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Extremely Low Frequency Electromagnetic Field Radiation (50 Hz, 200 µT & 300 µT) to Increase Edamame Productivity and Safety Risks to Health

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Abstract: More and more research results report that exposure to Extremely Low Frequency (ELF) magnetic fields at low intensity can increase cell proliferation. The ELF magnetic field interacts directly with cell membranes, capable of increasing intracellular calcium and under certain conditions affecting cell proliferation. This study wanted to prove the potential of ELF magnetic field radiation with intensity of 200 µT and 300 µT on edamame productivity. The research design used a completely randomized design. The research sample was 250 edamame soybeans of the Ryokkoh-75 variety which were divided into 5 groups. Samples were soaked in warm water for 3 hours and then cured for about 12 hours and exposed to ELF magnetic fields of intensity of 200 µT and 300 µT with variations in exposure time of 60 minutes and 120 minutes. Then it is seeded and planted in the field. Observation of the number of edamame pods and the number of pods was carried out when they were already fruiting, namely day 29 to day 43. The results of the study proved that the number of pods and the number of edamame pods in the group exposed to the 200 µT and 300 µT ELF magnetic fields was higher than the control. It appears that the highest number of fruits and pods occurred in the sample group exposed to the ELF magnetic field intensity of 300 µT. The conclusion is that exposure to the ELF magnetic field intensity of 300 µT has the potential to increase edamame productivity.

Keywords: ELF magnetic field; Number of fruits and pods; Productivity

Introduction

Edamame is a type of bean that originates from Japan, has larger seed sizes, is sweeter, and has a softer texture, with a higher nutritional content compared to local soybeans. Edamame soybeans can grow well in areas with tropical and subtropical climates with sufficient hot temperatures accompanied by relatively high rainfall, therefore edamame soybeans are one of the leading horticultural products in Indonesia. Edamame has a relatively short harvest period compared to ordinary soybeans, which is at the age of 65-68 days when the pods are fully filled and bright green in color (Nair et al., 2023). However, the problem that is still experienced by farmers as company partners is that the production of edamame crops does not meet the quality standards that have been set (Guo et al., 2020). Therefore it is necessary to make efforts to increase the quantity and quality of edamame production with the right method and not detrimental to health. One alternative method that is expected to become this innovation is the use of exposure to Extremely Low Frequency (ELF) magnetic fields.

The results of research on the use of ELF magnetic fields have been widely reported. Exposure to ELF magnetic fields with intensities of 60 mT for 20 minutes on tomato seeds, significantly affected to reduce acid bacteria activity, hence inhibiting putrefactive microorganism activity on foodstuffs associated with rising and decreasing average pH values (Nur et al.,

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2022), and the intensity of 1 mT, 2 mT, and 3 mT can increased the chlorophylls level for low magnetic flux density and low exposure duration (Racuciu, 2020). Exposure to the ELF magnetic field intensity of 600 µT for 60 minutes had the potential to maintain the physical quality of apple tomatoes (Sudarti et al., 2022). Exposure to an ELF magnetic field intensity of 300 µT for 120 minutes has a significant effect on edamame plant biomass (Prihatin et al., 2020). Meanwhile, exposure to an ELF magnetic field with an intensity of 0,3 mT for 20 minutes every day for five days can inhibit the growth of F. Oxysporum (Tirono et al., 2021). This description shows that there is a considerable difference in the intensity of the ELF magnetic field and the length of exposure used in research with the same benefits, so scientific evaluation is still needed.

The effect of proliferation by exposure to ELF magnetic fields is the mechanism underlying its utilization to trigger plant growth. Sudarti et al. (2020) put forward the hypothesis that, exposure to low-intensity ELF magnetic fields (< 500 µT) has the potential to increase cell proliferation. However, exposure to high-intensity ELF magnetic fields (> 1,000 µT) has the potential to increase cell apoptosis (Sudarti et al., 2020). This study aims to evaluate the utilization of Extremely Low Frequency Electromagnetic Field Radiation (50 Hz, 200 µT & 300 µT) to Increase Edamame Fruit Productivity and Safety Risks to Health.

