# Research Journal of
# Seed Science

ISSN 1819-3552

Academic
Journals Inc.

www.academicjournals.com

Research Journal of Seed Science 5 (3): 106-114, 2012
ISSN 1819-3552 / DOI: 10.3923/rjss.2012.106.114


# Exposure of Greengram Seeds (*Vigna radiate* var. *radiata*) to Static Magnetic Fields: Effects on Germination and α-amylase Activity

[1]K. Venkateswar Reddy, [2]S. Raisa Reshma, [2]S. Jareena and [2]M. Nagaraju
[1]Department of Biotechnology and Environmental Science, Jawaharlal Nehru Technological University, Hyderabad, A.P., 500083, India
[2]Department of Microbiology, National P.G. College, Nandyal, A.P., 518502, India

*Corresponding Author: M. Nagaraju, Department of Microbiology, National P.G. College, Nandyal, A.P., 518502, India*

## ABSTRACT

The effects of static magnetic field on germination and α-amylase activity of greengram (mung beans) seeds were investigated under laboratory conditions. Experimental results indicated that seeds exposed for 45 min to the static magnetic field have shown the highest percentage of germination and α-amylase activity, improvements of +2.1 and +1.8 times, respectively. Furthermore, α-amylase activity of seeds treated for 45 min was significantly higher at pH 6.0 and 29°C temperature. Nevertheless, data illustrate that the seeds exposed to static magnetic field kept their germination speed and capacity levels compared to the unexposed control.

**Key words:** Static magnetic field, greengram, germination, α-amylase

## INTRODUCTION

Beans of *Vigna*, important food crops both economically and nutrionally, are cultivated and consumed worldwide. With ever-rising costs of meats and fresh fruits and vegetables, dry beans are expected to add more to the human nutrition in coming years. Traditionally, they have been referred to as "poor man's meat" and have contributed much to the diets of many people of several countries in Asia, Africa, Middle East and South America. By using some traditional methods, speed of seed germination has successfully been improved in many incidences (Kaur *et al.*, 2009; Pradhan and Badola, 2010; Adebisi *et al.*, 2011; Alderete-Chavez *et al.*, 2010, 2011). Similarly, the effects of seed priming (Rajpar *et al.*, 2006; Berchie *et al.*, 2010), soaking condition and temperature (Rahman *et al.*, 2011), heat (Travlos and Karamanos, 2007) and light, temperature and stratification (Raboteaux and Anderson, 2010) on seed germination have been reported widely in the past couple of years. However, much current research focuses on the irradiation of seeds in optimizing crops in terms of maximization of yield, promotion of plant growth and protection against diseases. In recent years, a renewed interest in bean research in Western European countries and the US is evident.

In this direction, investigations into electromagnetic effects on plants have already been carried out with some remarkable results. The optimal external electromagnetic field could accelerate and activation of seed germination (Maeda, 1993; Oomori, 1992) but the mechanism of these actions is till poorly understood (Morar *et al.*, 1988; Xiyao *et al.*, 1988). Electric and/or magnetic treatments are assumed to enhance seed vigor by influencing the biochemical processes that involve free radicles and by stimulating the activity of proteins and enzymes (Kurinobu and Okazaki, 1995). A study was added to the evidence that the seeds treated by magnetic stimulation seem to show higher enzymatic activities which control the particular stages of seed germination (Aksyonov *et al.*, 2000). Perhaps, more alarmingly, the main advantage of using electromagnetic stimulation methods over traditional chemical processes is the absence of toxic residues. Likewise, several researchers reported on the stimulation effects that affects seed germination (Savostin, 1930; Murphy, 1942; Aladjadjiyan, 2002) and enzymatic activities (Akoyunoglou, 1964; Bhatnagar and Deb, 1977; Recuciui *et al.*, 2008) when using static magnetic field treatments. However, the impact of such techniques on germination and α-amylase activity of greengram seeds is scanty.

On the other hand, amylases are of commercial interest in traditional areas of applications such as starch processing in the food industry, in backing, beverage production, animal nutrition, leather, paper and pulp, textile and detergents (Pandey *et al.*, 2000; Dey *et al.*, 2001; Gigras *et al.*, 2002). In fact, germinating seeds are one of the imperative sources for amylase production. Hence physical parameters such as static magnetic field treatments considered for optimizing the production of enzymes. Nonetheless, enzyme-electromagnetic field activation is currently a fast growing field and a large number of studies have been produced currently.

