JPPIPA 9(7) (2023)

Jurnal Penelitian Pendidikan IPA

*Journal of Research in Science Education*

http://jppipa.unram.ac.id/index.php/jppipa/index

# Effective Treatment Time Using a Magnetic Field to Increase Soybean (*Glycine max*) Productivity

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Received: May 6, 2023
Revised: June 20, 2023
Accepted: July 25, 2023
Published: July 31, 2023

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DOI: 10.29303/jppipa.v9i7.3797



**Abstract**: Increasing the productivity of soybean plants using environmentally friendly techniques is urgently needed. This study aimed to determine the magnetic field (MF) treatment time that can optimize soybean growth and productivity. This study used soybean seed samples of the Grobogan variety. The seeds were obtained from the Research Institute for Various Nuts and Roots-Indonesia. The treatment was performed using MF of 0.3 mT, with treatment times varying from 0 to 30 minutes. Each treatment group was repeated once a day for five days. This study obtained the results that the time of MF treatment affected the sprouts' emergence time, plant growth, fruiting time, seed weight, and production per plant. Optimal results were obtained from seeds treated with a MF for 20 minutes. Treatment with time-varying MF requires lower magnetic flux density (MFD) and treatment time than stationary MF. Treatment time that is too long can reduce germination, plant growth, and soybean productivity

**Keywords:** Chlorophyll; Emergence of sprouts; Magnetic field; Plant growth; Seed weight

## Introduction

Soybeans (*Glycine max*) can be processed in various forms, such as tofu, tempeh, soy flour, milk, or soybean oil. The content of processed soybeans, namely isoflavones and lecithin, provides great benefits for the health of the body, one of which is lowering cholesterol levels (Ramdath et al., 2017). Soybeans generally contain as much as 40% protein, essential amino acids, especially glycine, tryptophan, and lysine, 23% carbohydrates, 20% fat, several vitamins, minerals and fiber, antioxidants, omega-3, fatty acids, and others, such as lecithin, phytosterols, and phenolic acids (Sharma et al., 2014). Soybean also has anti-nutritional properties that can reduce the work of trypsin and amylase (Gu et al., 2010), and chymotrypsin (Palavalli et al., 2012). The problem is that in Indonesia, the soybean cultivation process is generally carried out conventionally. Hence, the production results are not optimal and insufficient for domestic needs. The Central Statistics Agency released that in 2020 Indonesia imported 2,475,286.8 tons of soybeans, and in 2021 it increased to 2,489,690.5 tons. One of the causes of the low production of soybeans in Indonesia is the unprofitable economic value, so farmers are reluctant to plant (Krisdiana et al., 2021).

Plant productivity is an issue that continues to grow and attracts researchers worldwide, especially with applying innovative techniques that are friendly to the environment. Plant development, both from the production side and its nutritional content, is very important. Various new techniques to enhance plant development and production have emerged, some of which are synthetic crops, soil microbial biofortification, manure application, and nanotechnology. Seed treatment using MF has been known as an approach to increase plant growth and productivity that is environmentally friendly.

Recently, MFs have been widely used to induce plant growth, which has little side effect on the environment (Aladjadjiyan, 2010). Living organisms, including plants, have charged particles inside and outside their cell membranes, thereby generating transmembrane potentials. The charge on the cell membrane is constantly flowing in its activity. MFs can

**How to Cite:**
Tirono, M., & Hananto, F. S. (2023). Effective Treatment Time Using a Magnetic Field to Increase Soybean (Glycine max) Productivity. *Jurnal Penelitian Pendidikan IPA*, *9*(7), 5071–5077. https://doi.org/10.29303/jppipa.v9i7.3797

exert a force on electric charges moving across cell membranes, thereby affecting plant growth and metabolism (Teixeira da Silva et al., 2016). The interaction of magnetic particles with MF can convert field energy into heat due to magnetic hysteresis or the Brownian relaxation mechanism (Deatsch et al., 2014). The resulting eddy currents are capable of creating mechanical forces or torques so that they can directly induce cellular effects (Carrey et al., 2013) and the formation of free radicals such as reactive oxygen species (ROS) (Domenech et al., 2013). Plants interpret these effects as changes in morphogenesis and biochemical reactions within cells. Therefore MF treatment can affect living things, including plant seeds, by influencing free radical activity and changing ionic transport across cell membranes. MF treatment also affects the electrical properties, permeability, and metabolic pathways in plant cells (Sahebjamei et al., 2007).