Method

Research design

This research was a laboratory experiment using a completely randomized design. The research sample was 250 edamame soybeans of the Ryokkoh 75 variety, and met the seed quality standards, namely the seed coat was not detached, the seeds were not broken, and the seeds were not wrinkled. Samples were obtained from Y.Garden, a Jember horticultural seed producer. Samples were soaked in water at 28-30 oC for 5 hours, then drained and divided into 5 groups (@ 50 seed candidates). Then each group was exposed to an Extremely Low Frequency (ELF) electromagnetic field with variations in magnetic field intensity of 200 µT and 300 µT and variations in exposure time of 60 minutes and 120 minutes according to the research design.

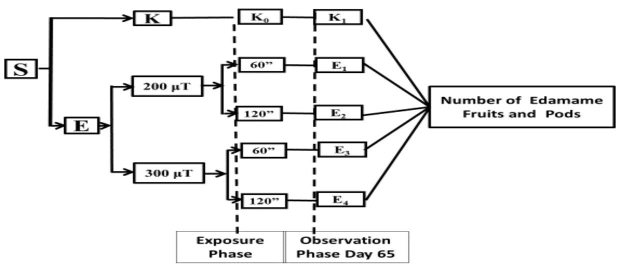

Figure 1. Research Design

Research stages

The stages of this study included: 1) preparation stage: samples of edamame soybean seeds were soaked in water at 28-30 oC for 5 hours then drained, and divided into 5 groups (50 seeds), 2) ELF EMF exposure stage: control group (K) exposed to a natural magnetic field; group A and B were exposed to 200 µT ELF magnets for 60 minutes and 120 minutes; Groups C and D were respectively exposed to an ELF magnetic field with an intensity of exposure of 300 µT for 60 minutes and 120 minutes. 3) seeding stage: each edamame seed is sown in a polybag, 4) harvesting stage: plant growth is observed until harvest at the age of 65 days, 5) as an indicator of productivity, the number of fruit and number of pods is calculated for each plant for all groups sample. The research data were analyzed using comparative statistical analysis to determine the intensity and duration of exposure to the ELF magnetic field which significantly increased the productivity of edamame fruit.

Source of exposure to ELF electromagnetic fields

The source of the role of the ELF electromagnetic field in this study uses an ELF electromagnetic field generator or an ELF EMF Generator with an ELF magnetic field measuring instrument and an ELF electric field using the HI-3604 Extremely Low Frequency Field Strength Measurement System, presented in the figure 2.

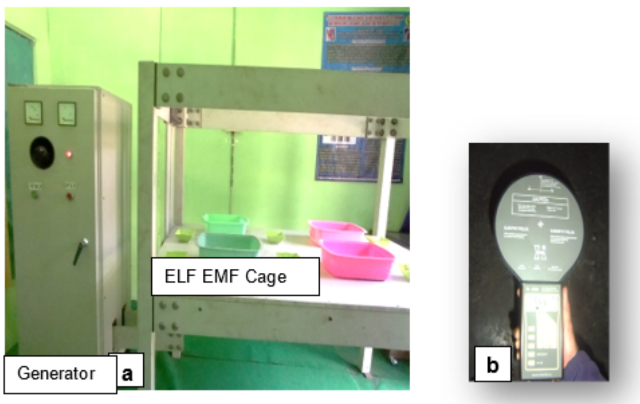

Figure 2. (a) Exposure of Edamame Seeds in an ELF_EMF Generator Cage (b) HI-3604 ELF Field Strength Measurement System.

This generator uses an input voltage source of 220 Vol, a strong current of 5 A, and a frequency of 50 Hz. It has a Stepdown transformer to lower the voltage and a Current-Transformer to increase the current strength, so that it can change the input voltage of 220 Volts to 7 Volts and the input current of 5 A to reach 85 A – 3000 A flowing on the copper plate in the ELF EMF exposure cage. This research requires exposure to ELF magnetic fields with intensity of 200 µT and 300 µT. Output voltage (7 – 25) Volts and Current (125 – 400) A, capable of producing exposure to an ELF magnetic field intensity of around 200 μT - 300 μT and exposure to an ELF electric field of around (20 – 50) Volts/m in an ELF EMF exposure cage.

Result and Discussion

Number of Edamame Fruit

The edamame fruit harvest stage is carried out when the plants are 65 days old. From each group, 30 plants that bear fruit were taken, and here is a photo of the edamame plants during harvest. Next, the number of edamame fruits in each plant is calculated by counting the number of fruits without differentiating the number of pods, and the following is a photo.

