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GEOMAGNETIC FIELD (GMF) AND PLANTS: THE FATE OF THE FLIP

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ABSTRACT

The Earth's magnetic field (Geomagnetic field) is an inescapable environmental factor, experienced by all living organisms including plants. Despite the progresses made in the field of plant senses the impact of Geomagnetic field (GMF) on plant growth and development is not fully explored. Variation of exposure intensity may influence a plethora of events at cellular, biochemical or molecular level asserting it as a positive or stressful factor depending on the plant species. In these context experiments elucidating the bio stimulation effect can address issues like 'zero hunger challenge' and the global growing problem of malnutrition. Study of the correlation of GMF reversal with plant evolution and mass extinction and the plausible role of magnetoreception can open new horizons to understand the very existence of life from simple magneto tactic bacteria to human beings to the whole biosphere. Further the impact of GMF effects can pave the way for designing sustenance system in future space expedition.

KEYWORDS: Geomagnetic field, bio stimulation effect, zero hunger challenge, magnetoreception, magneto tactic bacteria.

INTRODUCTION

The strength of GMF (measured in Tesla (T), its magnetic induction) ranges from less than 30µT in an area including most of the south of America and South Africa (the so called South Atlantic anomaly) to almost 70µT around magnetic poles in northern Canada and south of Australia and in part of Siberia (Occhipinti *et al*., 2014). Having an internal origin produced by the dynamo action of turbulent flows in the outer core of the planet (Quamili *et al*., 2013) the GMF protects the Earth from solar wind and cosmic rays (Occhipinti *et al*., 2014).

After the first report on weak magnetic field effects on plant seeds showing auxin like effect (Krylov and Tarakonva, 1960) many experimental conclusions have been communicated with few successful independent replication studies. Further most of them have been inconclusive owing to the dearth of plausible biophysical interaction mechanism (Harris *et al*., 2009). Recently among weak, super weak or conditionally zero and high magnetic field (MF) considerable attention has been directed on weak and super weak MF effects on biological systems for quite a few reasons especially inclusive of the space exploration programmes ascribed to the super weak magnetic environments (Maffei,2014). The consistent change in GMF has recently been reckoned as a possible driving force for plant diversification and speciation. The planet has been exposed to periods of reverse polarity during every geomagnetic reversal which might have allowed the ionizing radiation from solar wind inducing stress to all living organisms forcing gene alteration and ultimately evolution (Occhipinti *et al*., 2014). Plant developmental response studies has been carried out at various magnetic field intensities (from near null to very high) and their effects has been evaluated at all levels of organization (morphological, cellular, biochemical and molecular).

Relatively low intensity of magnetic field (lower than the GMF) stimulates growth as observed in Sunflower seedlings which upon exposure to 20µT vertical MF shows a significant increase in total fresh weight, shoot and root fresh weight while dry weight and germination rate remains unaffected (Fischer *et al*., 2004). Similarly longer epicotyls were observed in Pea under low MF condition compared to control which is attributed to the elongation of cells. Further the osmotic pressure of the seedlings was higher in low MF conditions compared to control (Yamashita *et al*., 2004). Pre sowing seed treatment of Soybean (*Glycine max*) seeds with magnetic field showed enhanced response in context with speed of germination, seedling length, fresh weight, dry weight, water uptake and vigour indices *in vitro* (Shine *et al*., 2011). Further the rate of seed germination was significantly increased when seeds of Soybean exposed to pulsed MF of 1500nT (Radhakrisnan and Kumari, 2013). Contradictorily species-specific response recorded in *in vitro* culture of Solanum upon near null MF exposure (Rakosy-Tican *et al*., 2005) resulting in stimulation or inhibition of growth of *in vitro* plants (Table-1). Normally positively gravitropic Cress (*Lepidium sativum*) roots exhibited negative gravitropism under the effect of a combined magnetic field (Kordyum *et al*., 2005). Inhibition of growth and development was observed specifically at very low MF with Barley showing a decrease in fresh weight of shoot and root and dry weight of shoot (Lebedev *et al*., 1977) and Wheat seedlings that grew slower than control (Bogatina *et al*., 1978). Removal of local GMF (a condition of near null MF) delays flowering in Arabidopsis (Xu *et al*., 2012) thus affecting reproductive growth and ultimately suppressing the yield and harvest index (Xu *et al*., 2013).

