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The Use of a Time-Changing Magnetic Field to Increase Soybean (*Glycine max*) Growth and Productivity

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ABSTRACT

This study aimed to accelerate the growth and increase the productivity of soybean plants by providing treatment using a magnetic field at the time of seed germination. The research sample was soybean seeds of the Grobogan variety obtained from Center for Research on Various Tubers and Nuts. The magnetic field used in the treatment is in the direction of the magnetic flux density, which changes with time, and the change frequency is 100 times per second. The treatments were given with magnetic flux density from 0.0 mT to 0.5 mT for 20 minutes per day and repeated for five days. Treatment with a 0.1 mT magnetic field resulted in optimum values of germination emergence time, stem growth, chlorophyll content, early flowering time, weight per 10 seeds, and productivity. Treatment with a 0.5 mT magnetic flux density had a negative or no effect on the growth and productivity of soybean plants. Treatment using a magnetic field of 0.1-0.4 mT positively affected soybean growth and productivity, while 0.5 mT did not affect or negatively affect. The treatment of the magnetic field can have positive and negative effects depending on the magnetic flux density used.

1. INTRODUCTION

Globally, soybean (*Glycine max*) is considered a major source of vegetable oil with a high protein content, making it an economically important crop [1]. The existence of soybeans is essential because it has a high nutritional content and commercial importance [2]. In general, soybeans contain about 40% protein, 23% carbohydrates, 20% fat, minerals, vitamins, and other beneficial compounds [3]. Apart from being a raw material for high protein content oil, soybean is a suitable material to use as a substitute for milk, meat, and fish at a lower price [4]. Soybeans are also known to have several anti-nutrients that can inhibit the action of trypsin, chymotrypsin, and amylase [5].

The high protein content in soybeans makes soybeans consumed a lot, so the need continues to increase. The demand for soybeans in Indonesia in 2021 is 3 - 3.5 million tons, while the total production is 950 thousand tons, so 70 percent of the demand is still imported [6]. Some major importing countries in 2017 were China, Mexico, and the Netherlands [7]. Part of the reason for the lack of soybean stocks in some countries is that soybean growth is affected by weather and requires large land areas for cultivation. In 2017, global soybean cultivation required 131 million hectares of land [7]. Meanwhile, one of the causes of the shortage of soybean products in Indonesia is the reluctance of farmers to plant because the production is low, making it economically unprofitable [8]. So that soybean cultivation has a higher economic value, efforts are needed to increase productivity without increasing the land area and maintenance costs.

It is known that treatment using a magnetic field of 10-1000 mT will reduce the surface tension and increase water viscosity [9, 10]. The 200 mT magnetic field treatment makes the water easy to be absorbed by the seeds [11, 12]. Magnetic field treatment also affects enzyme changes and increases hormones in seeds and sprout organs [13], thereby increasing plant growth and yield [14]. The magnetic field treatment causes oxidative stress in the seeds because the free radical ion produced is longer [15]. Oxidative stress will increase mutations [16] in plant cells. Therefore, treatment using a magnetic field at the beginning of seed growth can potentially increase plant growth and productivity.

Research using a stationary magnetic field is generally carried out using a magnetic field above 100 mT. To increase the growth of lentils using a stationary magnetic field of 150 mT [17], while to increase the growth of rice roots using a stationary magnetic field of 125 mT and 250 mT [18]. This study uses a magnetic field whose magnetic flux density changes with time, so the side effects are negligible. Theoretically, the magnitude of the magnetic field's interaction force generated depends on the material's susceptibility and volume, the field gradient, and the applied magnetic field [19]. This study aims to obtain optimum soybean growth and productivity by treating the seeds using a magnetic field.

2. MATERIALS AND METHODS

2.1 Magnetic field generation

The magnetic field used for exposure is generated by using two coils. The coil consists of 1000 turns with a radius of 200 mm made of copper wire of diameter 1.0 mm. The two coils are placed parallel at a distance of 0.2 m. The coil is connected to a direct current source with a strong current changing 100 times per second. The schematic of the experimental equipment circuit is shown in Figure 1. The resulting magnetic field satisfies the equation [20]:

$$\boldsymbol{B} = \frac{\mu_o NI}{R}\left[1 + \left(\frac{\alpha}{2R}\right)^2\right]^{-3/2} \quad (1)$$

where, N is the number of turns, I is coil current, α is the distance between the coils, μ_o is the permeability of free space and R is the coil radius.