An attempt, has therefore been made to evaluate the effects of static magnetic field on germination of greengram seeds. The specific objectives of this study were to determine the effects of static magnetic field on percent seed germination and to assess the influence of different levels of exposure periods, pH and temperature on α-amylase activity of treated seeds.

## MATERIALS AND METHODS

Germination tests were carried out at laboratory conditions with greengram seeds. This experiment was conducted as wholly randomized design with three replications. Each plot contained 25 seeds. Germination tests were performed according to the guidelines issued by the International Seed Testing Association (ISTA, 2004). Each filter paper with seeds was rolled and placed in a vessel containing distilled water. Four hours later, when seeds were soaked, each roll was subjected to a static magnetic field.

Primarily, rolls containing seeds were placed in between the two pairs of South pole coils at 5 millitesla field strength, and were exposed for different periods, viz., 15, 30, 45 and 60 min individually. In this study, non exposed seeds were used as control. After exposure, all the vessels containing seed rolls were labeled, then, seeds were moistened. Eventually, vessels were placed in germinator at 23°C temperature. Germination was considered to take place once the tip of the radicle (1-2 mm) has emerged from the seed (Moon and Chung, 2000). The number of germinating seeds was counted and tabulated after 24 h. Thus, percentage of germination was observed in seeds treated for different exposure periods at the above mentioned conditions.

Additionally, α-amylase activity in germinated seeds treated for different exposure periods was determined according to the method described by Bernfeld (1955) and modified by Dure (1960). Tissues were blended in a Kenmix with unbuffered distilled water and then centrifuged between 0-4°C. Supernatant was heated to 70°C to inactivate β-amylase (Sun and Henson, 1991). Reaction mixture included 0.8 mL enzyme solution, 0.5 mL of 0.1 M citrate buffer (pH 6.0) and 0.5 mL of 1% starch. This was incubated for 3 min in a water bath at 30°C and the reaction was stopped by adding 2.0 mL of 1% dinitrosalicylic acid colour reagent. Maltose released was measured at $A_{510}$ in a Spectronic-20D spectrophotometer. Finally, the reducing sugar formed by enzymatic activity was calculated (Guglielminetti *et al.*, 1995) using a standard curve obtained with glucose (0-5 μM).

Furthermore, α-amylase activity in germinated seeds was tested at different pH (viz. pH 4, 5, 6, 7 and 8) and temperatures (viz. 0, 8, 29, 37 and 60°C) conditions. To study the effect of pH on α-amylase activity under EMF, the following reaction was setup. Substrate (1% starch) of 0.5 mL and 0.5 mL of enzyme solutions were added to 0.5 mL of 0.1 M citrate buffer of different pH values. Then, tubes were incubated in a water bath at 30°C for 3 min and the reaction was stopped by adding 0.5 mL of dinitrosalicyhc acid reagent to all the tubes and the reducing sugar released was measured at 510 nm. Similarly, to determine the effect of temperature on α-amylase activity, the reaction mixture containing 0.5 mL of 0.1 M citrate buffer (pH 6.0), 0.25 mL of substrate and 0.25 mL of enzyme solution was subjected to different temperature conditions for 3 min. Finally, enzyme activity was determined by following the above mentioned procedure.

Meanwhile, for establishing the EMF, a locally designed MF generator (Sahebjamei *et al.*, 2007) and a 220 volts Alternative Current power supply equipped with a variable transformer as well as a single-phase full-wave rectifier was used. The maximum power was 1 kilo watts, the passing current 50 amperes Direct Current. This system was designed to generate EMFs in the range of 0.5 microtesla (μT) to 75 millitesla (mT). It consisted of two coils (each with 3000 turns of 3 mm copper wire) on a U-shaped laminated iron core (to prevent eddy current losses). Using two vertical connectors, the arms of the U-shaped iron core were terminated in four circular iron plates covered with this layer of nickel (each 23 mm thickness, 260 nm in diameter).

**Statistical analysis:** Data analysis was performed by using the SAS (Statistical Analysis System) statistical software package (SAS Institute, 1997), where a significance test based on ANOVA was done.