Various types of MFs have been used to test their effects on plants, including extra-low frequency MFs, static MFs, and where electromagnetic pulses used with varying duration and frequency of exposure (Shine et al., 2017). MFs changing with time have also been tested and shown to have profound effects on plant growth (Tirono, 2022). The force of the MF interaction with the seed of magnitude is affected by the changing MF gradient (Tao et al., 2019). MFD and treatment time significantly affect the lemon seed germination process compared to no treatment (Ulgen et al., 2017). However, prolonged interaction will cause an increase in temperature, water pH, and excess free radicals, which will have a severe impact on living cells. Therefore, this study aimed to determine the time of treatment using a MF that changes with time which can produce optimal soybean growth and productivity.

## Methods

*Generation of Magnetic Field*

The MF used in this study is generated from a Helmotz coil connected to a time-varying current source. The coil is made of copper wire with a diameter of 1.0 mm, a total of 1000 turns, and a coil radius of 20 cm. The current varies with time resulting from a rectifier circuit without a current rectifier capacitor. The number of current changes every second is 100 times.

*Sample*

Soybean seeds with the Grobogan variety were used as samples in this study. Soybean seeds were obtained from the Research Institute for Various Legumes and Roots-Indonesia. Before being treated, the seeds used as samples were selected to obtain almost the same size, from 0.2 to 0.3 grams. Next, the seeds were randomly separated into six groups. Each group has ten seeds.

*Giving Treatment*

Seed grouping is based on treatment time; namely, there are six. The seeds of each treatment group were laid out in kapok and then soaked for 15 minutes in water. Seeds moistened were treated with an MF with MFD of 0.3 mT with various treatment times, namely 0.0, 10, 15, 20, 25, and 30 minutes. The same treatment was repeated five times for five days. The seeds in cottonwood are watered twice a day to keep them moist. The temperature around the treatment area is around 27$^o$C, while the humidity is 56-98%.

*Planting*

Six days after being given the MF treatment, the grown soybean seeds were transferred to polybags for planting. Polybags for planting soybeans are 20 cm high and 30 cm in diameter. Before planting, polybags are filled with a mixture of pure soil and organic fertilizer and watered. The height of the soil in the polybag was 19 cm, with a pH of 7.0. When planting, the distance between one polybag and another is set at 10 cm. The temperature of the planting site is 24-32$^o$C, while the air humidity is 60-90%. Plants in polybags are watered every morning with a volume of 25 mL of water when they are one day to 14 days old and 250 mL after that when the plants are more than 14 days old. The age calculation starts from the plants being moved to polybags. When the plants were 10, 20, 30, and 40 days old, they were given NPK fertilizer with successive doses of 3, 5, 6, and 6 grams.

*Content Chlorophyll Measurement*

Measurement of chlorophyll content was carried out at the age of 30 days. The position of the leaves used as samples for measuring chlorophyll content is the third order from the bottom. Before calculating the chlorophyll content, the absorbance was measured using a UV-VIS spectrometer at 645 and 663 nm (Shibghatallah et al., 2013). Mathematically in mg/L, the chlorophyll content is calculated using the equation (1) (Shibghatallah et al. 2013).

$$C = 12.7\ A663 - 2.69\ A645 \quad \text{for chlorophyll-a}$$
$$C = 22.9\ A645 - 4.68\ A663 \quad \text{for chlorophyll-b} \qquad (1)$$

where A is the absorbance and C is the chlorophyll content.

