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Effects of geomagnetic field deprivation on germination and early growth of maize variety San (*Zea mays* L. cv. San)

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Abstract. The geomagnetic field (GMF) represents one of the major environmental factors which may suffer either natural or anthropogenic disturbances. According to available literature data, many plants species responds to GMF changes and its abnormalities can adversely affect live organisms. The aim of the study was to investigate the influence of GMF deprivation on selected morphological and physiological parameters of maize variety San (*Zea mays* L. cv. San). The examined parameters included germination capacity, seedling growth, fresh and dry weight, the water content and the level of disorganization of seedling cell membranes.

The obtained results suggest that GMF deprivation caused a reduction of germination capacity of maize. Moreover, roots of seedlings growing under disturbed GMF conditions (GMF intensity approx. 12 μT) were significantly longer as compared to the control group (GMF intensity approx. 38–42 μT). Fresh weight, dry weight, and coleoptiles length showed no differences among the groups. However, significantly lower electrolyte leakage was observed in maize seedlings of the experimental group.

Keywords: geomagnetic field deprivation, germination, maize seedlings

INTRODUCTION

The Earth's geomagnetic field (GMF) constitutes an indispensable element of the natural environment. Despite its static characteristics, it may undergo periodic fluctuations (circadian and annual) as well as natural or anthropogenic disturbances. All life forms adapted to present environmental conditions in the course of the evolution process, which also included development of various mechanism to detect and react to GMF alterations. Analysis of published literature data reveals that bacteria, plants and plentiful species of animals detect GMF presence and its disturbances may produce negative effects. First reports regarding the influence of the geomagnetic field on plant growth and development appeared in the 60-ties. According to Dubrov (1978), depending on the plant species, significant reduction of the GMF can lead to either growth acceleration or inhibition. For example, the growth acceleration was reported for cucumber and radish. The growth inhibition was observed in barley, maize and mustard. Seeds exposed to 2-week GMF deprivation develop more roots and growing points. Seeds of conifers germinating in reduced GMF conditions were characterized by prolonged seed dormancy as well as decreased germinating capacity, oxygen uptake and dry weight. Pittman (1963) observed that germination is influenced by the orientation of seeds in relation to the GMF. The seeds of wheat, flax, rye and barley which were oriented parallel to the magnetic field showed better germination parameters than those oriented perpendicular. The differences observed were not so considerable for oat. Derevenko and Molotkovskii (1970) noted that changes in maize seeds orientation in relation to the GMF influenced plant polarity and induced changes in weight ratio of above ground parts to undergo parts. Data regarding influence of the reduced GMF on plants is scarce. It has been observed that reduced GMF conditions can produce diverse biological effects in plants and other living organisms which affect cells, tissues or whole organs (Dubrov, 1978; Zhadin, 2001; Tombarkiewicz, 2004; Maffei, 2014). However, further experiments are necessary to discover precise mechanisms underlying the influence of the disturbed GMF on life forms. Earlier studies on maize (*Zea mays* L.) were focused on establishing effects produced by herbicides, temperature, drought, alternating and static magnetic fields, the electromagnetic field and other exogenous stimuli which have impact on morphometric and physiological parameters (Aladjadjiyan, 2002; Kim et al., 2007; Sánchez et al., 2014; Venkata

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et al., 2014). Experimental studies on the effect of GMF deprivation on maize (*Z. mays* L.) growth and development are not available.

Thus, the aim of the study was to determine the influence of GMF deprivation on the seeds germination capacity, seedling growth, fresh and dry weight, water content and the level of disorganization of cell membranes in maize variety San (*Zea mays* L. cv. San).

MATERIALS AND METHODS

Seeds and geomagnetic field shielding

To study the effect of geomagnetic field deprivation on germination capacity and early growth of maize seeds the experiment was carried out under laboratory conditions.

Maize grains of the variety San (*Zea mays* L. cv. San) were supplied by the Garden Seed Company POLAN (Poland).