Table 1: Morphological changes on plants observed upon exposure to low magneticfield (lower than GFM).

Plant species	Organ	Strength of MF	Effect	References
Pisum sativum	Epicotyl	< GMF	Increased osmotic pressure, Cell elongation	Negishi *et al*.,1999
Desmodiumgyrans	Leaf	50mT	Rapid change inextracellular potential of pulvinus	Sharma *et al*.,2000
Allium cepa	Root and shoot	< GMF	Decrease in cellnumber	Nanushyan and Murashov, 2001
Pisum sativum	Epicotyl	< GMF	Elevated cytosolic ca^{2+}, Ultrastructural alterations	Belyavskaya,2001
Vicia faba	Root tip	10 and 100 µT	Altered membranetransport	Stange *et al*.,2002
Catharanthusroseus	Protoplast	302 mT	Increased Young's modulus of cell wall	Haneda *et al*.,2006
Glycine max	Protoplast	< GMF	Increased protoplast fusion	Nudekha *et al*.,2007
Nicotianatabacum	Protoplast	< GMF	Increased protoplast fusion	Nudekha *et al*.,2007
Actinidiadeliciosa	Pollen	10 µT	Release of internal ca^{2+}	Betti *et al*., 2011

The effect of high magnetic field has been focussed mostly on seed germination studies. Pre- sowing magnetic treatment of 99mT for 11 min. in Okra (*Abelmoschus esculentus* cv. Sapz paid) resulted in a significant increase in germination percentage, number of flowers, fruits and seeds per plant, leaf area, plant height at maturity and pod mass per plant (Naz *et al*., 2012). Similarly pulsed EMF exposure of Corn seeds prior to sowing for 30- and 45-minutes improved germination percentage, chlorophyll content, leaf area, plant fresh and dry weight and yield with economic impact on producer's income in context of a modern, organic and sustainable agriculture (Bilalis *et al*., 2012). Pea seeds exposed to 60 and 180 mT for 5mins before sowing showed enhanced germination parameters that could be used practically to hasten the germination in Pea (Iqbal, 2012). Promotional effect of EMF was suggested on growth characteristics when imbibed Wheat seeds increased speed of germination upon exposure of 30mT static MF and a 10 kHZ EMF for 4days, each 5 hours (Payez *et al*., 2013). Specific combinations of field strength and exposure time can improve seed performance as observed in tomato (*Solanum lycopersicum*) cv. Lignon seeds. Among the various combinations 160 mT for 1 minute and 200 mT for 1 minute significantly reduces the germination time, enhances germination percentage and increases the shoot and root length of the seedlings compared to control seeds (De Souza *et al*., 2010). Significant effect of non-uniform MF is also documented in Tomato var. MST/32 seeds based on higher germination rate as compared to control (Poinapen *et al*., 2013, a). Mung bean (*Vigna radiata*) seeds exposed to static MF of 87-226mT in batches for 100 mins. Showed a linear increase in germination with increasing intensity (Mahajan and Pandey, 2014). Significant increase in speed of germination, seedling length, seedling dry weight, root length, root surface area and root volume were recorded in Chickpea (*Cicer arietinum*) compared to control upon MF application from 0 to 250 mT in steps of 50mT for 1 to 4 hours. Further among the treated seeds, rainfed conditions found advantageous for better performance. Under the same conditions, Sunflower seedlings showed higher seedling dry weight, root length, root volume and root surface area (Vashisth and Nagarajan, 2008). Seed germination and seedling growth of bean and wheat seeds under static magnetic field (4 or 7mT) showed promotional effects irrespective of the test conditions of increasing osmotic pressure provided by salt or sucrose. Of the test groups, exposure of 7mT recorded greatest germination and growth rates for both plants (Cakmak *et al*., 2010). Continuous exposure of pea seeds under static MF of 125 to 250 mT resulted in longer and heavier plants compared to control (Carbonell *et al*., 2011). Similarly, when germinating barley seeds were exposed to high MF conditions for different time intervals increase in length and weight was reported (Martinez *et al*., 2000). Enhanced rate of emergence, increased root number and increased average root length was also reported in *Dioscorea opposita* upon exposure with twice gradient MF (Li, 2000). Corn seeds when continuously exposed to 125 or 250 mT showed an increase in total fresh weight resulting in plants that are higher and heavier than control (Florez *et al*., 2007). Contradictorily reduction in mean germination time was observed in rice (*Oryza sativa*) when seeds were exposed to high MF (125 or 250 mT) conditions for different time intervals indicating that high MF treatment negatively affects germination and growth of rice plants (Florez *et al*., 2004). While pre-sowing Triticum seed treatment with magnetic fields 30 mT, 50Hz, 30s did not stimulate growth under optimal soil watering flooding suppressed the growth of both (with or without magnetic field treatment) test plants (Balakhnina *et al*., 2015).