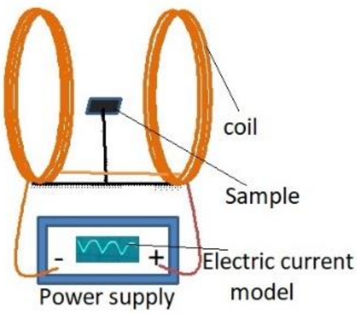

Figure 1. Schematic of a series of seed treatment equipment using a magnetic field

2.2 Sample

The soybean seed used in the research sample was the Grobogan variety obtained from Center for Research on Various Nuts and Tubers - Indonesia. Seeds are selected with almost the same mass, which is between 0.2 – 0.3 grams. The samples were grouped into six groups, each consisting of 12 seeds.

2.3 Treatment with magnetic field

Initially, the seeds are placed on the fiber of the kapok fruit and soaked in water for 15 minutes. Furthermore, the seeds were treated with a magnetic field with a magnetic flux density from 0.0 mT to 0.5 mT. The treatment was given for 20 minutes per day in each group and repeated for five days. The seeds on the cotton are watered two times a day so that the moisture is maintained.

2.4 Planting

On the 6th day, after wetting, the plants were transferred to polybags. The polybag used has a hole diameter of 30 cm and a hole height or depth of 20 cm. Polybags are first filled with pure soil with a pH of 7.0 as high as 19 cm mixed with organic fertilizer, and the soil is watered. The distance between one polybag to another is 15 cm. Plants in Polybags were watered once a day with a volume of 25 mL at the age of 1-14 days and 250 mL after the age of 14 days. Watering is done every morning. Plants were given NPK fertilizer at the age of 10 days, 20 days, 30 days, and 40 days, calculated from the time of transfer to polybags with a successive dose of 3 grams, 5 grams, 6 grams, and 6 grams. Plants are given support in the form of logs when the stem reaches 15 cm so that it does not collapse. The humidity and temperature of the planting environment are 70-80% and 24-31℃, respectively.

2.5 Measurement of leaf chlorophyll content

Leaf chlorophyll content was measured when the plant was 30 days old. The leaves whose chlorophyll content was measured were those in the third position from the bottom. Absorbance measurement (D) was performed using a UV-VIS spectrometer at 645 nm and 663 nm light wavelengths [21]. The chlorophyll content in mg/L is calculated using the equation [21]:

$$\begin{aligned} \text{Chlorophyll}_a &: 12.7\,\text{D}(663) - 2.69\,\text{D}(645) \\ \text{Chlorophyll}_b &: 22.9\,\text{D}(645) - 4.68\,\text{D}(663) \end{aligned} \quad (2)$$

where, D is absorbance.

2.6 Statistical analysis

Data on the emergence of germination, stem growth, chlorophyll content, time of flower emergence, and productivity were analyzed using ANOVA (Analysis of Variance) statistics to see the difference in mean between treatment groups. The significance of the differences from each treatment was then tested using DMRT (Duncan Multiple Range Test).

3. RESULTS AND DISCUSSION

3.1 Sprouts emergence time

The pH and viscosity of the water changed due to the magnetic field treatment, so the seed soaking process was optimal. Optimal immersion affects the emergence of sprouts. Therefore, the time of emergence of the resulting sprouts varies. Table 1 shows the emergence time of soybean seed germination, which was treated using a magnetic field. Germination time was faster in seeds treated with a 0.1 mT magnetic field compared to those not treated (0.0 mT). The time of emergence of seed germination without treatment was 2.40±0.24 days, while the treatment with 0.1 mT magnetic flux density was 1.00±0.00 days. However, the emergence of sprouts will slow down in the 0.2- 0.5 mT treatment compared to the 0.1 mT treatment. The standard deviation of 0.00 in the treatment with a magnetic flux density of 0.1 mT indicated that all seeds germinated a day after being treated. The statistical test showed that the treatment with 0.1 - 0.3 mT significantly accelerated the emergence of sprouts ($p \leq 0.05$), while the treatment with 0.4 - 0.5 mT was not significant. The insignificance occurred presumably due to the relatively high increase in water pH.