Based on the results of the description of the average value and standard deviation of the number of edamame fruits in each plant, they are presented in the following graph. Based on the graph, it illustrates the average edamame fruit production for each plant, in the control group (21.70 ± 0.750), the group exposed to 200 μT for 60 minutes (21.87 ± 0.776), the group exposed to 200 μT for 120 minutes (22.47 ± 1.196), the group exposed to 300 μT for 60 minutes (22.60 ± 0.968), the group exposed to 300 μT for 120 minutes (22.97 ± 1.474). It appears that there is an increase in edamame fruit production along with an increase in the intensity and length of exposure to the ELF magnetic field, but this still needs to be proven through statistical analysis.

Figure 3. Production of Edamame Fruit Control Group (K) and Group Exposure to ELF Magnetic Field with intensity of 200 μT and 300 μT for 60 minutes and 120 minutes

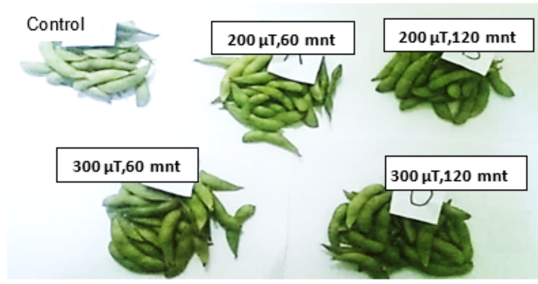

Figure 4. Number of Edamame Soybean Fruits on Each Plant

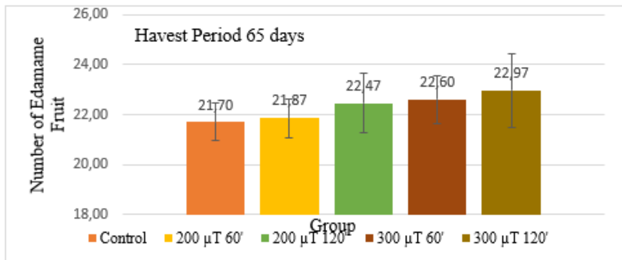

Figure 5. Graph of Average Number of Edamame Fruits for Each Plant

The results of the normal distribution test for 30 edamame plants in each study group proved that the data on the number of edamame fruits in all study groups were normally distributed ($p > 0.05$). The results of the One Way Anova analysis proved that there was a significant difference in the average number of edamame fruits between groups ($p = 0.0000$ or $p < 0.05$). Furthermore, based on the Least Significant Difference (LSD) test, it was shown that the average number of edamame fruits in the group exposed to the ELF magnetic field intensity of 200 μT for 120 minutes, 300 μT for 60 minutes and 120 minutes was significantly ($p < 0.05$) more much compared to control. Only the group exposed to an ELF magnetic field intensity of 200 μT for 60 minutes did not differ from the control ($p = 0.547$, or $p > 0.05$), but was significantly different ($p < 0.05$) compared to the other 3 groups. The mean number of edamame fruits between groups exposed to the ELF magnetic field intensity of 200 μT for 120 minutes, 300 μT for 60 minutes, and 300 μT for 120 minutes was not significantly different ($p > 0.05$).

Based on the results of this analysis, it proves that exposure to ELF magnetic fields with intensities of 200 μT and 300 μT for 60 minutes and 120 minutes has a significant effect on increasing edamame fruit production.

Number of Edamame Pods

Based on the number of pods in edamame fruit, the calculation of the number of edamame pods is done by classifying edamame fruit as having 1 pod, 2 pods, and 3 or more pods. The number of edamame fruit pods on each plant is presented in the following photo.

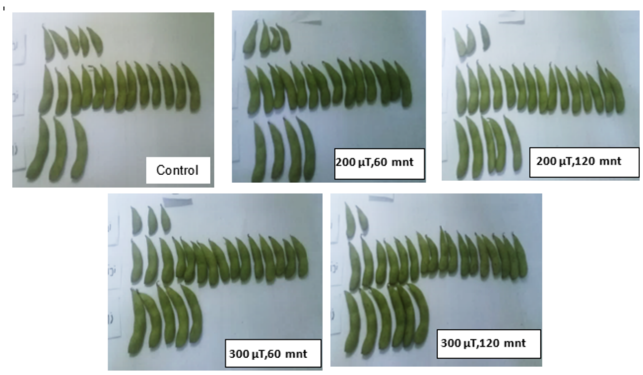

Figure 6. Number of Edamame Pods in 5 Research Groups

Figure 6. Describes the number of fruit containing 1 pod, 2 pods and 3 pods in each plant of the 5 study groups. The description of the mean value and standard deviation of the number of edamame pods in each plant based on the classification of 1 seed pod, 2 seed pod, and 3 seed pod, is presented in the following graph in figure 7.