Table 2: Morphological changes on plants observed upon exposure to high magneticfield (higher than GFM).

Plant species	Organ	Strength of MF	Effect	References
Carica papaya	Pollen	> GMF	Increased germination	Alexander and Ganeshan, 1990
Solanum tuberosum	Plantlets	4 mT	Enhancedgrowth	Iimoto *et al*.,1998
Dioscoreaopposite	Seedling	2 x GMF	Higher root number & root length	Li, 2000
Hordeumvulgare	Seedling	125mT	Increased lengthand weight of seedlings	Martinez *et al*.,2000
Cryptotaeniajaponica	Seed	500, 750 µT	Promotion ofgermination	Kobayashi *et al*.,2004
Desmodiumgyrans	Leaf	50mT	Reduction in rhythmic movements ofleaflet	Sharma *et al*.,2000
Fragaria vesca	Plantlets	0.096, 0.192 and 0.384 T	Higher fruityield	Esitken andTuran, 2004
Oryza sativa	Seed	125, 250 mT	Reduction in germination	Florez *et al*., 2004
Taxus chinensis	Suspension culture	3.5 mT	Higher taxolproduction	Shang *et al*.,2004
Paulowniafortunei	Tissue culture	2.9- 4.8 mT	Enhanced regenerationcapability	Yaycili and Alikamanoglu,2005
Paulowniatomentosa	Tissue culture	2.9- 4.8 mT	Enhanced regeneration capability	Yaycili and Alikamanoglu, 2005
Solanum lycopersicum	Shoot	160-200 mT	Increased meanfruit weight & yield	De Souza *et al*.,2006
Zea mays	Seed	125-250 mT	Increase in freshweight	Florez *et al*.,2007
Beta vulgaris	Seedlings	5mT	Higher root andleaf yield	Rochalska, 2008
Cicer arietinum	Root	0-250mT	Increased root length, root surface area and volume	Vashisth and Nagarajan, 2008
Cicer arietinum	Seed	0-250mT	Enhanced seedgermination	Vashisth and Nagarajan, 2008
Helianthusannuus	Seedling	50, 200 mT	Increased rootlength, root surface area,	Vashisth and Nagarajan, 2010
Phaseolusvulgaris	Seed	2 or 7 mT	Promotion ofgermination	Cakmak *et al*.,2010.
Triticumaestivum	Seed	4 or 7 mT	Promotion ofgermination	Cakmak *et al*.,2010.
Solanum lycopersicum	Seed	160-200 mT	Promotion ofgermination,	De Souza *et al*.,2010; Poinapen*et al*., 2013a.
Abelmoschusesculentus	Seeds	99mT	Increased germination	Naz *et al*., 2012
Zea mays	Seed		Promotion ofgermination	Bilalis *et al*.,2012.
Triticumaestivum	Seed	30 mT	Promotion ofgermination	Payez *et al*.,2013
Vigna radiata	Seed	87-226 mT	Promotion ofgermination	Mahajan andPandey, 2014