Randomly selected maize grains (the total number of 200) were washed in running water and subsequently in distilled water and were divided into two groups; the control (n = 100) and experimental group (n = 100), and placed on filter paper moistened with distilled water placed into sterile Petri dishes (5 dishes in each group; 20 seeds/1 dish). No other substances was added to the water during experimental period. The control group was maintained in non-disturbed geomagnetic field (GMF induction approx. 38–42 µT) and experimental group was exposed in weakened GMF (GMF induction approx. 12 µT).

The effect of geomagnetic field screening was obtained by application of special cages in which GMF was weakened below 12 µT. In addition the magnetic field in cages was nearly horizontal since the vertical component of the earth-magnetic field was damped by a factor of 0.1 or less as measured with Geo-Scaner BPM 3010 (Weiss and Partner, Bio-Physic Technologie, Wassenach, Germany). Schielding of GMF was achieved by using cages made of steel (the S235JRG2 type; CMC Zawiercie, Poland). The cages were constructed of steel bars 6 mm in diameter with 25 mm spacing between them. The floor of the cage was made of 1.5 mm steel sheet of the same type as the bars. The construction of the cages was previously described in Roman and Tombarkiewicz (2009).

The study was performed at the end of spring under laboratory condition in natural light cycle (14 hours light/10 hours darkness). The experiment was carried out under stable thermal and humidity conditions (ambient daily temperature: 25 ± 1 °C, night temperature 22 ± 1 °C, relative humidity of the air: 65 ± 5%).

To ensure the same light conditions in both groups, the plates of control group were placed in an identical cages which was used to weaken GMF but constructed of wood that did not cause geomagnetic field disturbances.

Germination capacity

Germination capacity was assessed by determining the number of germinated seeds on the 7th day of the experiment. Seeds were considered as germinated when root length was at least half of the seeds length.

Morphometry, fresh and dry weight, water content, electrolyte leakage

Morphometric analysis was performed on randomly selected 7-day maize seedlings (20 seedlings from each group). Measurements were taken using analog caliper (MAUa HOGETEX 9M01.1.16, Poland) with 1 mm accuracy. The following parameters were determined: seedling fresh weight (FW), seedling dry weight (DW), water content (according to Możdżeń et al., 2017), and the level of disorganization of cell membranes which was established based on percentage of electrolyte leakage (according to Sutinen et al., 1992). A fresh weight was determined using an analytical laboratory scale. To obtain a dry weight (DW), the plant material was frozen at -75 °C and then freeze-dried for 48 h (Scanvac CoolSafeTM PRO 55-4, Denmark). On the basis of the results of FW and DW, the water content was calculated according to the formula: % H_2O = 100 – [(DW × 100) / FW]. For the percentage of electrolyte leakage determination single maize seedlings were placed in polypropylene tubes with 15 ml of deionized water with a conductivity of 0.05 µS cm^{-1} and shaken for 3 hours on a shaker (ProBlot Rocker, Labnet International). The samples were mixed on a vortex (TK3S, Techno Kartell) for 15 minutes. The electrolyte leakage for live seedlings (LZ) was measured using a conductometer (CX-701 Elmetron, Poland) with a K = 1.04 electrode. Then, the plant material in tubes with water were frozen at -75 °C for 24 hours to macerate the tissues. Next, the samples with the plant material were subjected to the same shaking procedure as described above. The electrolyte leakage was measured to determine the total electrolyte content in the dead tissues (LM). Determination of the percentage of electrolyte leakage (EL) from the cell membranes of maize seedlings was made according to the following formula: EL = (LZ / LM) × 100%.

Statistical analysis

The Levene's test was applied to check the homogeneity of variances. The results were evaluated by a one-way analysis of variance followed by the Tukey's *post hoc* test (α = 0.05). The data was analyzed using Statistica 13.0 PL Program.