*Statistic Analysis*

Statistical analysis of variance was used to examine the effect of the length of MF treatment on sprouting time, stem growth, leaf chlorophyll content, time of flower emergence, seed weight, and crop production. Meanwhile, the Duncan Multiple Range Test was used to test the significance of the differences in each treatment.

## Result and Discussion

*Sprouts Emergence Time*

Treatment using MF 0.3 mT with a treatment time of 10-30 minutes proved to have an effect on the sprouts' emergence time. Table 1. The sprout's emergence time of soybean was treated with 0-30 minutes using 0.3 mT MF and repeated every day for up to five days. Numerically, the emergence time of sprouts was different for each treatment time. Giving MF treatment for 10-30 minutes accelerates the emergence of sprouts. However, a significant change ($p \leq 0.05$) occurred at a time of treatment of 20 minutes, from 3.04±0.55 days to 1.60±0.55 days.

**Table 1.** Sprouts Emergence Time of Soybean after Being Treated with a MF of 0.3 mT for 0-30 Minutes

| Treatment time (minutes) | Time of sprouts emergence (days) | |
|---|---|---|
| 0.0 | 3.40±0.55 | b |
| 10 | 3.20±0.45 | b |
| 15 | 2.60±0.89 | b |
| 20 | 1.60±0.55 | a |
| 25 | 3.00±0.84 | b |
| 30 | 3.00± - | b |

*Plant Growth*

Treatment using a MF can affect the movement of charged particles through the cell membrane so that water and nutrients are absorbed by cells more optimally (Nyakane et al., 2019). The increased amount of water and nutrients absorbed makes plants grow faster. Figure 1 shows the growth of soybean plants from seven days to 49 days after being treated for 0-30 minutes using 0.3 mT MF. Optimal plant growth occurs in seeds with a treatment time of 20 minutes, namely 96.9±1.19 cm, while those not given treatment were 79.26±1.36 cm or an increase of 22.26%. MF treatment for 10-25 minutes is significant ($p \leq 0.05$) increased plant growth, while the 30-minute treatment was not significant. Insignificance occurs because treatment over a long time will increase water temperature and pH and increase reactive oxygen species.

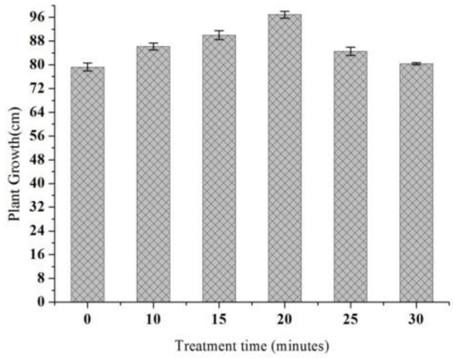


**Figure 1**. Growth of soybean plants from seven days to 49 days after being treated with MF for 0-30 minutes

*Chlorophyll Content*

One way to assess the health of a plant is from its chlorophyll content. The chlorophyll content indicates plant health (Dhawi et al., 2009). Measurement of chlorophyll content was carried out at the age of 30 days. The leaf's position where the chlorophyll content is measured is leaf number 3 from the bottom. The measurement results show that the MF treatment time affects the content of chlorophyll-a and chlorophyll-b. A graph of the chlorophyll content due to changes in the MF treatment time is shown in Figure 2. The treatment time of 10-30 minutes resulted in a higher chlorophyll-a content compared to that which was not treated. The chlorophyll-a content of the plants without treatment was 7.99±2.87 mg/L, while plants treated for 10, 15, 20, 25, and respectively were 9.48±0.22 mg/L, 11.57±1.00 mg/L, 12.63±1.65 mg/L, 10.98±2.56 mg/L, and 9.42±0.45 mg/L. Plants that were treated for 20 minutes proved to have the highest chlorophyll-a content. The test results using statistics show that the MF treatment for 10-30 minutes is significant ($p \leq 0.05$) in increasing the chlorophyll-a content.