## RESULTS

Results of ANOVA indicated that the seed germination percentage and α-amylase activity were notably influenced by static magnetic field treatment of seeds. In fact, seed germination percentage was appreciably increased by increasing the exposure period over control and later declined (Fig. 1). For instance, at 5 mT field strength, in South pole field, the germination percentage at 15 min was 43, it was increased by 1.5 times to 63% at 45 min, later declined by 1.9 times to 33% at 60 min. Thus, greatest percentage of germination was noticed at 45 min. Furthermore, α-amylase activity in germinated seeds was increased by increasing the exposure period over control and later declined (Fig. 2). For example, enzyme activity was 5 micromoles per milliliter at 15 min; it was drastically increased by 3.8 times to 19.2 μM $mL^{-1}$ at 45 min and later decreased by 1.5 times to 12.5 μM $mL^{-1}$ at 60 min.

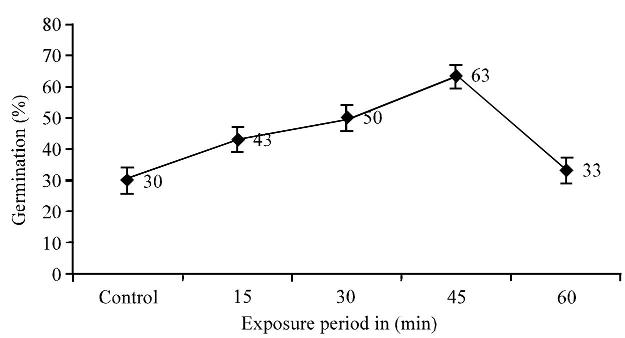


Fig. 1: Percent germination of greengram seeds as influenced by static magnetic treatment at 5 mT field strength in South pole field

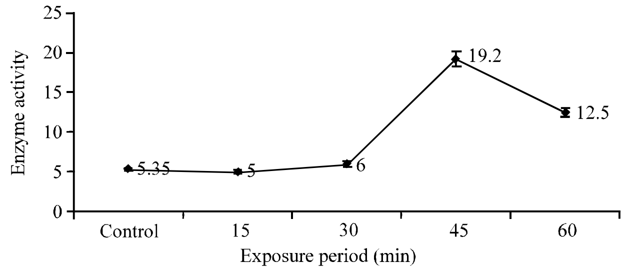


Fig. 2: Activity of α-amylase (μM $mL^{-1}$) in germinated greengram seeds as influenced by static magnetic treatment at 5 mT field strength in South pole field

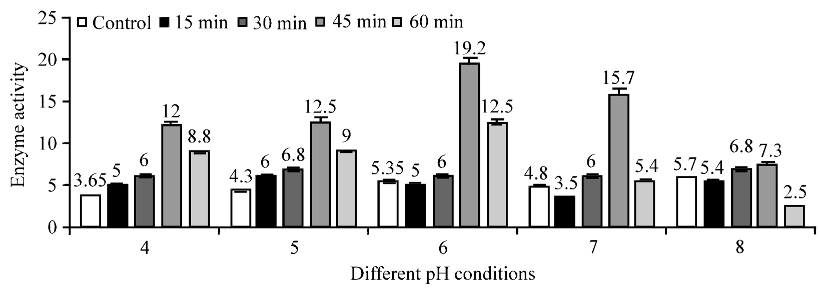


Fig. 3: Activity of α-amylase (μM $mL^{-1}$) in treated (5 mT field strength in South pole field) germinated greengram seeds as influenced by different pH conditions

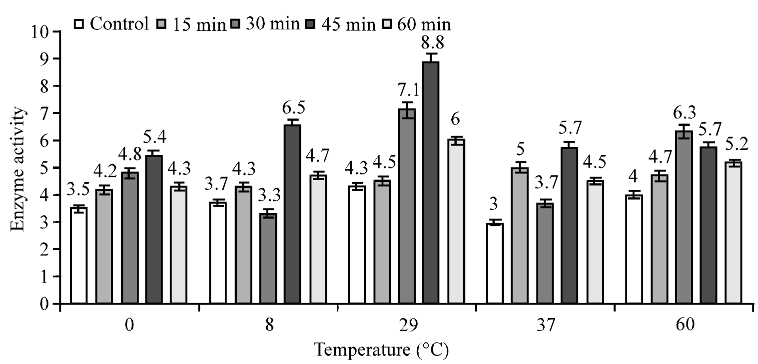


Fig. 4: Activity of α-amylase (μM $mL^{-1}$) in treated (5 mT field strength in South pole field) germinated greengram seeds as influenced by different temperature conditions