At cellular level longer pea epicotyls under low MF condition (Yamashita *et al*., 2004) can be correlated to elongation of cells due to increased osmotic pressure (Negishi *et al*., 1999).

Further a number of noticeable events observed under low MF condition in Pea seedlings including increase in size and relative volume of mitochondria, reduction in creastae, an electron transparent matrix, reduction in phytoferritin in plastids, development of lytic compartments, accumulation of lipid bodies and effects on ultra structure of root cells due to disruptions in different metabolic systems including ca^{2+} homeostasis (Belyavskaya, 2001). Low MF intensities (10 and 100 µT at 50 or 60 Hz) altered membrane transport process in root tips in Broad bean (*Vicia faba*) seedlings (Stange *et al*., 2002). Increase in frequency of protoplast fusion in Tobacco (*Nicitiana tobacum*) and Soybean protoplast with participation of elevated cytosolic ca^{2+} after exposure to very low MF (Nedukha *et al*., 2007) suggests ca^{2+} entry might play a crucial role in early MF sensing mechanism (Belyavskaya, 2001). On the same line it was also found that release of internal ca^{2+} under low MF (10 µT) conditions in *Actinida deliciosa* positively regulated pollen germination (Betti *et al*., 2011). Uncytokinetic mitosis under very low MF conditions in root and shoot of onion (*Allium cepa*) meristems resulted in formation of binuclear, tetra nuclear and giant cells by fusion of normal nuclei. Further artificial shielding of GMF resulted in a significant decrease in cell number in root and shoot meristem (Nanushyan and Murashov, 2001).

The slower rhythmic leaflet movements of *Desmodium* *gyrans* under static MF (50mT) was ascribed to a rapid change of extracellular potential of the pulvinus mediated through electrical processes in the pulvinus tissue (Sharma *et al*., 2000). Single suspension cultured cells and protoplasts of *Catharanthus roseus* when exposed to high MF (302±8 mT) conditions for several hours (by anchoring to a glass plate) almost tripled the Young's modulus of the cell wall which are newly synthesized suggesting the effects of high MF exposure conditions (Haneda *et al*., 2006).

Table 3: Cellular changes on plants observed upon exposure to magnetic field.

Plant species	Organ	Strength of MF	Effect	References
Pisum sativum	Epicotyl	< GMF	Increased osmotic pressure, Cell elongation	Negishi *et al*.,1999
Desmodiumgyrans	Leaf	50mT	Rapid change inextracellular potential of pulvinus	Sharma *et al*.,2000
Allium cepa	Root and shoot	< GMF	Decrease in cellnumber	Nanushyan and Murashov, 2001
Pisum sativum	Epicotyl	< GMF	Elevated cytosolic ca^{2+}, Ultrastructural alterations	Belyavskaya,2001
Vicia faba	Root tip	10 and 100 µT	Altered membranetransport	Stange *et al*.,2002
Catharanthusroseus	Protoplast	302 mT	Increased Young's modulus of cell wall	Haneda *et al*.,2006
Glycine max	Protoplast	< GMF	Increased protoplast fusion	Nudekha *et al*.,2007
Nicotianatabacum	Protoplast	< GMF	Increased protoplast fusion	Nudekha *et al*.,2007
Actinidiadeliciosa	Pollen	10 µT	Release of internal ca^{2+}	Betti *et al*., 2011

