Analysis of the Impact of 200 μT and 300 μT *Extremely Low Frequency* (ELF) Magnetic Fields on the Growth Rate of Edamame Plants

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Abstract. The Extremely Low Frequency (ELF) magnetic field has an ability to penetrate almost all materials and is non-ionizing radiation so that it can trigger cell proliferation. This study aims to examine the effect of exposure to the 200–300 μT ELF magnetic fields on the growth rate of Edamame plants. This study is included in a laboratory experiment with a completely randomized design research. The sample of this study was 250 Edamame seeds consisting of 50 seeds as the control group and 200 seeds equally divided in four groups (50 seeds for each) exposed to the 200 μT and 300 μT ELF magnetic fields for 60 min and 120 min. Indicators of growth rate consisted of the height, number of leaves, and wet mass. The data analysis using One-Way Anova proved that the group exposed to the 300 μT ELF magnetic field for 120 min was significantly ($p < 0.05$) higher than that of the control group and other groups on the indicators of height of plants, number of leaves, and wet mass. This study concludes that an exposure to the 300 μT ELF magnetic field for 120 min has a significant effect on the growth rate of Edamame plants.

Keywords: Extremely Low Frequency (ELF) magnetic field · Height of plants · Number of leaves · Wet mass

1 Introduction

Electromagnetic field comprises a combination of a magnetic field and an electric field. Electromagnetic fields have a very wide frequency range, from low to the high one. Extremely Low Frequency (ELF) magnetic field is included in the magnetic field with very low frequency around 0 Hz to 300 Hz. It produces a very small energy that does not make any change in temperature (non-thermal) when interacting or inducing the system. ELF magnetic field is unobstructed and can penetrate biological tissue freely so that it can interact with moving charges, such as ions, proteins, etc. [1]. It acts as a non-critical agent but stimulates cell growth under certain exposure conditions [2]. It can also affect cell activities and metabolism [3]. Magnetic fields can change cell physiology, metabolism, and morphology [4]. As time goes by, many studies has done this to investigate the effects of exposure to extremely low frequency (ELF) magnetic

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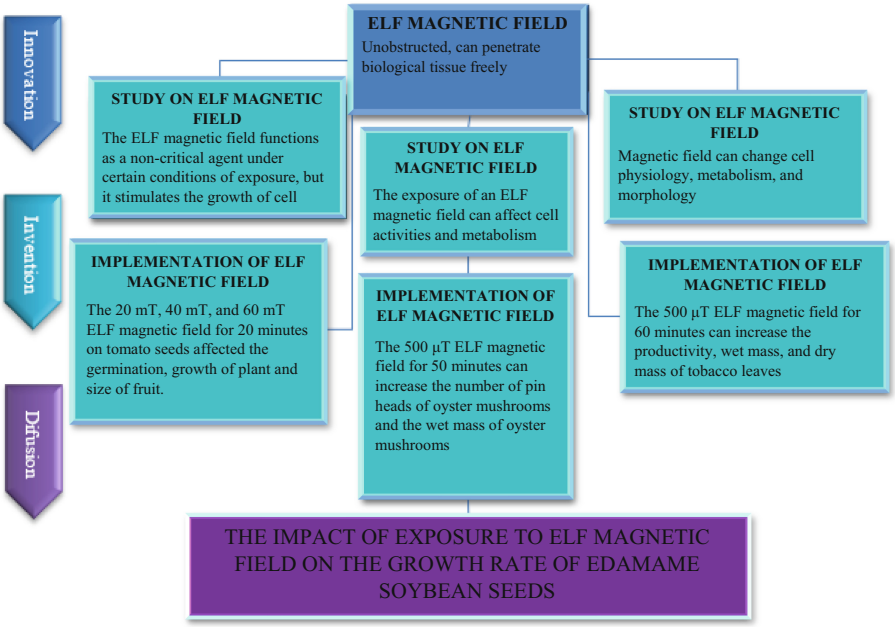

Fig. 1. State of art of the magnetic field.