Table 1. Time of emergence of sprouts and stem height of soybean plants treated using a magnetic field

Magnetic field (mT)	Time of emergence of sprouts (days)				Plant height at the age of 49 days (cm)			
0.0	2.40	±	0.24	b	72.75	±	5.55	d
0.1	1.00	±	0.00	a	131.51	±	5.73	a
0.2	1.20	±	0.20	a	123.17	±	2.88	b
0.3	1.40	±	0.24	a	114.80	±	7.05	c
0.4	1.80	±	0.37	ab	114.25	±	5.67	c
0.5	2.00	±	0.45	b	67.58	±	2.13	d

3.2 Plant stem height

Treatment with a low magnetic field on the seeds made the epicotyl elongated [22] and increased the activity of enzymes [13] and phytohormones [23], thereby affecting plant growth. Table 1 shows the effect of treatment using a magnetic field on soybean plant stem height. Stem height was measured when the plant was 49 days old. The stem height is calculated from the polybag's soil surface to the stem's top. Plants without magnetic field treatment had a stem height of 72.75±5.55 cm, while plants treated with 0.1 mT magnetic field had a stem height of 131.51±5.73 cm. The 0.1 mT magnetic field treatment made the rod height more optimum than other treatments, namely 0.2 - 0.5 mT. The tendency of negative effects occurred in the 0.5 mT magnetic field treatment, which made the plant stems lower than without magnetic field treatment. Statistical tests showed that the treatment with a 0.1-0.4 mT magnetic flux density significantly increased the stem height of soybean plants (p≤0.05).

3.3 Plant stem growth

Magnetic field treatment changes the structure of plant cell membranes so that more water and nutrients are absorbed by plants [24]. Absorption of more nutrients can encourage faster cell division so that plant stems grow faster, thus making differences in stem height in each treatment. Figure 2 shows a graph of soybean stem growth at 7 - 49 days after being treated with a magnetic field. Optimal plant stem growth occurred in plants treated with a magnetic field with a magnetic flux density of 0.1 mT, 106.85±3.85 cm, while plant stem growth without treatment was 61.65±5.88 cm. Treatment of 0.2 - 0.5 mT increased plant stem growth, although slower than the treatment with 0.1 mT. Statistical tests found that the 0.1-0.4 mT treatment significantly increased soybean stem growth (p≤0.05).

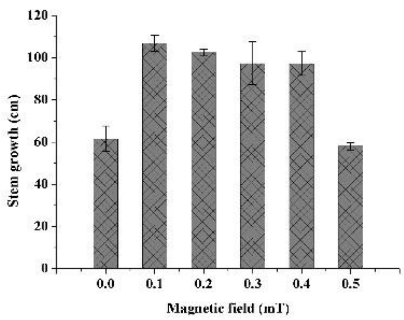

Figure 2. Growth of plant stems aged 7 - 49 days after planting into polybags

3.4 Plant stem growth pattern

Treatment using a magnetic field affects plants enzymes and hormonal systems [25], thus affecting the growth of plant stems. Figure 3 shows the pattern of plant stem growth at the age of 7-49 days. The graph shows that the seeds treated with a 0.1 mT magnetic flux density optimum stem growth occurred at 7-35 days and then slowed down. Treatment of 0.2-0.4 mT made optimum stem growth occur at 14-35 days; then, growth slows down. For seeds treated with 0.5 mT, optimum growth occurred at 7-21 days, then slower than the untreated plants.Therefore, the treatment of 0.1 – 0.4 mT has the potential to increase soybean stem growth, while 0.5 mT tends to slow it down. The growth pattern of soybean stems treated with a 0.1 mT magnetic field can be approximated by a polynomial function with the equation:

$$y = -0.65 + 3.5\,x + 2.057x^2 \tag{3}$$

where, *y* is the height of the stem and *x* is the age of the plant. Treatment using a 0.2-0.4 mT magnetic field can be approximated by a polynomial function:

$$y = a - 1.65x + 0.23x^2 \tag{4}$$

where, a is a constant whose value depends on the magnetic flux density used. For a magnetic field of 0.2- 0.4 mT, the value is between 21.41 - 19.37. The growth pattern of plant stems that were not treated with a magnetic field and treated with 0.5 mT can be approximated by the linear equation:

$$y = 4.42 + 1.37x \tag{5}$$

The approach has an R-Square value greater than 0.98.

