | 13822.00             | 0.0009                     |        |
| Treatment (T)                 | 3  | 6.49         | 0.44***      | 3.55       | 11.17       | 38          | 7.63     | 0.11     | 5.72     | 13822.00             | 0.0009                     |        |
| Line x treatment (L x T)      | 12 | 6.36         | 0.25         | 4.25       | 11.17       | 38          | 7.63     | 0.11     | 5.72     | 13822.00             | 0.0009                     |        |
| Error                         | 38 | 7.63         | 0.11         | 5.72       | 13822.00    | 0.0009      |          |          |          |                      |                             |        |

Studies in maize by Aguilar et al., (2009) showed to induce a positive biostimulation, which is dependent on optimal exposure parameters of magnetic stimulation and also on the genotype used. Present study indicates extent of the effect of ELF-SMF treatment in mungbean seed and sprouts for protein and mineral nutrient concentrations will depend on seed line used and exposure parameters of the magnetic field treatment.

The interaction effects between the mungbean lines and the different magnetic field treatments has resulted in significant response for calcium in seed and sprouts, total phosphorus in seed and differential response for protein concentrations in sprouts. In interpreting these study results, factors that influence the change include the following:

(i) The frequency, intensity of an alternating magnetic field exposure has a bearing on the experimental outcome. Often described as “Response-windows”, studies on effects of low-frequency (LF) electromagnetic (EM) fields have revealed a variety of sensitive cell-physiologic end-points in plants. Alternating magnetic fields of extremely low frequency elicit a variety of positive effects in plants. Many of the experiments have been motivated by the Ion Cyclotron Resonance (Liboff, 1985) and the Ion Parametric Resonance (Lednev 1991) mechanisms. The various effects on growth and seed germination of plants depend in a complex way on magnetic flux densities, frequencies, pretreatment of the plant material and treatment duration (Galland and Pazur, 2005). Stele and Xylem vessels have been shown to develop and grow more than control and parenchyma cells larger in magnetic field treated seeds than control suggesting some intensities of magnetic field improve significantly seed germination and growth (Majd et al., 2009). Studies have shown enhanced early growth could be induced by select frequencies of sinusoidal pulsed width modulation (SPWM) magnetic fields, with inhibitory effects (Huang and Wang, 2008).

(ii) Pulsed Magnetic Field (PMF) treatment plays an important role in improvement of crop productivity through (biochemical pathways responsible for the morphological changes that occur on the germination of seeds and plant growth). The present study showed increased protein content in sprouts due to MF exposure. Wadas (1991) stated that magnetic field below a certain limit value of intensity causes an increase of enzyme activity in an organism accelerating their metabolism. Chen et al., (2012) in their study on pretreatment of mungbean seeds with 600 mT static magnetic field observed improvement in accumulation of the concentrations of soluble protein, soluble sugar, vitamin C and anthocyanin in sprouts. They hypothesized that the underlying mechanism might be due an increase in certain enzyme activities such as amylase and proteinase in response to the magnetic field treatment.
enhancement of protein, mineral accumulation and enzyme activities, which leads to increase in growth and yield. (Radhakrishnan and Kumari, 2013). Strong correlation has been established between pulsing magnetic field effect and initial water content of seeds, as well as on the age of seeds underscoring the treatment effect on seeds (Magnetoreception). Studies elucidate that PMF mediated improvement in seed quality of aged seeds facilitate fine tuning of free radicals by the antioxidant defense system and protein oxidation (Bhardwaj et al., 2016).

(iii) It has been shown that while orientation of seeds in the magnetic field during biostimulation does not influence crop yield, seeds should not be sown later than two weeks after pre-sowing magnetic stimulation (Pietruszewski, 1996). Studies by Madras Institute of Magnetobiology using weak sinusoidal magnetic fields have shown that most optimal Philippines, Korea, and Japan.

results were obtained when the seeds were sown post exposure within a period of 15-18 days. A germinating model called hydrothermal magnetic time constant for pre-sowing exposure for seeds has been developed which incorporates effect of different intensities of static magnetic field for different seed population (Mahajan and Pandey, 2012).

CONCLUSION

ELF Sinusoidal Magnetic Field treatment seems to offer scope as a simple and ecologically compatible method to achieve improvement in the mineral nutrient and protein content in mungbean.

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REFERENCES

Aguiar, C.H., Domínguez-Pacheco, A., Carballo, A.C., Cruz-Orea, A., Ivanov, R., Bonilla, J.L.L. and Montanez, J.P.V. (2009). Alternating magnetic field irradiation effects on three genotype maize seed field performance. *International Agrophysics*, 14: 1.

Aksyonov, S.I., Buchylev, A., Grunina, T.Yu., Goryachev, S.N. and Turovetsky, V.B. (2000). Physiochemical mechanisms of efficiency of treatment by weak ELF-EMF of wheat seeds at different stages of germination. Proc. 22th Annual Meeting Eur. *Bioelectromagnetics* Ass. Munich, 112-113.

Ayrapetyan, S. and De, J. (2014). Cell Hydration as a biomarker for estimation of biological effects of nonionizing radiation on cells and organisms. *The Scientific World Journal*, Article ID 890518.

Bilalis, D.J., Katsenios, N., Efthimiadou, A., Karkanis, A., Khah, E.M. and Mitsis, T. (2013). Magnetic field pre-sowing treatment as an organic friendly technique to promote plant growth and chemical elements accumulation in early stages of cotton *Australian Journal of Crop Science*. 7(1):46-50.

Belyavskaya, N.A. (2001). Ultrastructure and calcium balance in meristem cells of pea roots exposed to extremely low magnetic fields. *Advances in Space Research*, 28: 645–650. doi: 10.1016/S0273-1177(01)00373-8.