fields on living things, which have been observed from food, agriculture, and health. Exposure to the 20 mT, 40 mT, and 60 mT ELF magnetic fields with for 20 min a day on tomato seeds significantly affected the germination, growth of plant, and size of fruit [5]. The extremely low frequency (ELF) magnetic field was able to affect the growth of oyster mushrooms with exposure to a magnetic field 500 μT for 50 min to increase the number of pin heads of oyster mushrooms as well as the wet weight of oyster mushrooms in tobacco seeds, the 500 μT ELF magnetic field for 60 min could increase the productivity of tobacco leaves, wet mass, and dry mass [6]. Based on the results of this study, an exposure to the ELF magnetic fields can affect the process of cell proliferation which results in an increase in cell metabolism so that it can affect the speed of growth (Fig. 1).

Edamame is a type of legume plant that is popular because it has high nutritional value. Edamame itself is consumed in Asia and the United States. In the United States, the market demand for edamame continues to increase significantly since edamame is known for its benefits and nutrition [7]. Edamame has a larger grain size, sweet taste, and softer texture than the regular soybeans. They can grow well in areas with tropical and subtropical climates with sufficient hot temperatures by relatively high rainfall to become one of the ideal lands for growing edamame, and thus, Indonesia is an ideal place for edamame cultivation. Edamame has a relatively shorter harvest period that that of the ordinary Edamame. The reported vegetation period of edamame plants is between 75 and 100 days [8]. Edamame plants need sunlight, fertile and moist soil, and warm temperatures during the growing period [9]. Their pod color is an indicator that determines the

main quality of edamame, which is influenced by light, moisture, fertilization, varietal characteristics, planting density, and harvesting method [8]. Edamame plants have an economically great market opportunity, both domestic and foreign market demand. The high market demand in Edamame plants become an attraction for Edamame farmers. The important role of soybeans as a food ingredient and health nutrition, as well as having a quite high economic value, makes.

Edamame plants potential to develop. Based on the description above, the use of an Extremely Low Frequency (ELF) magnetic fields with the right dose is expected to maximize the rate of plant growth as an alternative solution in reducing the use of chemical fertilizers on plants that can damage environmental ecosystems. Therefore, the researcher attempted to conduct a study titled "Analysis of the Impact of Exposure to Extremely Low Frequency (ELF) Magnetic Fields on the Growth Rate of Edamame Plants".

2 Materials and Methods

This study is included in a laboratory experimental research with randomized post-test only control group design. The sample was randomly obtained (random sampling) and then grouped into two parts, i.e., the experimental group and the control group. The experimental group was exposed to 200 μT and 300 μT ELF magnetic fields for 60 min and 120 min. The control group is the group that was not exposed to the ELF magnetic field. Figure 2 presents the research design used in this study.

2.1 Research Location and Time

The process of exposure to the ELF magnetic field was performed at the Physics Education Laboratory FKIP, University of Jember. Meanwhile, the planting and treatment of

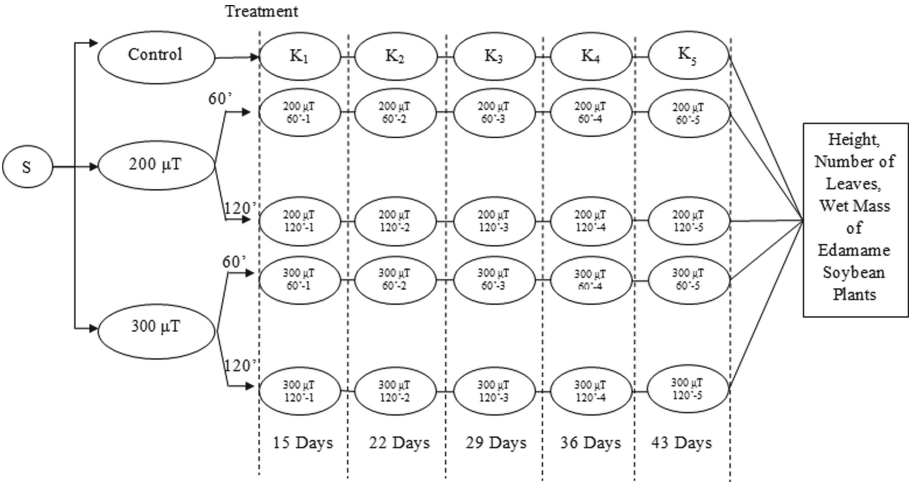

Fig. 2. Research design.