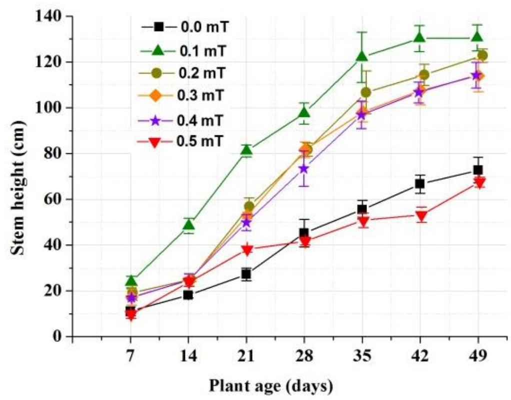

Figure 3. The growth pattern of soybean stems from 7 days to 49 days after planting into polybags

3.5 Chlorophyll content

The leaf chlorophyll content is one of the variables related to plant health and productivity [26]. Therefore, information about leaf chlorophyll content is very important to know the positive and negative effects of treatment using a magnetic field. The absorbance of the solution containing leaf chlorophyll was measured using a UV-Vis Spectrometer. The position of the leaves whose chlorophyll content was measured was third from the bottom and when the plants were 30 days old. Figure 4 shows the chlorophyll content of soybean leaves treated with a magnetic field. Treatment with a 0.1-0.4 mT magnetic flux density made the chlorophyll-a content of the leaves higher than without treatment. The chlorophyll-a content of leaves without treatment was 8.70±2.38 mg/L, while with treatment was 12.74±1.75 mg/L, 11.31±1.87 mg/L, 10.44±1,45 mg/L, and 8.92±2.58 mg/L. successively for the treatment of 0.1 mT, 0.2 mT, 0.3 mT, and 0.4 mT. The chlorophyll-a content of the leaves decreased or became 8.14±1.72 mg/L when treated with 0.5 mT. Chlorophyll-a became optimum for seeds treated with 0.1 mT.

The chlorophyll-b content of soybean leaves with 0.1-0.4 mT treatment was higher than without treatment. Where the content of chlorophyll-b in the leaves without treatment was

3.42±1.45 mg/L, while the treatment was 0.1; 0.2; 0.3; and 0.4 mT were 6.325±0.93 mg/L, 4.09±0.61 mg/L, 3.75±0.59 mg/L, and 3.58±2.79 mg/L, respectively. The chlorophyll-b content of the leaves became optimum with 0.1 mT treatment. Statistical test results showed that the 0.1 mT treatment significantly increased the chlorophyll content of soybean leaves, chlorophyll-a, and chlorophyll-b.

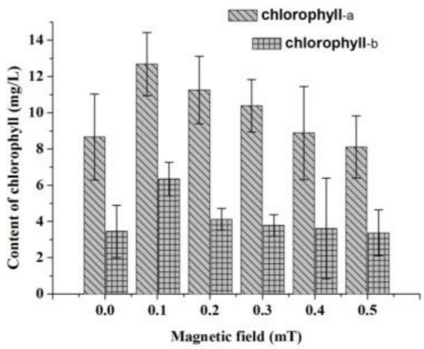

Figure 4. Chlorophyll-a and chlorophyll-b of the content of soybean leave treated with a magnetic field

3.6 Flowering time

The time of appearance of flowers is taken when the first flower appears. Because the seeds were treated with a magnetic field, the early flowering time of soybean plants was different for each treatment. Figure 5 shows a graph of the initial time of flower emergence from soybean plants with 0.0-0.5 mT treatment. Treatment with a magnetic flux density of 0.1 mT to 0.5 mT made plants flower faster than without treatment. The initial flowering time of the plants without treatment was 33.5±3.89 days, while those treated with 0.1 mT were 30.50±0.84 days. From the results of statistical tests, the 0.1 mT treatment significantly ($p \leq 0.05$) accelerated the early flowering time, while the 0.2-0.5 mT treatment was not significant.