The normal distribution test results for data on the number of edamame pods with 1 pod, 2 pods and 3 pods in all study groups were normally distributed ($p > 0.05$). The results of the One Way Anova analysis proved that there was a significant difference in the average number of edamame fruits between groups ($p = 0.0000$ or $p < 0.05$). Furthermore, based on the Least Significant Difference (LSD) test showed that the average number of edamame fruit with 1 pod, was significantly ($p < 0.05$) the control group was higher than the group exposed to the ELF magnetic field intensity of 200 µT for 120 minutes, 300 µT For 60 minutes and 120 minutes.

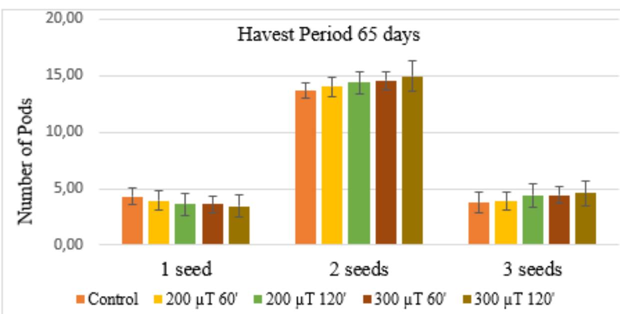

Figure 7. Graph of Average Number of Edamame Pods for Each Plant

The average number of edamame fruit with 2 pods in the group exposed to the ELF magnetic field intensity of 200 µT for 120 minutes, 300 µT for 60 minutes and 120 minutes was significantly ($p < 0.05$) higher than the control group. It was proven that the group was exposed to the ELF magnetic field with an intensity of 300 µT for 120 minutes. It was significantly ($P < 0.05$) higher than the other groups.

The average number of edamame fruit with 3 or more pods in the group exposed to the ELF magnetic field intensity of 200 µT for 120 minutes, 300 µT for 60 minutes and 120 minutes was significantly ($p < 0.05$) higher than the control group or the group exposed to 200 µT for 120 minutes. While there was no significant difference ($p > 0.05$) between the groups exposed to the ELF magnetic field intensity of 200 µT for 120 minutes, 300 µT for 60 minutes, and 120 minutes. The results of this analysis prove that short-term exposure to ELF magnetic fields with an intensity of 200 - 300 µT can increase edamame productivity.

The Role of Ca2+ By the Influence Of The ELF Magnetic Field In The Edamame Growth Process

Biological effects of Extremely Low Frequency (ELF MF) magnetic fields have been widely reported through research, however, only a few researchers have investigated the application of ELF magnetic fields to growth. More and more research results are reporting the effects of cell proliferation and cell apoptosis by exposure to the ELF magnetic field. However, the underlying mechanism is still unclear. The research results reported so far still have many differences in both the intensity of the magnetic field and the length of exposure. One of the main factors is the source of exposure to the ELF magnetic field which is used in research using a different design.

There should be many benefits that can be obtained from the ELF magnetic field. The ELF magnetic field can be likened to a knife blade, it will be very useful if the method of use is appropriate. The apoptotic effect by exposure to the ELF magnetic field certainly provides a very useful inspiration, especially to support sterilization technology in an effort to secure food security. While the proliferation effect also provides inspiration which is very useful to support technology in agriculture.

The results of this study prove that exposure to the ELF magnetic field intensity of 300 µT for 60 minutes, and for 120 minutes can consistently and significantly increase fruit productivity and the number of edamame pods. Until now, not many have reported the results of research on the application of ELF magnetic fields to plants. Relevant to the results of previous studies which have proven that exposure to weak static magnetic fields (0-100 µT) in plants shows the potential to increase germination rates, root and shoot growth; productivity; photosynthetic pigment content; and plant cell proliferation, as well as absorption of water and nutrients (Sarraf et al., 2020).