Edamame plants were performed at the Biology Education Greenhouse FKIP, University of Jember.

2.2 Sample

The sample of this study consisted of 250 seeds of prospective Edamame seeds purchased from Y. Garden, a Jember horticultural seed producer with Ryokkoh 75 varieties. The Edamame seeds met the criteria well, i.e., the seed coat did not come off, the seeds did not break, and the seeds were not wrinkled.

2.3 Procedure of ELF Magnetic Fields Exposure

The sample of 250 Edamame seeds were soaked in water for 4 h, then drained and placed in a seedling box covered with banana leaves for 24 h. On the exposure stage, the sample was divided into five groups, i.e., one control group, two groups exposed to the 200 μT ELF magnetic field for 60 min and 120 min, and two groups exposed to the 300 μT ELF magnetic field for 60 min and 120 min. The next stage was seeding on media in polybags and observing growth with indicators, i.e., height, number of leaves, and wet mass of Edamame plants.

2.4 Procedure in Measuring the Growth Rate of Edamame Plants

The measurement of the height and number of leaves were performed at the age of 15 days, 22 days, 29 days, 36 days, and 43 days after sowing. The measurement was performed for the height of plant by setting up a ruler and looking at the scale from the ground (measuring the base of the rootstock) to the growing point (tip) of the plant (below the top of the leaf). The number of leaves was leaf trifoliate on Edamame plants. Wet mass measurements were carried out at the age of 29 days and 43 days by taking 10 samples of cleaned plants and then weighing them using a digital balance.

2.5 Techniques of Data Analysis

The technique of data analysis used in this study was the OneWay Anova test as continued with the LSD (Least Significance Different) test using SPSS 23 software.

3 Results and Discussion

This study also describes the data obtained from the measurement of the height of plant, number of leaves, wet mass of Edamame plants.

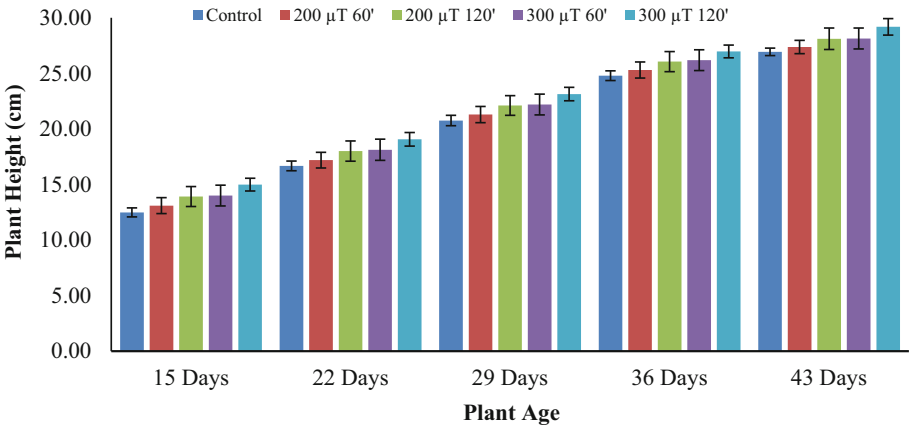

Fig. 3. The height of edamame plants.

3.1 Height Rate

The results of measuring the height of Edamame plants until the age of 43 days are presented in Fig. 3.