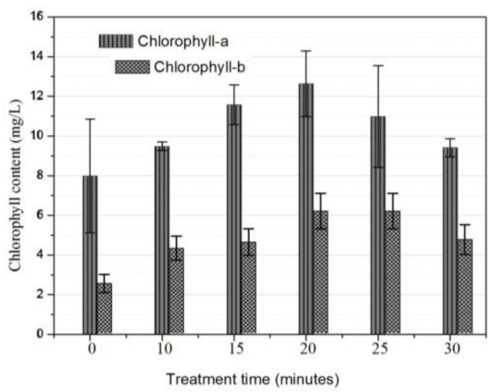


**Figure 2.** The content of chlorophyll-a and chlorophyll-b in soybean leaves due to MF treatment for 0-30 minutes

Treatment with a MF of 0.3 mT for 10-30 mT made the chlorophyll-b content higher than without treatment.

Figure 2 is a graph of the chlorophyll-b content of soybean plants treated for 0-30 minutes each day. The leaf chlorophyll content of untreated plants was 2.51±1.02 mg/L while the treatment for 10 minutes, the chlorophyll-b content became 4.29 ± 1.35 mg/L. Treatment for 20 minutes and 25 minutes resulted in an optimum chlorophyll-b content of 6.17±2.01 mg/L. The statistical analysis resulted that treatment for 20 and 25 minutes significantly ($p \leq 0.05$) increased the chlorophyll-b content of soybean leaves.

*Early Flowering Time*

The MF treatment during the seed-growing process affected the initial appearance of flowers. Treatment with 0.3 mT MFD for 10-30 minutes accelerated the emergence of cauliflower, as shown in Figure 3. The effect of treatment time was significant ($p \leq 0.05$) 10-25 minutes, while the 30-minute treatment was insignificant. The time of emergence of plant flowers without being treated with MF was 27.4 ± 0.89 days, while those given the treatment for 20 minutes were 20.4±0.55 days. MF treatment for 10, 15, 25, and 30 minutes the initial flowering time was 23.2±0.84 days, 21.8±0.45 days, 22.8±0.84 days, and 26±0.71 days respectively.

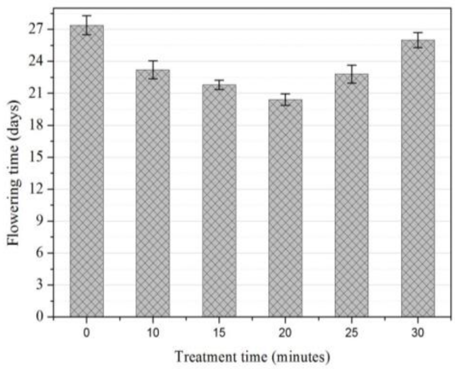


**Figure 3.** Initial flowering time of soybean plants due to MF treatment for 0-30 minutes

*Early Time of Fruiting*

Not all flowers can process into fruit, so there is no linear relationship between the initial appearance of flowers and fruit. However, in general, the earlier the flower appears, the earlier the fruit appears. Figure 4 shows the initial graph of the appearance of soybean fruit which was treated with a 0.3 mT MF for 10-30 minutes. MF treatment makes plants bear fruit earlier when compared to no treatment. Without the MF treatment, the appearance of the fruit occurred when the plants were 81.6 ± 0.89 days old, whereas, with the 10-minute treatment, the fruiting time became 79.2±0.84 days. The optimum early fruiting time occurred in plants treated for 20 minutes, namely 74.4±0.55 days. Statistical analysis showed that the 0.3 mT MF treatment for 10-30 was significant ($p \leq 0.05$) in speeding up the initial fruiting time.