From a biochemical prospective altered activity of free radical scavenging enzymes like protease, α-amylase, dehydrogenase, catalase, esterase, polyphenol oxidase, β-amylase, acid phosphatise, superoxide dismutase, alkaline phosphatase, nitrate reductase, peroxidise and ascorbate peroxidise upon exposure to high MF condition suggestes accumulation of reactive oxygen species (Xia and Guo, 2000; Anand *et al*., 2012; Polovinkina *et al*., 2011; Jouni *et al*., 2012; Shine and Guruprasad, 2012; Shine *et al*., 2012; Payez *et al*., 2013; Radhakrisnan and Kumari., 2012,2013; Aleman *et al*., 2014; Rajabbeigi *et al*., 2013; Haghighat *et al*., 2014; Vashisth and Nagrajan., 2010; Serdyukov and Novitskii., 2013). These results are based on various plant species including pea, raddish, soyabean, cucumber, broad bean, *Leymus chinensis*, corn, parsley and wheat. An enhanced esterase activity with low frequency MF was reported during esterase induction in wheat (Aksenov *et al*., 2000). When Soybean seeds are primed with static magnetic field (150 mT and 200 mT) a reduction was observed in O_2 radical (superoxide) level (Baby *et al*., 2011). In addition, an increase in superoxide radicals and H_2O_2 was reported in *Cucumis sativus* seedlings under high MF (Bharadwaj *et al*., 2012). Recently a significant difference was recorded in ascorbate peroxidise (APX), glutathione reuctase (GR) and guaiacol peroxidise (GPX) activity along with thiobarbituric acid reactive substance (TBAR) level in wheat depending on soil watering condition and whether or not the seeds are pre-treated with magnetic field. It was observed that under optimal soil wateringTBAR level decreased when magnetic field is applied where as under flooding condition TBAR level increased irrespective of the condition of seed pre-treatment with magnetic field. Increased APX activity was recorded only during the initial period with applied magnetic field under optimal soil watering whereas plants with magnetic field applied under flooding condition showed higher APX activity throughout the observation period in wheat leaves. While no stimulating effect was recorded for GR, GPX showed enhanced activity in the leaves and roots only under flooding condition if seeds are pre-treated with magnetic field (Balakhnina *et al*., 2015). Pre-sowing magnetic treatment in soybean showed improved biomass accumulation by an increase in intensities of protein bands corresponding to the larger and smaller subunit of Rubisco (Shine *et al*., 2011).

Magnetic field produced a very low number of proteomic alterations in Arabidopsis under different levels of gravity and magnetic field strength (Herranz *et al*., 2013). However MF leads to redistribution of cellular activities and this is why application of proteomic analysis to the whole organs or plants is not so informative (Maffei, 2014). Interestingly a striking difference between blue light dependent phosphorylation of CRY-1 and CRY-2 and their dephosphorylation in dark under varying magnetic field suggests that a change in GMF could affect the activated state of cryptochrome. Under high MF (500µT) both CRY-1 and CRY-2 gets phosphorylated while under near null MF only CRY-2 gets phosphorylated. Dephosphorylation of CRY-1 and CRY-2 slows down in dark in high MF (500µT) but accelerated in near null MF (Xu *et al*., 2014).

The increase in NO concentration and NOS activity following cadmium stress in mung bean seedlings treated with 600mT MF compared to cadmium stress alone shows that the compensation of MF for the toxicological effects of cadmium exposure are related to NO signal (Chen *et al*., 2011). Further pre seed magnetic treatment has been reported to minimize the drought induced adverse effects in corn by photochemical and non photochemical quenching and by improving chlorophyll-a (Javed *et al.*, 2011). Increase in photosynthesis, stomatal conductance and chlorophyll content was also observed in corn plants exposed to static MF of 100 and 200 T under irrigated and mild stress condition (Anand *et al.*, 2012).