Additionally, α-amylase activity was increased by increasing the pH of the buffer and later declined (Fig. 3). For instance, enzyme activity of seeds exposed for 45 min was 12 μM $mL^{-1}$ at pH 4.0, it was increased by 1.6 times to 19.2 μM $mL^{-1}$ at pH 6.0 and later severely declined by 2.6 times to 7.3 μM $mL^{-1}$ at pH 8.0. Same trend was observed in seeds exposed for different time periods. Similarly, α-amylase activity was increased by increasing the temperature and later decreased (Fig. 4). Indeed, the activity was increased gradually but not significantly. For example, enzyme activity of seeds exposed for 45 min was 5.35 μM $mL^{-1}$ at 0°C, it was improved by 1.6 times to 8.8 μM $mL^{-1}$ at 29°C and later decreased by 1.5 times to 5.7 μM $mL^{-1}$ at 60°C. Similar tendency was also observed in seeds exposed for different time periods.

## DISCUSSION

In many treatments applied in this study, seedlings grown from seeds treated with static electromagnetic fields developed longer hypocotyle and roots. In this direction, favorable effects of magnetic field on germination and emergence of seeds were shown for Oak (Celestino *et al.*, 2000), onion and rice (Alexander and Doijode, 1995), lettuce (Reina *et al.*, 2001), white mustard (Edmiston, 1972), potato (Pittman, 1972), tomato (De Souza *et al.*, 2006), barley (Mericle *et al.*, 1966), rice (Carbonell *et al.*, 2000), maize (Kato, 1988; Aladjadjiyan, 2003; Florez *et al.*, 2007), tobacco (Aladjadjiyan and Ylieva, 2003) and soya bean (Aladjadjiyan, 2003). More recently, Gholami and Sharafi (2010) reported that the percentage of germinated seeds was increased and simultaneously time required for germination was decreased upon electromagnetic field treatment of two wheat cultivars. In all, the previous studies have shown that the seed germination was faster after treatments with magnetic fields.

In this review, we found that the germination percentage of seeds was notably enhanced by 2.1 times over control when treated in South pole field, at 5 mT field strength for 45 min (Fig. 1). Same was reported by Martinez *et al.* (2000) in reference to the growth and development of barley seeds subjected to static magnetic field. Additionally, studies conducted by Florez *et al.* (2004), Florez *et al.* (2007) and Vashisth and Nagarajan (2008) indicate that magnetic field can be used as a method of seed vigor improvement in rice, maize and chick pea respectively. Like wise, numerous reports have indicated that the best effects of seeds stimulation with physical factors are possible to obtain when optimal exposure doses and exposure periods are applied.

Further, α-amylase activity was significantly higher in seeds exposed to static magnetic field for 45 min (Fig. 2). According to Vashisth and Nagarajan (2010), in germinating seeds, enzyme activities of α-amylase, dehydrogenase and protease were considerably higher in treated seeds in contrast to controls. In fact, the higher enzyme activity in magnetic field treated seeds could be triggering the fast germination and early vigor of seedlings. Several other studies have also demonstrated an improvement of amylase activity in germinated seeds by ultrasonic stimulation (Yaldagard *et al.*, 2008), gamma irradiation (Rao and Vakil, 1983; Kurobane *et al.*, 1979; Ananthaswamy *et al.*, 1970), selenium (Malik *et al.*, 2011) and static magnetic field (Bhatnagar and Deb, 1977). Prashanth *et al.* (2008) and Shaoyi *et al.* (2009) combinedly reported that static magnetic field treatment of α-amylase solution could enhance the activity over control. Moreover, many studies have found that evidence to support the static EMF stimulation of α-amylase that the starch and oligosaccharide levels gradually decreased, subsequently, the reducing sugar levels increased during early hours (48-96 h) in germinating seeds (Paul *et al.*, 1970; Jaya and Venkataraman, 1981; Shastry and John, 1991). Contrary to this, continuous and delayed exposure of power frequency electro magnetic fields could decrease the α-amylase activity in germinating seeds of *Vicia faba* L. (Rajendra *et al.*, 2005). Furthermore, utmost activity of α-amylase was recorded at pH 6.0 in seeds exposed for 45 min (Fig. 3). This is a basic property of all enzymes and is probably due to concomitant alteration in the confirmation of the enzyme protein caused by changes in the pH of its environment. Similarly, greatest activity of α-amylase was observed at temperature 29°C in seeds exposed for 45 min (Fig. 4). This may perhaps be accounted for by denaturation of the enzymes protein at temperature higher than this.