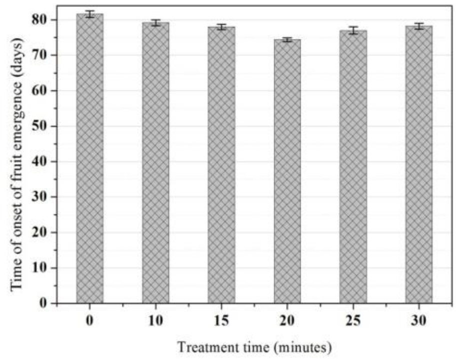


**Figure 4.** The initial time of fruiting of soybean plants due to MF treatment for 0-30 minutes

*Fruit Weight*

The weight per 10 soybean seeds was weighed without drying. The measurement results showed an effect of 0.3 mT MF treatment for 10-30 minutes on the weight per 10 seeds. Figure 5 shows that MF treatment for 10-30 increases the weight per 10 soybean seeds. The weight of plant seeds without treatment was 2.18 ± 0.01 grams, while those treated for 10 minutes were 2.29±0.029 grams or an increase of 5.05%. Optimum seed weight occurred in seeds treated for 20 minutes, namely 2.42±0.05 or an increase of 11% compared to no treatment. Statistical analysis showed that the treatment for 10-25% was significant ($p \leq 0.05$) and increased the weight per 10 soybean seeds, while the treatment for 30 minutes was not significant.

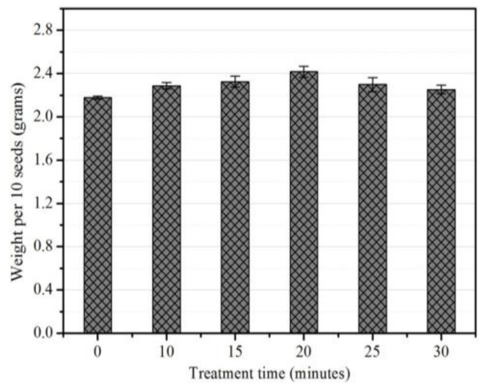


**Figure 5.** Weight per 10 soybean plants due to MF treatment for 0-30 minutes

*Production Per Plant*

The weight is in the form of seeds without skin and without drying process. The weighing results showed that the weight of the seeds produced per plant was affected by the length of treatment using MF. Figure 6 reveals that the treatment using MF for 20 minutes yielded higher yields than the other treatments, namely

14.17±0.80 grams. Meanwhile, the production per plant without treatment was 10.46±0.87 grams. Tests using statistics revealed that treatment using MF of 0.3 mT for 15, 20, and 20 minutes significantly ($p \leq 0.05$) affected the productivity of soybean plants, while treatments for 10 and 30 minutes had no significant effect.

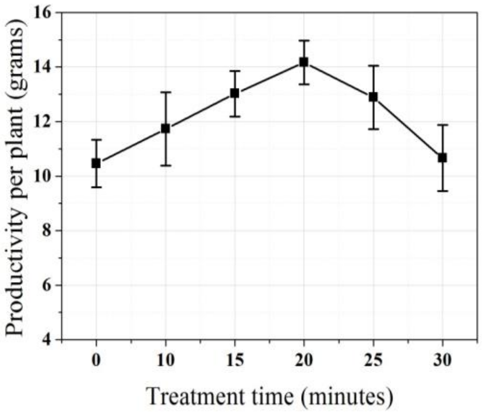


**Figure 6.** Effect of magnetic field treatment time for 0-30 minutes on crop productivity

*Discussion*

The treatment time using MF positively affected the sprout emergence, stem height, chlorophyll content, flower emergence time, soybean seed weight, and production per plant. The optimum effect of the MF treatment was obtained on seeds treated for 20 minutes. The treatment time above 20 minutes has a lower effect and tends to get lower.