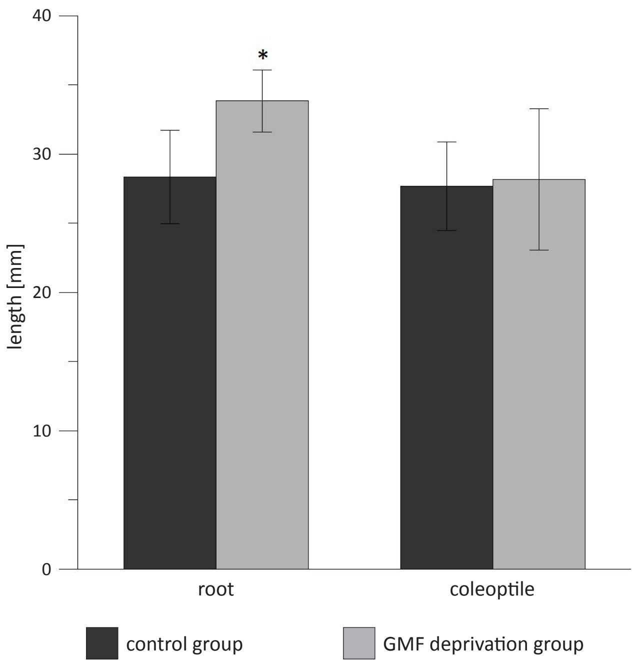

Figure 1. The length of the root and coleoptile of seedlings of maize (*Zea mays*) germinated under control conditions and in conditions of GMF deprivation. The mean values (± SD, n = 20) marked with * statistically significantly differ as compared to the control group (α = 0.05).

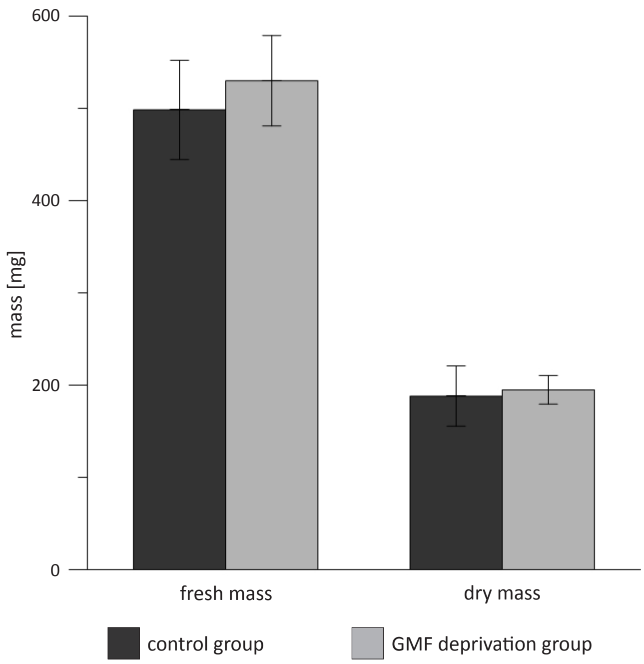

Figure 2. Fresh and dry weight of seedlings of maize (*Zea mays*) germinated under control conditions and in conditions of GMF deprivation. The data are presented as mean (± SD, n = 20, α = 0.05).

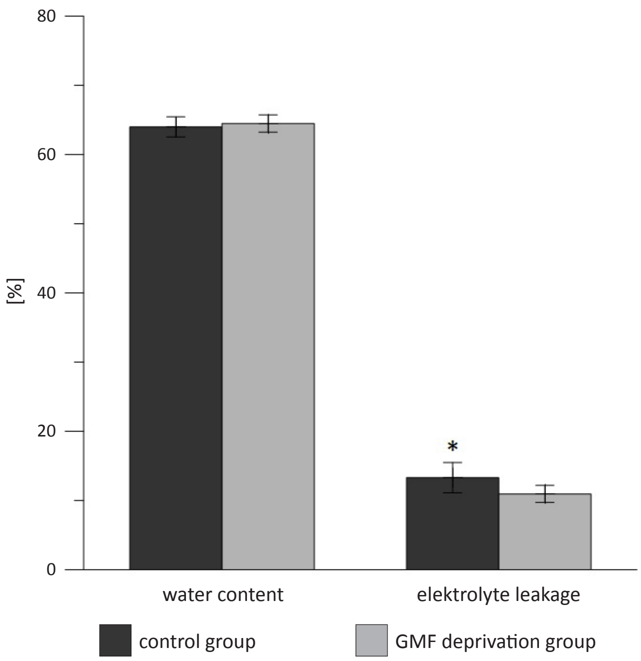

Figure 3. The water content and electrolyte leakage from seedlings of maize (*Zea mays*) germinated under control conditions and in conditions of GMF deprivation. The mean values (± SD, n = 20) marked with * statistically significantly differ as compared to the control group (α = 0.05).