## CONCLUSION

The results of the present investigation clearly indicated that magnetic field application noticeably enhanced seed performance in terms of laboratory germination, speed of germination, seedling length and α-amylase activity compared to unexposed control. The greatest increase was obtained for seeds continuously exposed to 5 mT field strength for 45 min. Additionally, highest activity of α-amylase was noticed at pH 6.0 and temperature 29°C. Therefore, the present findings are significant in terms of determining the suitable combination of physical parameters to optimize the percentage of seed germination and α-amylase activity in electro magnetically treated seeds. As a result, this would not only useful in enhancing the seed germination percentage but also provides an excellent source of α-amylase, is extensively used industrially.

## ACKNOWLEDGMENT

We wish to thank Dr. S. Imthiyaz Ahamed, Principal, National P.G. College (Research centre), Nandyal for providing lab facilities and encouraging us through out this study.

## REFERENCES

Adebisi, M.A., S.O. Akintoye, T.O. Kehinde and M.F. Adekunle, 2011. Seed priming for improved seedling emergence and vigour of cordia (*Cordia millennii*) seed. Res. J. Seed Sci., 4: 137-147.

Akoyunoglou, G., 1964. Effect of a magnetic field on carboxydimutase. Nature, 202: 452-454.

Aksyonov, S.I., A. Buchylev, T.Y.U. Grunina, S.N. Goryachev and V.B. Turovetsky, 2000. Physicochemical mechanisms of efficiency of treatment by weak ELF-EMF (Extremely Low Frequency and Electromagnetic Fields) of wheat seeds at different stages of germination. Proceedings of the 22nd Annual Meeting European Bioelectromagnetics Association, June, 11-16, Munich, Germany.

Aladjadjiyan, A., 2002. Study of influence of magnetic field on some biological characteristics of *Zea mays*. J. Central Eur. Agric., 3: 89-94.

Aladjadjiyan, A., 2003. Use of physical factors as an alternative to chemical amelioration. J. Environ. Protect. Ecol., 4: 662-667.

Aladjadjiyan, A. and T. Ylieva, 2003. Influence of stationary magnetic field on the early stages of the development of tobacco seeds (*Nicotiana tabacum* L.). J. Central Eur. Agric., 4: 131-138.

Alderete-Chavez, A., D.A. Rodriguez-Trejo, V. Espinosa-Hernandez, E. Ojeda-Trejo and N. de la Cruz-Landero, 2010. Effects of different scarification treatments on the germination of *Lupinus leptophyllus* Seeds. Int. J. Botany, 6: 64-68.

Alderete-Chavez, A., N. de la Cruz-Landero, J.J. Guerra-Santos, E. Guevara and R. Gelabert *et al*., 2011. Promotion of germination of *Bauhinia divaricata* L. seeds by effects of chemical scarification. Res. J. Seed Sci., 4: 51-57.

Alexander, M.P. and S.D. Doijode, 1995. Electromagnetic field, a novel tool to increase germination and seedling vigour of conserved onion (*Allium cepa* L.) and rice (*Oryza sativa* L.) seeds with low viability. Plant Genet. Res. Newslett., 104: 1-5.

Ananthaswamy, H.N., U.K. Vakil and A. Sreenivasan, 1970. Susceptibihty to amylolysis of gamma-irrradiated wheat. J. Food Sci., 35: 792-794.

Berchie, J.N., H. Adu-Dapaah, J. Sarkodie-Addo, E. Asare, A. Agyemang, S. Addy and J. Donkoh, 2010. Effect of seed priming on seedling emergence and establishment of four Bambara groundnut (*Vigna subterranea* L. Verdc.) landraces. J. Agron., 9: 180-183.

Bernfeld, P., 1955. Amylases, α and β. In: Methods in Enzymology. Colowick, S.P. and N.O. Kaplan (Eds.), Academic press, New York, pp: 149-158.

Bhatnagar, D. and A.R. Deb, 1977. Some aspects of pre-germination exposure of wheat seeds to magnetic field: Germination and early growth. Seed Res., 5: 129-137.

Carbonell, M.V., E. Martinez and J.M. Amaya, 2000. Stimulation of germination in rice (*Oryza sativa* L.) by a static magnetic field. Electr. Magnetobiol., 19: 121-128.