The MF treatment on the seeds during the growth process causes the water atoms to be polarized, changing their physicochemical properties, surface tension, and viscosity (Cai et al., 2009). Water is a medium in which most of the biochemical reactions can occur, it is thought that slight changes in the physicochemical properties of intracellular and extracellular water can dramatically alter the cellular metabolic activity of organisms (Ayrapetyan et al., 2013). Therefore MF treatment can increase metabolism and mitosis in plant cells and meristematic (Belyavskaya, 2004). MF treatment makes the time of sprouts emergence faster than without being treated with an MF. Previous research stated that treatment using static MF between 1.2 mT to 3.75 mT in water caused a significant increase in temperature after 30 minutes (Ayrapetyan et al., 2013). It has also been stated that treatment using MF 2000 G for more than 24 hours increased the water's pH from 6.4 to 8.6 (Karkush et al., 2019). Excessive increase in temperature and pH resulted in lower germination in the 30-minute treatment compared to 20 and 25 minutes. Identical conditions have been reported that the initial emergence of tomato seed sprouts by treatment for 20 minutes is faster using a 0.3 mT MF compared to 0.5 mT (Tirono, 2022). Different conditions showed that treatment using a stationary MF of 126 mT with a treatment time of 1.0 hours proved to increase germination and the percentage of seeds germinating (Flórez et al., 2012).

Previously it has been reported that treatment with MF can change the content of enzymes and increase the content of the hormone (Podleśny et al., 2021). Increased metabolism and hormone content due to treatment for 10-30 minutes make plant stems grow faster, leaves have a higher chlorophyll content, flower faster, and increase production. Identical results reported that treatment of tomato seeds using MF 0.1 T for 15 minutes increased stem height and diameter, leaf area, and fruit weight in fresh and dry conditions (Hussein et al., 2012). Treatment for 72 hours with stationary MF 150 mT obtained the optimum plant height, total chlorophyll content, and number and weight of tubers per plant (Bahadir et al., 2020). Potatoes had the highest stems, number of leaves, number of fruits, and tuber K and P content when seeding was treated with MF 30 mT for 10 minutes (El-Gizawy et al., 2016). The MF treatment on the sprouts will affect the ions calcium ($Ca^{2+}$) in cell membrane protein channels (Koch et al., 2003) that drive entrycalcium ions ($Ca^{2+}$) without proliferative effect (Miyakoshi, 2005), thereby increasing the permeability of the cell membrane (Zhang et al., 2017). $Ca^{2+}$ permeable channels of the cell membrane interact with $Ca^{2+}$-activated NADPH oxidase to form ROS-$Ca^{2+}$ hubs, which can confer transduction and amplification of initial $Ca^{2+}$ or ROS stimuli into more sustained responses (Demidchik et al., 2018). Because it has implications for cell growth, hormonal signaling, and stress response, it can be stated that $Ca^{2+}$ ions have a role in regulating plant growth and development (Hepler 2005). Calcium is an important structural, metabolic, and signaling element (Demidchik et al. 2018). Calcium ions ($Ca^{2+}$) that enter through the cell membrane in excess will cause damage to the cell membrane. It has previously been reported that the interaction between MFs and cells can cause the stiffness of the cell membrane to increase (Lin et al., 2013).Therefore Long, treatment tends to negatively affect soybeans' growth and productivity, such as treatment for 30 minutes. The same results showed that treatment of 10 minutes and 15 minutes using MF 40 mT on potatoes decreased the number of sprouts, plant height, number of leaves, tubers per plant, sweet potato fresh weight per plant, and tuber diameter (El-Gizawy et al., 2016).

## Conclusion

MF treatment with MFD changing with time affects germination, growth, and productivity of soybean plants. To obtain optimum results, using a MF with a changing MFD requires less time than a stationary MF. The MF treatment was repeated five times in five days; the optimum results were obtained with a treatment time of 20 minutes. Treatment using a MF is an environmentally friendly solution to increase the growth and productivity of soybeans.

**Acknowledgments**
This research received funding support from the Ministry of Religion of the Republic of Indonesia through the State Islamic University of Maulana Malik Ibrahim Malang. Thanks to the Ministry of Religion of the Republic of Indonesia and State Islamic University of Maulana Malik Ibrahim Malang.

**Author Contributions**
Mokhamad Tirono: methodology, research data collection, analyzing data, writing articles. Farid Samsu Hananto: methodology, research data collection, check writing and language.

**Funding**
Funding assistance for this research came from the Ministry of Religion of the Republic of Indonesia through the State Islamic University of Maulana Malik Ibrahim Malang.

**Conflicts of Interest**
Authors declare no conflicts of interest.

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