We and our students have conducted many studies using low-intensity ELF magnetic field exposure (less than 1000 µT) on various plants. The ELF magnetic field is generated by the same ELF electromagnetic field generator as shown in Figure.2. The following is a research report that has been published in the Indonesian National Journal, we present it in table 1.

Table 1. Summary of Research Results of Exposure to ELF Magnetic Fields in Plants

Year	Author	Research Result
2020	Racuciu, (2020)	The intensity of 1 mT, 2 mT, and 3 mT can increased the chlorophylls level for low magnetic flux density and low exposure duration
2020	Prihatin et al. (2020)	Exposure to an ELF magnetic field intensity of 300 μT for 120 minutes has a significant effect on edamame plant biomass
2021	Tirono et al. (2021)	Exposure to an ELF magnetic field with an intensity of 0,3 mT for 20 minutes every day for five days can inhibit the growth of F. Oxysporum
2022	Nur et al. (2022)	Exposure to ELF magnetic fields with intensities of 60 mT for 20 minutes on tomato seeds, significantly affected to reduce acid bacteria activity, hence inhibiting putrefactive microorganism activity on foodstuffs associated with rising and decreasing average pH values
2022	Sudarti et al. (2020)	Exposure to the ELF magnetic field intensity of 600 μT for 60 minutes had the potential to maintain the physical quality of apple tomatoes

Based on the results of this study, it can be concluded that exposure to low-intensity ELF magnetic fields (less than 1000 μT) with short-term exposure has the potential to support agricultural technology, proven to be able to increase plant growth and productivity, but the underlying mechanisms still need scientific explanation.

Based on magnetic properties, all materials can be classified as ferromagnetic, paramagnetic, and diamagnetic. If the material is in a magnetic field, the ferromagnetic and paramagnetic components will experience magnetization in the direction of the magnetic field, while the diamagnetic components will experience magnetization in the opposite direction to the magnetic field. Edamame soybean seeds are composed of millions of cells, and contain various types of ions and molecules. These ions and molecules can be classified into ferromagnetic components, for example iron ions, paramagnetic components, for example, calcium ions (Ca2+) and magnesium ions, and many other ions and molecules.

The characteristics of the magnetic field are different from the electric field, the magnetic field is able to penetrate almost all materials but the electric field is not the case. Exposure to the ELF magnetic field on edamame soybean seeds will interact directly with the membrane of the cells that make up the edamame soybean seeds. Through the magnetic force will interact directly with ions and molecules on the cell membrane, so that the ions and molecules will be polarized. This condition will certainly affect the biophysical and biochemical activities in cellular metabolism. It has been widely understood that calcium ion is an ion that plays a very important role in cell metabolism.

Since the late twentieth century, several researchers have hypothesized that calcium ions play a role in mediating the biological effects of exposure to ELF magnetic fields (Ma, Ding, Liu, & Wu, 2023). The ELF magnetic force directly interacts with the cell membrane, especially towards the ions on the inner wall of the channel protein, changing the direction of the dipole field for each ion, so that the arrangement of the ions which originally had random formations becomes unidirectional, this results in a decrease in the membrane potential. Facilitate Ca2+ entry intracellular.

Several research results have concluded that exposure to the ELF magnetic field has the potential to decrease the binding constant with calcium receptors (Ma *et al*., 2023). Effect of exposure to ELF magnetic fields on wheat plants through a signaling system that regulates intracellular Ca2+ concentration and H+-ATPase activity (Grinberg et al., 2022). This description explains the support that the role of Ca ions plays an important role in mediating the impact of exposure to ELF electromagnetic fields.

Ca2+ ions are classified as paramagnetic materials. The form of the influence of the magnetic field on paramagnetic materials is the spin of electrons contained in the material which initially randomly becomes polarized in the same direction as the magnetic field. This condition is thought to cause the opening of Ca2+ ion channels in the cell membrane. Due to the opening of Ca2+ ion channels, there will be an increase in intracellular calcium influx ([Ca2+]i). The next hypothesis is that intracellular [Ca2+]i levels that meet the needs of cell metabolism will trigger cell proliferation processes. However, if the [Ca2+]i level exceeds the threshold requirement in cellular processes, it will have an impact on decreasing cell function resulting in inhibition of cell proliferation to cell death or apoptosis.