Bhardwaj, J., Anand, A., Pandita and V.K., Nagarajan, S. (2016). Pulsed magnetic field improves seed quality of aged green pea seeds by homeostasis of free radical content. *Journal of Food Science and Technology*, 53: 3969–3977.

Chen, Y-P., He, J-M. and Le, R. (2012). Effect of magnetic fields pretreatment of mungbean seeds on sprout yield and quality. *African Journal of Biotechnology*. 11: 36.

Clarey, S.F. (1993). A Review of In vitro studies: Low Frequency Electromagnetic Fields. *Journal of American Industrial Hygiene Association*. 54:178-185.

Galland, P. and Pazar, A. (2005). Magneto-reception in plants. *Journal of Plant Research*, 118:371–389.

Huang, H-H. and Wang, S-R. (2008). The effects of inverter magnetic fields on early seed germination of mung beans.*Bioelectromagnetics*, 29: 649–657. doi: 10.1002/bem.20432.

Javed, N., Ashraf, M., Akram, N.A. and Al-Qurainy, F. (2011). Alleviation of adverse effects of drought stress on growth and some potential physiological attributes in maize (Zea mays L.) by seed electromagnetic treatment. *Photochemistry and Photobiology*, 87: 1354–1362.

Krylov, A.V. and Tarakanova, G.A. (1960). Magnetotropism of plants and its nature. *Plant Physiology*, 17: 156-160.

Lednev, V. V. (1991). Possible mechanism for the influence of weak magnetic fields on biological systems. *Bioelectromagnetics* 12:71-75.

Liboff, A. R. (1985). Geomagnetic cyclotron resonance in living things. *Journal of Electromagnetic Biology and Medicine*, 6: 177–180.

Liboff, A. R. (1985). Basic electromagnetism: Health effects and research needs. *Advances in Space Research*, 5: 36.

Mahajan, T.S. and Pandey, O.P. (2012). Magnetic time model for seed germination. *African Journal of Biotechnology*. 11: 88.

Mahajan, T.S. and Pandey, O.P. (2011). Reformulation of Malthius-Verhulst equation for blackgram seeds pretreated with magnetic field. *International Agrophysics*, 25:355-359.

Majd, A. and Shabrangi, A. (2009). Effect of Seed pretreatment by magnetic fields on Seed germination and Ontogeny Growth of Agricultural plants. Progress in Electromagnetic Research Symposium. Beijing, China. Mar 23-27.

Matthew, S.W., Teresa, O.F. and Lyndon, Palmer. (2011). A cost-effective acid digestion method using closed polypropylene tubes for inductively coupled plasma optical emission spectrometry (ICP-OES) analysis of plant essential elements, *Analytical Methods*, 3: 2854-2863.

Negishi, Y., Hashimoto, A., Tsushima, M., Dobrota, C., Yamashita, M. and Nakamura, T. (1999). Growth of pea epicotyl in low magnetic field implication for space research. *Advances in Space Research*, 23: 2029–2032.doi:10.1016/S0273-1177 (99)00342-7.

Pietruszewski, S. (1996). Effect of Magnetic Biostimulation of wheat seeds on germination, yield and proteins. *International Agrophysics*, 10: 51-55.

Pietruszewski, S. (1993). Effect of magnetic seed treatment on yields of wheat. *Seed Science and Technology*, 2: 621 – 626.

Podlezza, J., Pietruszewski, S. and Podlezza, A. (2004). Efficiency of magnetic biostimulation of broad bean cultivated in the experimental plot conditions. *International Agrophysics*, 18: 65-71.

Radhakrishnan, R. and Kumari, B.D.R. (2013). Influence of pulsed magnetic field on soybean (Glycine max L.) seed germination, seedling growth and soil microbial population. *Indian Journal of Biochemistry and Biophysics (IJBB)*, 50: 312–317.

Repacholi, M.H. and Greenbaum, B. (1999). Interaction of static and extremely low frequency electric and magnetic fields with living systems: Health effects and research needs. *Bioelectromagnetics*, 20:133–201.

Sahrawat, K.L., Ravi Kumar, G. and Murthy, K.V.S. (2002). Sulfuric acid-Selenium digestion for multi-element analysis in a single plant digest. *Communications in Soil Science and Plant Analysis*, 33: 19 and 20, 3757-3765.

Savostin, P.W. (1930). Magnetic growth relations in plants. *Planta*. 12:327.

Shine, M., Guruprasad, K. and Anand, A. (2011). Enhancement of germination, growth and photosynthesis in soybean by pre-treatment of seeds with magnetic field. *Bioelectromagnetics* 32: 474–484.doi:10.1002/bem.20656.

Vashisth, A. and Nagarajan, S. (2008). Exposure of seeds to static magnetic field enhances germination and early growth characteristics in chickpea (*Cicer arietinum* L.). *Bio electromagnetics* 29: 571–578.doi:10.1002/bem.20426.

Wadas, R. (1991). Biomagnetism. PWN, Warszawa

Yamashita, M., Tomits-Yokotani, K., Hashimoto, H., Takai, M., Tsushima, M. and Nakamura T. (2004). Experimental concept for examination of biological effects of magnetic field concealed by gravity. *Advances in Space Research*, 34: 1575–1578. doi: 10.1016/j.asr.2004.01.022

Yu, X., Liu, H., Klejnot, J. and Lin, C. (2010). The Cryptochrome Blue Light Receptors. The Arabidopsis Book / *American Society of Plant Biologists*, 8:e0135. doi:10.1199/tab.0135.