Celestino, C., M.L. Picazo and M. Toribio, 2000. Influence of chronic exposure to an electromagnetic field on germination and early growth of *Quercus suber* seeds: Preliminary study. Electro. Magnetobiol., 19: 115-120.

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

Dey, G., A. Mitra, R. Banerjee and B.R. Maiti, 2001. Enhanced production of amylase by optimization of nutritional constituents using response surface methodology. Biochem. Eng. J., 7: 227-231.

Dure, L.S., 1960. Site of origin and extent of activity of amylases in maize germination. Plant Physiol., 35: 925-934.

Edmiston, J., 1972. The effect of the field of a permanent magnet on the germination and growth of white mustard seeds. Int. J. Biometeorol., 16: 13-24.

Florez, M., M.V. Carbonell and E. Martinez, 2004. Early sprouting and first stages of growth of Rice seeds exposed to a magnetic field. Issue TOC, 23: 157-166.

Florez, M., M.V. Carbonell and E. Martinez, 2007. Exposure of maize seeds to stationary magnetic fields: Effects on germination and early growth. Environ. Exp. Botany, 59: 68-75.

Gholami, A. and S. Sharafi, 2010. Effect of magnetic field on seed germination of two wheat cultivars. World Acad. Sci. Eng. Technol., 62: 279-282.

Gigras, P., V. Sahai and R. Gupta, 2002. Statistical media optimization and production of intermediate temperature stable α-amylase from *Aspergillus oryzae* in a bioreactor. Curr. Microbiol., 45: 203-208.

Guglielminetti, L., J. Yamaguchi, P. Peratia and A. Alpi, 1995. Amylolytic activities in cereal seeds under aerobic and anaerobic conditions. J. Plant Physiol., 109: 1669-1676.

ISTA, 2004. International rules for seed testing. International Seed Testing Association, Zurich, Switzerland.

Jaya, T.V. and L.V. Venkataraman, 1981. Changes in the carbohydrate constituents of chickpea and greengram during germination. Food Chem., 7: 95-104.

Kato, R., 1988. Effects of magnetic field on the growth of primary roots of *Zea mays*. Plant Cell Physiol., 29: 1215-1219.

Kaur, R., S. Arora and A.K. Thukral, 2009. Enhancing seed germination of *Chlorophytyum borivilianum* Sant. Et fernand. with pgrs, steroidal hormones and zinc. Res. J. Seed Sci., 2: 32-39.

Kurinobu, S. and Y. Okazaki, 1995. Dielectric constant and conductivity of one seed in germination process. Proceeding of the Annual Conference Record, Institute of Electrical and Electronics Engineers/Industry Applications Society. December, 8-10, Orlando, Florida, United States of America, pp: 1329-1334.

Kurobane, I., H. Yamaguchi, C. Sander and R. Nilan, 1979. The effects of gamma irradiation on the production and secretion of enzymes and enzymatic activities in barley. Environ. Exp. Bot., 19: 75-84.

Maeda, H., 1993. Do the Living Things Feel the Magnetism?. Kodansha, Kodansha Press, Tokyo, Japan.

Malik, J.A., S. Kumar, P. Thakur, S. Sharma and N. Kaur *et al*., 2011. Promotion of growth in Mungbean (*Phaseolus aureus* Roxb.) by Selenium is associated with stimulation of carbohydrate metabolism. Biol. Trace Element Res., 143: 530-539.

Martinez, E., M.V. Carbonell and J.M. Amaya, 2000. A static magnetic field of 125 mT stimulates the initial growth stages of barley (*Hordeum vulgare* L.). Electro- Magnentobiol., 19: 271-277.

Mericle, R.P., L.W. Mericle and D.J. Montgomery, 1966. Magnetic fields and ionizing radiation: Effects and interaction during germination and early seeding development. Radiat. Botany, 6: 111-127.

Moon, J. and H. Chung, 2000. Acceleration of germination of tomato seeds by applying ac electric and magnetic fields. J. Electrostatics, 48: 103-114.

Morar, R., A. Iuga, L. Dascalescu, V. Neamtu and I. Munteanu, 1988. Separation and biostimulation of soybeans using high-intensity electric fields. Proceeding of the International Conference on Modern Electrostatics. October, 21-25, Beijing, China.

Murphy, J.D., 1942. The influence of magnetic field on seed germination. Am. J. Bot., 29: 15-15.

Oomori, U., 1992. Bioelectromagnetics and its Applications (in Japanese). Fuji Techno System Press, Tokyo, Japan.