In radish seedlings MF stimulated synthesis of glycolipids and phospholipids in cell membranes including membranes of chloroplast and mitochondria (Novitski *et al.*, 2014). Magnetic field effects in plasma membranes of seeds of tomato plants showed enhanced lipid order resulting in an increase in gel component and decrease in fluid component of the lipids (Poinapen *et al.*, 2013 b). Further increased lipid peroxidation and H_2O_2 levels was reported in Shallot (Allium ascalonicum) leaves under low intensity static magnetic field (7 mT, 20 kV/m) suggesting the role of apoplastic constituents as potential regulator of redox imbalance (Cakmak *et al.*, 2012).

Table 4: Biochemical changes on plants observed upon exposure to magnetic field.

Plant species	Organ	Strength of MF	Effect	References
Triticumaestivum	Seed and seedlings	20 nT to 0.1 mT	Enhanced esterase activity	Aksenov *et al.*,2000
Leymus chinensis	Seedlings	200 mT, 300 mT	Increase in peroxidise activity	Xia and Guo,2000
Helianthusannuus	Seedlings	50, 200 mT	Enhanced activities of protease, α-amylase, dehydrogenase	Vashisth and Nagrajan., 2010
Glycine max	Seedlings	150 mT, 200 mT	Increase in intensities of Rubisco	Shine *et al.*, 2011
Glycine max	Seedlings	150 mT, 200 mT	Reduction of O_2 radical level	Baby *et al.*,2011
Pisum sativum	Seedlings	125 mT, 250 mT	Affects induction, stabilization andinhibition of SOD activity	Polovinkina *etal.*, 2011
Vigna radiata	Seedlings	600mT	Increase in NO concentration and NOS activity and decrease in H_2O_2	Chen *et al.*,2011
Cucumis sativus	Seedlings	100-250 mT	Increased superoxide radicals and H_2O_2	Bhardwaj *et al.*, 2012
Glycine max	Seedlings	150 mT, 200 mT	Production of reactive oxygenspecies	Shine *et al.*,2012
Allium ascalonicum	Seedlings	7 mT	Increased lipid peroxidation and H_2O_2 levels	Cakmak *et al.*,2012
Vicia faba	Plantlets	15 mT	Accumulation of reactive oxygenspecies	Jouni *et al.*,2012
Zea mays	Seedlings	100 mT, 200 mT	Decrease in level of Peroxidase, CAT, SOD and H_2O_2 and enhancedrate of photosynthesis	Anand *et al.*,2012
Zea mays	Seedlings	100 mT, 200 mT	Reduction in antioxidant enzymes,enhanced photosynthesis	Shine and Guruprasad, 2012
Glycine max	Seedlings	1500 nT	Altered activity of β-amylase, acid phosphatase, polyphenol oxidase,catalase, α-amylase,alkaline phosphatase, protease, nitrate reductase and increase in total soluble sugar, total protein and phenol content.	Radhakrisnanand Kumari.,2012, 2013
Arabidopsisthaliana	*In vitro*callus culture	10.1 T and 16.5 T	Proteomic alterations	Herranz *et al.*,2013
Petroselinum crispum	Cells	30 mT	Multiple effects on CAT and APXactivities under experimental condition	Rajabbeigi *et al.*, 2013
Solanum lycopersicum	Seeds	0.126 T, 0.208 T	Enhanced lipid order	Poinapen *et al.*,2013 b
Triticumaestivum	Seeds	30 mT	Increase in CAT activity and proline content and decrease in rateof lipid peroxidation and peroxidise activity	Payez *et al.*,2013
Raphanussativus	Seedlings	185 µT to 650 µT	Activity of SOD and CAT inhibited at low intensities andactivated at high intensities	Serdyukov and Novitskii., 2013
Arabidopsisthaliana	Seedlings	500µT	Phosphorylation of CRY-1 andCRY-2	Xu *et al.*, 2014
Raphanus sativus	Seedlings	500 µT	Enhanced lipid synthesis	Novitski *et al.*, 2014
Coffea arabica	Seedlings	2 mT	Decreased SOD, APX and CATactivities	Aleman *et al.*,2014
Vicia faba	Plantlets	30 mT	Increase in CAT activity andaccumulation of H_2O_2	Haghighat *et al.*,2014