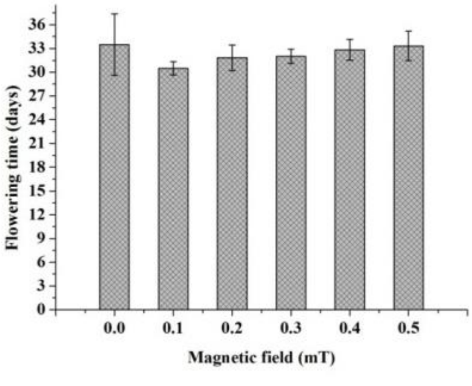

Figure 5. Time of the earliest flower appearance of soybean plants

3.7 Fresh soybean weight

Weighing is done per 10 soybeans in fresh or not dry condition. Soybeans produce fruit that generally contains three seeds per fruit. Treatment with a magnetic field during seed growth affects the weight of fresh seeds. Figure 6 shows the effect of magnetic field treatment on the weight per 10 fresh soybeans. The optimum seed weight obtained from plants treated with 0.1 mT was 2.43 grams, while plants without treatment were 2.15 grams. Treatment of 0.1-0.4 mT significantly increased the weight of soybean seeds. Seed weight became optimum with 0.1 mT treatment, while the treatment with 0.5 mT; the effect is not significant, which weights 2.17 grams. The insignificance occurred because the treatment with a 0.5 mT magnetic field caused the cell membrane stiffness to almost exceed the threshold.

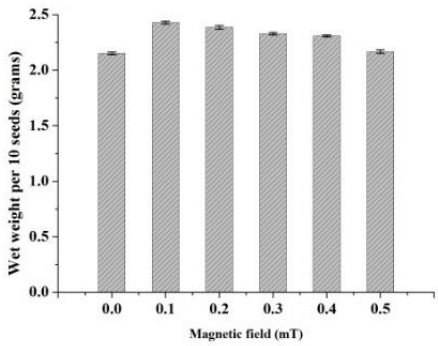

Figure 6. Weight of 10 seeds of fresh soybeans

3.8 Production per plant

Seed weighing is carried out on seeds produced by one soybean tree. Weighing is done when the seeds are still fresh or not yet dried. Treatment using a magnetic field affects seed weight and fruit number, thus affecting soybean productivity. Figure 7 shows a graph of the effect of treatment using a magnetic field on productivity per soybean plant. Treatment with magnetic flux density from 0.1 mT to 0.4 mT increased productivity, while 0.5 mT treatment decreased productivity. Productivity per soybean without treatment was 10.68±2.58 grams, while with 0.1 mT treatment, it was 15.62±3.68 grams or 1.46 times heavier than without treatment. Statistical tests concluded that the treatment with 0.1 mT significantly increased soybean productivity ($p \leq 0.05$), while the treatment with 0.2 - 0.4 mT was insignificant. Seed weight per tree with treatment 0.2; 0.3; 0.4; and 0.5 mT were 13.76±1.55 grams, 13.36±1.77 grams, 10.77±2.48 grams, 7.76±1.33 grams. The increase in the size and number of fruit occurs because the magnetic field treatment can change enzymes and hormone content in plants [13]. The most hormone increase occurred in the 0.1 mT magnetic field treatment, while the decrease in the amount of hormone occurred in the 0.5 mT treatment.

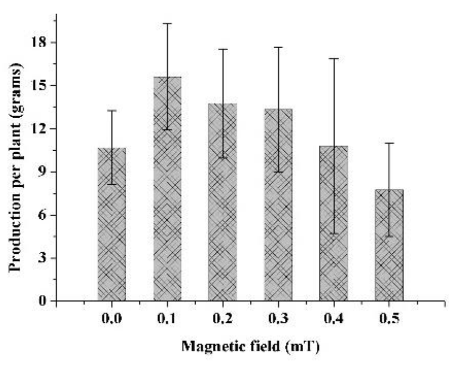

Figure 7. Weight of fresh seeds produced by one soybean plant

3.9 Discussion

In this study, there was a positive, negative, or absence of a magnetic field treatment effect on the emergence of sprouts, stem growth, chlorophyll content, early flowering time, and soybean productivity. A positive effect was obtained from seeds treated with a 0.1 mT magnetic flux density, while a negative effect or no effect was obtained from seeds treated with 0.5 mT. Optimal stem growth occurs when the plant is 7 days to 35 days old, depending on the magnetic flux density used to give the treatment. Treatment with 0.1 mT optimum growth time was longer than the others.