Pandey, A., P. Nigam, C.R. Soccol, V.T. Soccol, D. Singh and R. Mohan, 2000. Advances in microbial amylases. Biotechnol. Applied Biochem., 31: 135-152.

Paul, A.K., S. Mukherji and S.M. Sircar, 1970. Enzyme activities in germinating Mungbean (*Phasioulus aureus*) seeds and their relation with promoter and inhibitors of protein synthesis. Osterreichische Botnische Zeitschrift, 118: 311-320.

Pittman, U.J., 1972. Biomagnetic responses in potatoes. Can. J. Plant Sci., 52: 727-733.

Pradhan, B.K. and H.K. Badola, 2010. Chemical stimulation of seed germination in *ex situ* produced seeds in *Swertia chirayita*, a critically endangered medicinal herb. Res. J. Seed Sci., 3: 139-149.

Prashanth, K.S., T.R.S. Chouhan and S. Nadiger, 2008. Effect of 50 Hz electromagnetic fields on alpha amylase activity. Rom. J. Biophys. Bucharest, 18: 255-263.

Raboteaux, N.N.G. and N.O. Anderson, 2010. Germination of *Cleome hassleriana* and *Polanisia dodecandra* seed lots in response to light, temperature and stratification. Res. J. Seed Sci., 3: 1-17.

Rahman, M.M., K.U. Ahammad and M.M. Alam, 2011. Effect of soaking condition and temperature on imbibition rate of maize and chickpea seeds. Res. J. Seed Sci., 4: 117-124.

Rajendra, P., H.S. Nayak, R.B. Sashidar, C. Subramanyam and D. Devendranath *et al*., 2005. Effects of power frequency electromagnetic fields on growth of germinating *Vicia faba* L., the broad bean. Electromagn. Biol. Med., 24: 39-54.

Rajpar, I., Y.M. Khanif and A.A. Memon, 2006. Effect of seed priming on growth and yield of wheat (*Triticum aestivum* L.) under non-saline conditions. Int. J. Agric. Res., 1: 259-264.

Rao, V.S. and U.K. Vakil, 1983. Effects of gamma-irradiation on flatulence-causing oligosaccharides in greengram (*Phaseolus aureus* L.). J. Food Sci., 48: 1971-1975.

Recuciui, M., D. Creanga and I. Horga, 2008. Plant growth under static magnetic field influence. Rom. J. Phys., 53: 353-359.

Reina, F.G., L.A. Pascua and I.A. Fundora, 2001. Influence of a stationary magnetic field on water relations in lettuce seeds, Part II: Experimental results. Bioelectromagnetics, 22: 596-602.

SAS Institute, 1997. SAS/STAT Users Guide. SAS Institute Inc., Cary, NC.

Sahebjamei, H., P. Abdolmaleki and F. Ghanati, 2007. Effects of magnetic field on the antioxidant enzyme activities of suspension-cultured tobacco cells. Bioelectromagnetics, 28: 42-47.

Savostin, P.W., 1930. Magnetic growth relations in plants. Planta, 12: 327-327.

Shaoyi, J., L. Yong, W. Songhai and W. Zhibin, 2009. Effect of static magnetic field on α-amylase activity and enzymatic reaction. Trans. Tianjin Univ., 15: 272-275.

Shastry, M. and E. John, 1991. Biochemical changes and *in vitro* protein digestibility of the endosperm of germinating *Dolichos lablab*. J. Sci. Food Agric., 55: 529-538.

Sun, Z. and C.A. Henson, 1991. A quantitative assessment of importance of barley seed α-amylase, β-amylase, debranching enzyme and α-glucosidase in starch degradation. Arch. Biochem. Biophys., 284: 298-305.

Travlos, I.S. and A.J. Karamanos, 2007. Influence of heat on seed germination and seedling emergence of chaste tree (*Vitex agnus castus* L.). J. Agron., 6: 25-28.

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

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

Xiyao, B., M. Ancheng, M. Jingrun, L. Xiaoling, Y. Li and W. Qingzhao, 1988. Physiological and biochemical experiments in electrostatic treated seeds. Proceeding of the International Conference on Modern Electrostatics, October, 21-25, Beijing, China.

Yaldagard, M., S.A. Mortazavi and F. Tabatabaie, 2008. Influence of ultrasonic stimulation on the germination of barley seed and its alpha-amylase activity. Afr. J. Biotechnol., 7: 2465-2471.