Based on the results of the research we have done in Table 1, it can be assumed that exposure to low-intensity ELF magnetic fields (less than 1000 μT) has the potential to increase cell proliferation. On the contrary, it is suspected that exposure to high intensity ELF magnetic fields (more than 1000 μT) has the potential to increase cell apoptosis. This is relevant to the results of a study by Tirono (2022), which showed that exposure to an ELF magnetic field with an intensity of 100 μT for 15 minutes on soybean seeds can change enzyme content and increase growth hormone content. Meanwhile, Sudarti et al. (2023), according to exposure to a magnetic field of 300 μT on edamame seeds with an exposure time of 120 minutes was able to stimulate the growth of the first stage of edamame seeds, statistically showing an increase significantly on germination, and on early seed development and growth. It is suspected that longer exposure to magnetic fields results in greater changes in the physical and chemical properties of water, thereby triggering water hydration in seeds and activating hormones and enzymes for faster germination (Podleśny et al., 2021). Meanwhile exposure to the ELF magnetic field intensity of 1,00 mT intermittently 2 hour/day for 5 days can inhibit cell proliferation (Mehdizadeh et al., 2023). Exposure to ELF magnetic fields intensity of 2 mT was able to increase apoptosis of rat brain cells (Çakit et al., 2023).

While it was also reported that exposure to the ELF magnetic field intensity of 200 mT for 20 minutes on carrot seeds showed a higher germination percentage than control seeds (Dziergowska et al., 2021). Meanwhile, exposure to a static magnetic field of 340 mT intermittently 4 hours/day for 4 days was able to accelerate the wheat germination process compared to control (Ćirković et al., 2017). This study uses very high intensity magnetic fields (180 mT and 340 mT or 160,000 μT and 340,000 μT). The intensity of this magnetic field is very high for the treatment of plant seeds. We have not yet received references to other research results, so it is necessary to carry out an evaluation related to the intensity and duration of exposure, as well as the source of exposure to the electromagnetic field used in the study.

Exposure to ELF magnetic fields with intensities of 200 μT and 300 μT was treated on edamame soybean seeds which had been soaked in water previously. This intensity is expected to be able to increase intracellular calcium levels in accordance with the needs of cell metabolism and can increase growth hormone activity. Next, the process of growing the edamame plant is followed until it bears fruit. The results of the study proved that there was a significant increase in the productivity of edamame fruit in the group exposed to ELF magnetic fields with intensities of 200 μT and 300 μT compared to the control. The highest number of fruit production and number of pods were obtained in the sample group exposed to an intensity ELF magnetic field of 300 μT for 120 minutes.

Food Safety Risk to Health by Exposure to ELF Magnetic Fields

The characteristics of the Extremely Low Frequency (ELF) magnetic field are able to penetrate almost any material, but are non-ionizing radiation and non-thermal. But until now there are still suspicions of the possibility of toxic effects by exposure to ELF magnetic fields.

Several studies have been reported that prove that exposure to ELF magnetic fields does not cause toxic effects. The results of Sudarti's research, (2016), proved that exposure to the ELF magnetic field with an intensity of 646.7 μT had no effect on changes in texture, color and taste, and did not cause toxicity to Gado-gado vegetables. Perez et al. (2021), also confirmed that exposure to ELF electromagnetic fields acts as a non-toxic substance. Meanwhile, exposure to 50Hz ELF-EMF at an intensity of up to 1000 μT has been shown to have no neurotoxic effects (Bertagna et al., 2021). Exposure to a 50Hz ELF magnetic field at an intensity of 2000 μT does not cause genotoxide effects (DNA damage) (Su, Yimaer, Wei, Xu, & Chen, 2017).

Based on the results of these studies, it proves that exposure to high-intensity ELF magnetic fields (646.7 μT and 2000 μT) does not cause toxicity to the exposed material. While the intensity of exposure to the ELF magnetic field used in this study was only 200 μT and 300 μT, so it clearly did not cause a toxic effect on the edamame produced. In contrast to gamma rays which are ionizing radiation, which allows residual radiation in food ingredients after being irradiated. The results of this study are useful as a basis for developing agricultural technology based on Extremely Low Frequency (ELF) magnetic fields that are economically beneficial and safe for health.