The figure illustrates that the growth of Edamame plants height increases linearly to the age of the plants. The results of One-Way Anova analysis indicated that the height of plants in the group exposed to the 200 µT and 300 µT ELF magnetic field was significantly ($p < 0.05$) higher than that of the control group. The fastest increase in the height of stem was found in the Edamame exposed to the 300 µT ELF magnetic field for 120 min, starting at the age of 15 days to 43 days. The increase in the height compared to that of the control group at the age of 15 days, 22 days, 29 days, 36 days, and 43 days was 2,496 cm, 2,394 cm, 2,383 cm, 2.18 cm, and 2.257 cm respectively. It confirms that the exposure to the 300 µT ELF magnetic field for 120 min can increase the growth rate of the height of Edamame plants.

At the age of 15 days to 36 days, the plant growth increased rapidly. However, it grew slower at the age of 43 days. The slow growth might happen because the Edamame had its pod formation phase at the age of 43 days so that the growth of plants was slow since most of the assimilate is used for generative organs for pod formation and seed filling. The results of a study conducted by Rico revealed that the exposure to 3.6 mT magnetic field for 5 min affects the germination of broccoli seeds [10].

3.2 Growth of Leaves

The leaf is a part of a plant organ or plant which is a place to synthesize food. The food synthesis is useful to meet the needs of the plant itself. These plants need to function as food reserves. Leaves have chlorophyll which is a green substance in leaves that plays an important role in the process of photosynthesis. The more the number of leaves, the more places for photosynthesis to take place so that the resulting height of plants is more optimal. Therefore, it can be concluded that sample D (300 µT for 120 min) has an average number of Edamame plant leaves which is always higher than that of the control

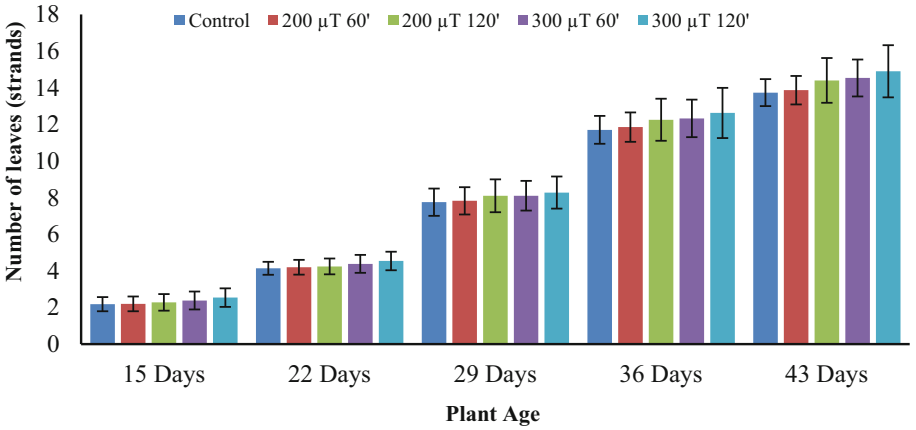

Fig. 4. Number of edamame plant leaves.

sample. The results of a study conducted by El-Gizawi showed that an exposure to the 40 mT magnetic field can increase germination and optimum growth of potatoes [11].

Figure 4 illustrates that the number of leaves increased linearly to the age of the plants. The results of One-Way Anova analysis showed that the increase in Edamame leaves from the age of 15 days to 43 days in the group exposed to the 300 μT ELF magnetic field for 60 min and 120 min was significantly higher ($p < 0.05$) than that of the control group. However, the group exposed to the 200 μT ELF magnetic field for 60 min and 120 min did not significantly differ ($p > 0.05$) from that of the control group. This indicates that an exposure to the 300 μT ELF magnetic field for 60 min and 120 min can increase the growth rate of the Edamame leaves.

3.3 Wet Mass

The measurements of the wet mass of Edamame plants were performed at the age of 29 days and 43 days, as presented in Fig. 5.