The magnetic field significantly induces cellular metabolism and mitosis in plant meristematic cells [27]. Flórez et al. [28] reported that applying a stationary magnetic field of 126 mT for 1 hour accelerated germination and the percentage of germinated seeds in the treatment group. Shabrangi et al. [29] reported that treatment with 3 mT and 10 mT ELF magnetic fields for four hours resulted in significantly increased catalase (CAT) and ascorbic peroxide (APX) activity in root and shoot tissues. Prihatini et al. [30] reported that the 6 mT magnetic field treatment for 0.5 hours increased banana shoot growth by 27.3%. This study found that the treatment of a time-varying unidirectional magnetic field with a flux density of 0.1-0.3 mT accelerated the emergence of sprouts.

Karkush et al. [10] studied the effect of magnetic fields on water and reported that magnetic fields in water could change several properties such as pH, surface tension, electrical resistivity, viscosity, and inhibition of calcite formation. The characteristics of water flow are very capable of increasing plant growth [31]. It was further reported that a 2000 G magnetic field for more than 24 hours made the pH of the water rise from 6.4 to 8.6. Meanwhile Uguru et al. [32] reported that the high pH of the water can make it harder for seeds to grow. Therefore, the treatment using a magnetic flux density of 0.5 mT did not accelerate germination and even tended to slow it down. Identical results were reported by Shabrangi and Majd [33], where treatment using a magnetic field of 0.3 T for 20 minutes inhibited root and shoot growth in Lens culinaris cultivar seedlings.

The treatment of a unidirectional magnetic field whose magnetic flux density changes with time on sprouts will hit calcium ions (Ca^{2+}) in protein channels in cell membranes [34] which effectively increases the influx of calcium ions (Ca^{2+}) without a proliferative effect [35], thereby causing an increase in cell membrane permeability [36]. Increased calcium ions into the cell membrane can increase metabolism. Podleśny et al. [13] reported that magnetic field treatment can change enzyme content and increase hormone content. Increased metabolism and hormone levels made the 0.1 mT magnetic field treatment accelerate stem growth, increase chlorophyll content, increase grain yield and increase soybean productivity. Similar results have been reported that treatment of tomato seeds with a 0.1 T magnetic field for 15 minutes increased the transplanted stem length, stem diameter, leaf area, and fresh and dry fruit weight [37]. Bahadir et al. [38] also reported that magnetic field treatment of 150 mT for 72 hours obtained the best plant height, number of tubers, tuber weight, and total chlorophyll content. Potato seeds treated with a magnetic field of 30 mT for 10 minutes produced the highest plant length, the number of leaves, fruit yield, and chemical content (P and K) of potato tubers [39].

Excess calcium ions (Ca^{2+}) that enter the cell will damage the cell membrane. Lin et al. [40] reported that the interaction of magnetic fields with cells can increase the stiffness of cell membranes. Therefore, in this study, the magnetic field treatment with a 0.5 mT magnetic flux density tends to have a negative effect on soybean growth and productivity. Similar results were reported by El-Gizawy et al. [39], who stated that exposure to a magnetic field of 40 mT for 10 minutes and 15 minutes in potatoes had a negative effect on the percentage of germination, plant height, number of leaves, number of tubers per plant, fresh weight of potato tubers per plant, and tuber size.

4. CONCLUSIONS

The results showed that germination, plant stem growth, chlorophyll content, and soybean productivity changed due to magnetic field treatment. Magnetic field treatment with a flux density of 0.1 mT can increase soybean productivity to 1.46 times greater than without treatment, which is 15.65 grams per plant. Soybean productivity decreased when treated with a 0.5 mT magnetic field, which was 7.76 grams per plant. Therefore, treatment using a time-varying magnetic field with a low magnetic flux density can be used to increase soybean productivity. The use of changing magnetic fields with time has lesser side effects on the environment.

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