Conclusion

Based on the results of the research and discussion that has been carried out, it can be concluded that exposure to an Extremely Low Frequency magnetic field at an intensity of 300 μT for 120 minutes has a significant effect on the productivity of edamame soybeans. However, it is still necessary to carry out further research using a more diverse intensity and duration of exposure so that a more effective and accurate intensity and duration of exposure will be obtained for plants that can be produced and consumed in the community.

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Author Contributions
Conceptualization, S, & W.M; methodology, S.; validation, S, E.P, & S.; formal analysis, S & S.; investigation, S, E.B.U & W.N.P; resources, S and E.B.U; data curation, S, W.M.: writing—original drafting, S and S.B; writing—review and editing, E.B.U & W.N.P: visualizations, E.P & E.B.U. All

authors have read and agree to the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

References

Bertagna, F., Lewis, R., Silva, S. R. P., McFadden, J., & Jeevaratnam, K. (2021). Effects of electromagnetic fields on neuronal ion channels: a systematic review. *Annals of the New York Academy of Sciences*, *1499*(1), 82–103. https://doi.org/10.1111/nyas.14597

Çakit, M. O., Koca, G., Akbulut, A., Erdem, O., Çetinkaya, S., Umurhan, G., … Korkmaz, M. (2023). The effects of extremely low-frequency magnetic field exposure on apoptosis, neurodegeneration and trace element levels in the rat brain. *Anatolian Current Medical Journal*, *5*(2), 102–110. https://doi.org/10.38053/acmj.1245104

Ćirković, S., Bačić, J., Paunović, N., Popović, T. B., Trbovich, A. M., Romčević, N., & Ristić-Djurović, J. L. (2017). Influence of 340 mT static magnetic field on germination potential and mid-infrared spectrum of wheat. *Bioelectromagnetics*, *38*(7), 533–540. https://doi.org/10.1002/bem.22057

Dziergowska, K., Lewandowska, S., Mech, R., Pol, M., Detyna, J., & Michalak, I. (2021). Soybean germination response to algae extract and a static magnetic field treatment. *Applied Sciences (Switzerland)*, *11*(18), 1–18. https://doi.org/10.3390/app11188597

Grinberg, M., Mudrilov, M., Kozlova, E., Sukhov, V., Sarafanov, F., Evtushenko, A., … Mareev, E. (2022). Effect of extremely low-frequency magnetic fields on light-induced electric reactions in wheat. *Plant Signaling and Behavior*, *17*(1). https://doi.org/10.1080/15592324.2021.2021664

Guo, J., Rahman, A., Mulvaney, M. J., Hossain, M. M., Basso, K., Fethiere, R., & Babar, M. A. (2020). Evaluation of edamame genotypes suitable for growing in florida. *Agronomy Journal*, *112*(2), 693–707. https://doi.org/10.1002/agj2.20136

Ma, T., Ding, Q., Liu, C., & Wu, H. (2023). Electromagnetic fields regulate calcium-mediated cell fate of stem cells: osteogenesis, chondrogenesis and apoptosis. *Stem Cell Research and Therapy*, *14*(1), 1–13. https://doi.org/10.1186/s13287-023-03303-w

Mehdizadeh, R., Madjid Ansari, A., Forouzesh, F., Shahriari, F., Shariatpanahi, S. P., Salaritabar, A., & Javidi, M. A. (2023). P53 status, and G2/M cell cycle arrest, are determining factors in cell-death induction mediated by ELF-EMF in glioblastoma. *Scientific Reports*, *13*(1), 1–11. https://doi.org/10.1038/s41598-023-38021-z

Nair, R. M., Boddepalli, V. N., Yan, M. R., Kumar, V., Gill, B., Pan, R. S., … Somta, P. (2023). Global Status of Vegetable Soybean. *Plants*, *12*(3). https://doi.org/10.3390/plants12030609

Nur, S. U. K., Sudarti, & Subiki. (2022). Pengaruh Paparan Medan Magnet Extremely Low Frequency (ELF) Terhadap Derajat Keasaman (pH) Buah Tomat. *ORBITA. Jurnal Hasil Kajian, Inovasi, Dan Aplikasi Pendidikan Fisika*, *8*(1), 45–51. Retrieved from https://journal.ummat.ac.id/index.php/orbita/article/view/8395