RESULTS

Germination capacity

The percentage of germinated grains in the control group was 81.38% and 63.94% in the experimental group.

Morphometry, fresh and dry weight, water content, electrolyte leakage

Biometric analysis of 7-day maize seedlings revealed differences in root length. Roots of the seedlings from the experimental group were significantly longer than in the control group (Fig. 1). No statistically significant effect of GMF deprivation on coleoptile length was observed (Fig. 1).

Fresh weight and dry weight (Fig. 2) as well as water content (Fig. 3) remained unaffected by experimental conditions. However, significantly lower percentage of electrolyte leakage was observed in maize seedlings of the experimental group (Fig. 3).

DISCUSSION

The current study indicated that disturbance of the Earth's magnetic field reduced germination capacity of maize. The obtained results prove that the geomagnetic field plays an important role in embryogenesis of this plant species. Later stages of plant growth and development depend strongly on germination dynamics. Fast germination results in proper development of seedlings which are more resistant to adverse environmental conditions and produce higher crops (Podleśny, 2004). Experiments conducted by Kornarzyński and Pietruszewski (2008) demonstrated that same positive effects may be obtained by treating seeds with an additional alternating magnetic field. Positive effects were observed in case of bean (*Phaseolus vulgaris* L.), cucumber (*Cucumis sativus* L.) and radish (*Raphanus* sp.) and were especially significant for old seeds with low germination capacity. Magnetic treatment improved seed germination capacity as well as other sowing properties. What is more, other research data indicated that exposure to an alternating magnetic field improves germination capacity of sugar beet (*Beta vulgaris* L.) (Pietruszewski, Wójcik, 2000), wheat (*Triticum* sp.) (Pietruszewski, 1996) and common sunflower (*Helianthus annuus* L.). Research undertaken by Rochalska (2002) revealed that a low-frequency alternating magnetic field can be successfully applied to improve seed vigor. Other scientists reported that the electromagnetic field generated by 110 kV transmission lines (magnetic induction amounting to 2,56 μT) produced positive effects on wheat (*Triticum* sp.) and triticale (×*Triticosecale*). Plants exposed to magnetic induction were characterized by improved germination and produced more spikes with increased number of grains (Rochalska, 2007).

The present study demonstrated that GMF deprivation stimulates the root growth. Unfortunately, biochemical mechanisms underlying such phenomenon are not known (Aksenov et al., 1996). According to the available literature data, treatment with low induction magnetic fields leads to ultra-structural changes in root meristems of pea (*Pisum sativum* L.) including reduction of the size and volume of mitochondria. Belyavskaya (2004) observed increased protein synthesis and accumulation of lipid bodies as a response to stimulation with weak magnetic field.

Maize grains exposed to the reduced GMF developed longer coleoptiles but the differences detected in the present study failed to reach significance level. Negishi et al. (1999) observed epicotyl elongation in field pea (*P. sativum* L.) exposed to reduced geomagnetic fields. Statistically significant changes induced by a lowered geomagnetic field showed a decrease of electrolyte leakage from cell membrane of maize seedlings, indicating increased integrity of cell membranes.

CONCLUSIONS

1. Increased integrity of cell membranes (as indicated by lower electrolyte leakage) and acceleration of elongation growth in roots suggest that plants developed some adaptive mechanisms in response to GMF deprivation. Despite undertaking effort to adapt to changeable conditions, maize was characterized by reduced germination capacity which may suggest that mechanisms of homeostatic adaptation are not sufficient.

2. There is no doubt that the GMF disturbance has influence on plant life cycle and effects produced by magnetic field alteration may be either positive or negative. Further research is necessary in order to determine the influence of the disturbed GMF on early growth of cultivated plants.

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