At molecular level artificial shielding of GMF enhanced the DNA content in root and shoot of onion (*Allium cepa*) meristems (Nanushyan and Murashov., 2001). Alterations in condensed chromatin distribution and reduction in volume of granular nucleolus component with appearance of nucleolar vacuole under low MF conditions was observed in Pea roots suggesting a decrease in activity of r-RNA synthesis in some nucleoli (Belyavskaya, 2004). In Arabidopsis under near null MF, the change in the transcript level of three cryptochrome related genes PHYB, CO and FT after PCR analysis suggests that delayed flowering in Arabidopsis under near null MF might be cryptochrome related (Xu *et al*., 2012). Induction of Adh/GUS transgene (Alcohol dehydrogenase (Adh) promoter driving β-glucuronidase (GUS) reporter gene) in engineered Arabidopsis was reported with high magnetic strength. Microarray analysis revealed differential expression of 114 genes including stress related genes and transcription factors (Paul *et al*., 2006).

Apart from this many findings further correlates the change in GMF with a wide array of promising future implications. Mesozoic mass extinction is characterised by a significantly reduced virtual dipole moment of GMF as compared to today's values (Shcherbakov *et al*., 2002). This change in polarity, the so called geomagnetic reversal has been estimated to occur every 300,000 years (Maffei, 2014). The present polarity started around 7, 80,000 years ago and an imminent reversal would not be so unexpected (De Santis *et al*., 2004). Recently the variation caused by the cease of GMF during polarity transition has been correlated to plant evolution (Occhipinti *et al*., 2014). It has been shown that the periods of normal polarity overlapped with the diversion of most familial angiosperm lineages. This correlation appears to be particularly relevant to angiosperms compared to other plants (Occhipinti *et al*., 2014). In this context exposure of artificially reversed GMF to Arabidopsis has significant effects on plant growth and gene expression supporting the hypothesis of role of GMF reversal in plant evolution (Bertea *et al*., 2015). Amyloplast based gravity sensing system under experimental stimulation by high gradient MF can serve as directional stimulus during seed germination in low gravity environments as observed in movement of corn, wheat and potato starch grains in suspension with vedio-microscopy (Hasenstein *et al*., 2013). Further diamagnetic levitation of transgenic seedling of Arabidopsis containing either the CYC B1-GUS proliferation marker or the DR5-GUS auxin mediated growth marker led to changes that decoupled meristematic cell proliferation from ribosome biogenesis and altered auxin polar transport similar to those caused by real (on board the International Space Station (ISS)) or mechanically stimulated microgravity (Manzano *et al*., 2013).

Primary mechanism of interaction between magnetic field and biological system has become a central question in explaining the wide range of effects caused by magnetic field. Considerable attention has been given to cryptochrome as a plant magneto-sensor. The mechanism involving flavin-tryptophan radical pair in cryptochrome involving molecular oxygen as a reaction partner is currently the only plausible mechanism of magnetoreception (Occhipinti, 2014). This is strengthened by the ability of cryptochrome to respond to magnetic field corresponding to Earth's strength at physiological temperature (Maeda *et al*., 2012).

CONCLUSION AND THE WAY FORWARD

Despite preliminary studies regarding the biological effects of GMF, the mechanism of magnetoreception and its downstream cellular pathways that convert biophysical to cellular responses are not yet fully explored. Recent correlation between GMF reversal and diversion of most familial angiosperms can encourage experimental approach to demonstrate changes in morphology and gene expression to address the role of geological GMF variation in plant evolution. Environments lacking a GMF are expected to generate reactions in living organisms. In this context understanding the mechanism of magnetoreception and downstream cellular response will help to design sustenance system in future space expedition.

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