Perez, F. P., Maloney, B., Chopra, N., Morisaki, J. J., & Lahiri, D. K. (2021). Repeated electromagnetic field stimulation lowers amyloid-β peptide levels in primary human mixed brain tissue cultures. *Scientific Reports*, *11*(1), 1–13. https://doi.org/10.1038/s41598-020-77808-2

Podleśny, J., Podleśna, A., Gładyszewska, B., & Bojarszczuk, J. (2021). Effect of pre-sowing magnetic field treatment on enzymes and phytohormones in pea (Pisum sativum l.) seeds and seedlings. *Agronomy*, *11*(3), 1–12. https://doi.org/10.3390/agronomy11030494

Prihatin, N. W., Sudarti, & Prihandono, T. (2020). Pengaruh Medan Magnet Extremely Low Frequency Terhadap Biomassa Tanaman Edamame. *Jurnal Pendidikan Fisika Tadulako Online (JPFT)*, *8*(3), 51–57. Retrieved from http://jurnal.untad.ac.id/jurnal/index.php/EPFT/article/view/16933

Racuciu, M. (2020). Development of tomato (Solanum lycopersicum L.) seedlings under the action of extremely low frequency magnetic field in a controlled environment conditions. *AIP Conference Proceedings*, *2206*. https://doi.org/10.1063/5.0000268

Sarraf, M., Kataria, S., Taimourya, H., Santos, L. O., Menegatti, R. D., Jain, M., … Liu, S. (2020). Magnetic field (MF) applications in plants: An overview. *Plants*, *9*(9), 1–17. https://doi.org/10.3390/plants9091139

Su, L., Yimaer, A., Wei, X., Xu, Z., & Chen, G. (2017). The effects of 50 Hz magnetic field exposure on DNA damage and cellular functions in various neurogenic cells. *Journal of Radiation Research*, *58*(4), 488–500. https://doi.org/10.1093/jrr/rrx012

Sudarti. (2016). Utilization of Extremely Low Frequency (ELF) Magnetic Field is as Alternative Sterilization of Salmonella Typhimurium In Gado-Gado. *Agriculture and Agricultural Science Procedia*, *9*, 317–322. https://doi.org/10.1016/j.aaspro.2016.02.140

Sudarti, Prihandono, T., & Prihatin, W. N. (2023).

Proceedings of the 4th International Conference on Life Sciences and Biotechnology (ICOLIB 2021). *Proceedings of the 4th International Conference on Life Sciences and Biotechnology (ICOLIB 2021)*, 4–14. https://doi.org/10.2991/978-94-6463-062-6

Sudarti, S., Bektiarso, S., Prastowo, S. H. B., Prihandono, T., Maryani, & Handayani, R. D. (2020). Optimizing lactobacillus growth in the fermentation process of artificial civet coffee using extremely-low frequency (ELF) magnetic field. *Journal of Physics: Conference Series*, *1465*(1). https://doi.org/10.1088/1742-6596/1465/1/012010

Sudarti, Sudarti, Nur, S. U. K., Permatasari, E., Dewi, N. M., & Laili, S. N. (2022). Analysis of Physical Resistance of Apple Tomatoes After Exposed to A Magnetic Field Extremely Low Frequency (ELF) Intensity 600 μT and 1000 μT. *Jurnal Penelitian Pendidikan IPA*, *8*(6), 2872–2878. https://doi.org/10.29303/jppipa.v8i6.2306

Sudarti, Supriadi, B., Subiki, Harijanto, A., Nurhasanah, & Ridlo, Z. R. (2020). A potency of ELF magnetic field utilization to the process of milkfish preservation (chanos chanos). *Journal of Physics: Conference Series*, *1465*(1). https://doi.org/10.1088/1742-6596/1465/1/012005

Tirono, M. (2022). The Use of a Time-Changing Magnetic Field to Increase Soybean (Glycine max) Growth and Productivity. *International Journal of Design and Nature and Ecodynamics*, *17*(5), 737–743. https://doi.org/10.18280/ijdne.170511

Tirono, M., Hananto, F. S., Suhariningsih, & Aini, V. Q. (2021). An effective dose of magnetic field to increase sesame plant growth and its resistance to fusarium oxysporum wilt. *International Journal of Design and Nature and Ecodynamics*, *16*(3), 285–291. https://doi.org/10.18280/IJDNE.160306