Figure 5 illustrates that the wet mass of Edamame plants increased linearly with the age of the plants. The results of One Way Anova analysis showed that the increase in the wet mass of Edamame plants at the age of 29 days and 43 days in the group exposed to the 200 μT and 300 μT ELF magnetic fields for 60 min and 120 min was significantly ($p < 0.05$) higher than that of the control. This shows that the exposure to the 200 μT and 300 μT ELF magnetic fields for 60 min and 120 min can increase the growth rate of Edamame plant biomass. The highest average wet mass of Edamame plants was found in the group exposed to the 300 μT ELF magnetic field for 120 min. The wet mass at the age of 43 days sharply increased because the plants began having its fruit formation phase. This is in accordance with the results of previous study revealing that an exposure to the 0.06 mT magnetic field affected germination and increases wet mass and vigor index of shallots [12]. Figures 6, 7, 8, 9 and 10 presents two pictures of the growth and development of Edamame plant.

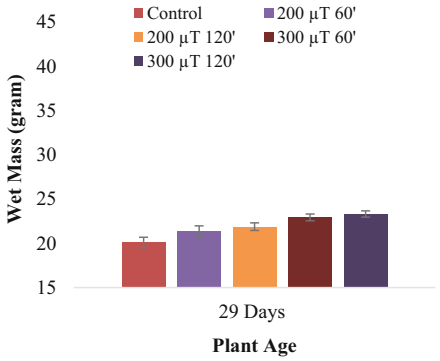

Fig. 5. The wet mass of edamame plants.

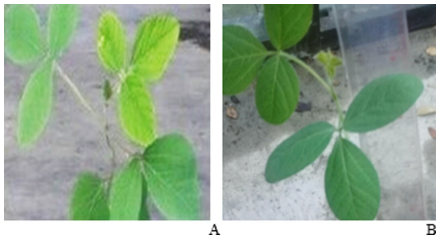

Fig. 6. The growth of Edamame plants aged 15 days: a) group exposed to 300 μT ELF magnetic field for 120 min; b) Control group.

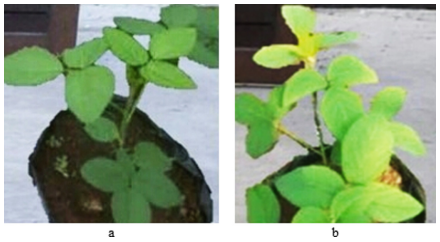

Fig. 7. The growth of Edamame plants aged 22 days: a) control group; b) group exposed to 300 μT ELF magnetic field for 120 min.

The growth of Edamame plants in the control group tended to be longer than that of the experimental group. The height of Edamame in the control group reached 21 cm with 8 leaves after 29 days of seeding. The number of flowers was not as much as that of the experimental group, and thus affecting the amount of Edamame that was produced, which tended to be lower. At the age of 43 days, the height began to slow down because they got their pod formation phase.

The growth of Edamame group exposed to the 300 μT ELF magnetic field for 60 min was faster than that of the control group. This indicates that there is an effect of exposure to the ELF magnetic field on the growth rate of Edamame plants. This is evidenced by

Fig. 8. The growth of Edamame plants aged 29 days: a) control group; b) group exposed to 300 μT ELF magnetic field for 120 min.

Fig. 9. The growth of Edamame plants aged 31 days: a) control group, b) group exposed to 300 μT ELF magnetic field for 120 min.

Fig. 10. The growth of Edamame plants aged 43 days old: a) control group, b) group exposed to 300 μT ELF magnetic field for 120 min.

the results of observations made on the height, number of leaves, number of flowers and number of fruits that tended to be higher than that of the control group.

A magnetic field can affect ion activities and polarizations of the dipoles in cell so that it can affect the metabolism in the cell. Edamame contain Ca^{2+} (calcium) ions which are classified as a paramagnetic material that can be affected by a magnetic field (magnetized). The Ca^{2+} ions, which are paramagnetic in Edamame plants, can open Ca^{2+} ion channels due to being magnetized in the direction of the magnetic field. As a result of the opening of Ca^{2+} ion channels, an increase in Ca^{2+} ion activity occurs which then causes an increase in cell activity. An increase in cell activities will increase cell proliferation which can accelerate the growth process of Edamame plants.

The presence of exposure to a magnetic field creates changes in the movement and increase in the rate of calcium ions which results in changes in the transportation in cell membranes. The field exposed to a magnetic field is able to produce a force for the

calcium ions to move actively and is able to affect the condition of opening channel gates on the cell membrane, so the levels of calcium ions in cells may increase. The magnetic field can increase the levels of calcium ions in the cells. The changes in calcium ion levels make the changes in osmosis and changes in the capacity of cells to absorb water. Due to the increase in calcium ions in the cell, the osmotic pressure in the cell can increase, which results in an increase in the water absorption capacity of the cell. The increase in water absorption in seed cells can stimulate the activity of germination enzymes in seeds, one of them is the α-amylase enzyme, and thus, the metabolism in seeds is faster. The α-amylase enzyme is one of the enzymes that play an active role in the germination process of plant seeds. Germination is the beginning of growth characterized by the appearance of radicles or roots in seeds. The group of Edamame plants exposed to a 50 mT magnetic field for 60 min indicated that seed germination, α-amylase enzyme activity, dehydration, and proteases were significantly higher than that of the control group [13]. The exposure to a 300 mT magnetic field for 3 min on Marigold seeds gave the maximum performance of α-amylase enzyme activities [14]. Meanwhile, the results of another study showed that the exposure to the 0.2 μT magnetic field that induced garden balsam, mizuna, komatsuna, and mescluns seeds shows a growth rate of 1.4 times faster than that of the control group in 8 days of observation [15].

The embryonic cells in Edamame seeds exposed to magnetic fields will be affected, especially the movement or regulation of calcium ions. The changes in the speed of calcium ions can give changes and differences in organisms in the form of resonance in calcium ions in protein coding process that occurs in Ribose Nucleic Acid (RNA). The increase in protein coding will lead to increased enzyme activities in cells. The metabolic processes in the cells increase along with the increase in enzymes so that the nutrients that enter the cells can be digested and absorbed optimally.

Proliferation (cell multiplication) is related to the differentiation process so that the cells in Edamame seeds exposed to magnetic fields will proliferate more quickly due to changes in the flow of calcium ions resulting in a faster differentiation process (formation of plant organs, including leaves) which results in the increased number of leaves and the mass of plant. The changes are caused by the growth of Edamame flowers from the armpits of leaves. If the number of leaves is higher, the number of flowers and fruits will be higher as well. If the plant has more nutrients, the formation of pods with 2 or 3 seeds will be a lot since the nutrients have been fulfilled.

Based on several studies, the ELF magnetic field could affect the growth of plants. The 12.5 mT magnetic field for 10 min and 15 min resulted in an effective dose on the number of leaves per plant, shoot diameter, fresh weight, dry weight, and number of flowers of tomato plants [16]. Giving electromagnetic field radiation for 24 h affected the height and fresh weight of green beans [17]. The growth of roots was significantly enhanced by 600 mT magnetic field treatment [18]. The results were different when Zea mays seeds were exposed to a 1 GHz magnetic field radiation, showing a mutagenic effect and inhibiting cell proliferation [19]. The treated seeds experienced 100% germination and increased root and shoot length in all samples treated with electromagnetic fields [20].

The results of this study proved that the exposure to a 300 μT ELF magnetic field on Edamame seeds for 120 min was proven to increase the growth rate of Edamame plants.

The increase was caused by the magnetic field component that affects the structure and developmental characteristics as well as the plant phytochemical factors [20]. Also, there were changes in the physical and chemical properties of water so that it could enter the plants easier and activate the plant cells which resulted in more fertile growth of the plants. Besides, there were micro components that might be influenced by magnetic fields, such as calcium, potassium, and the like, that could easily enter the plants and increase the nutrients.

The conclusion that can be drawn from this study is that the exposure to the 300 μT ELF magnetic field for 120 min has a significant effect on the growth rate of Edamame seeds.

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Authors' Contributions. S and TP preparing this article from formulating research question, experimental design, and drawing conclusions. WNP and IMSP conducting research and writing the first version of manuscript. S and TP read and finalized the final version of manuscript. All authors read and approved the final manuscript.

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