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An Effective Dose of Magnetic Field to Increase Sesame Plant Growth and Its Resistance to *Fusarium oxysporum* Wilt

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ABSTRACT

Globally, sesame consumption continues to increase, so it requires additional production to balance. Often there are obstacles in the production process, both technique and the presence of pests. One way to increase production is to treat it with a magnetic field during seed growth and germination. This study aims to determine the magnetic flux density (MFD) to obtain the optimal stem growth, chlorophyll content, fruit size, and plant resistance to *Fusarium oxysporum*. The seeds are processed by giving treatment using a MFD of 0.0-0.5 mT, which oscillates with a frequency of 50 Hz. Plant seeds were treated using a magnetic field every day for five days with a treatment time of 20 minutes each. The results showed that sesame seeds treated with magnetic fields had earlier emergence time of sprouts, higher stems, more chlorophyll content, faster flowering, larger fruit sizes, and more resistance to *F. oxysporum* wilt attacks. Treatment with a MFD of 0.3 mT resulted in optimal plant growth, health, and resistance to *F. oxysporum* attack. Treatment of seeds using magnetic fields ranging from wetting the seeds to germinating makes the plants healthier, bigger fruits, and more resistant to *F. oxysporum* wilt attacks.

1. INTRODUCTION

At present many studies are being carried out to determine the effect of magnetic fields on living organisms. Magnetic fields induce an electric potential that exerts cellular pressure, thereby causing changes in the biochemical, physical, and physiological structures and functions of cells in living systems [1]. Magnetic fields influence the activation of protein synthesis [2], cause changes at the cellular level [3], and increase cell viability, organization, and differentiation [4]. The application of magnetic fields in agriculture is a new, environmentally friendly technology to improve seed germination and increase yields by influencing physiological and biochemical processes in seed materials [5, 6]. Treatment using magnetic fields during seeding and seed germination will affect cell-reproduction and metabolism [7], Deoxyribo Nucleic Acid [8], and enzyme activity [9]. Previous studies have reported that treatment using magnetic fields can accelerate the growth and enlargement of okra and eggplant fruit [10]. The MFD of 130 mT increased shoot length and the chlorophyll content of lupine [11]. The MFD of 600 mT affects root growth [12].

Sesame has essential nutrients for humans, either in the form of oil, paste, or mixed with other foods [13]. Consumption of sesame globally continues to increase mainly due to changes in consumption patterns and consumer awareness. Global sesame consumption was USD 6,559.0 million in 2018 and will reach USD 7,244.9 million by 2024 with a CAGR (compound annual growth rate) of 1.7% [14]. The problem is that sesame production in most areas is carried out traditionally, resulting in low crop production and productivity [15]. The presence of weeds, pests, and insect diseases, moisture stress during the nursery and growth stages causes a significant decrease in the yield and quality of the sesame [15]. Sesame plants are susceptible to biotic and abiotic stresses [16] and are prone to suffering from various diseases [17].

Previous studies have reported that growth and improved yield of lettuce can be accomplished by treating the seeds before they grow, using non-uniform sinusoidal magnetic fields [18]. The treatment of magnetic fields will change the properties of water, including surface tension and viscosity [19], so that the ability to soak the seeds increases [20]. Treatment using magnetic fields on seeds can prolong the life of free radical ions by inducing unpaired singlet-triplet electron transitions causing oxidative stress [21]. Oxidative stress is the main factor that increases mutations [1] in plant cells. The magnetic field has an effect on photochemical activity; for example, the absorption rate of CO_2 in radish (*Raphanus sativus L.*) decreases after treatment to the magnetic field [22]. The chlorophyll content is an indicator of plant health and productivity [23].

Based on the results of previous research, the treatment of magnetic fields in sesame seeds is carried out when wetting them until they grow sprouts, making the sprouts appear and growing the plants faster, the plants healthier and more resistant to *F. Oxysporum* wilt. Treatment is carried out using a magnetic field that changes with time by varying the density of magnetic flux to obtain an effective dose to increase its growth and resistance to *F. oxysporum* wilt. Previous studies have not yet reported the effects of magnetic field treatment from wetting the seeds to germinating and revealed an effective dose to increase growth and resistance of *F. oxysporum* wilt.

This study aims to determine the effective dose of the magnetic field to accelerate the emergence time of sprouts and stem growth, increase the chlorophyll content of leaves, accelerate flowering time, and increase the fruit weight of the sesame plant both in conditions without infection or infection with *F. oxysporum* wilt.

2. METHODOLOGY

2.1 Magnetic field generation

The magnetic field used in the seed treatment comes from two Helmholtz coils arranged parallel so that the resulting MFD along the coil axis is [24]:

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

where, N=Number of turns of the coil, I=current flowing in the coil, R=radius of coil, α=distance between the two coils, and μ_o=permeability of free space. The MFD at the center of the coil system $(x=0)$ is:

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

The coil flows an electric current that meets the equation:

$$I = I_m \sin(2\pi f t + \varphi) \qquad (3)$$

where, f=frequency, I_m=maximum current, and φ=phase angle. If the current flow has a frequency of 50 Hz, the resulting electric field oscillates with a frequency of 50 Hz.

Changes in MFD are carried out by changing the strength of the current flowing in the coil. The resulting MFD density was measured using the Kanetec TM801 Tesla Meter.

2.2 Sample

The research sample was the Winas 1 variety of sesame seeds, which is a great yielding variety of the early sesame from Indonesian Center for Estate Crops Research and Development. Sesame sizes are almost the same and weigh 4-5 milligrams of the seeds. The sample consisted of 12 groups, each group numbering ten seeds or replicates.

2.3 Magnetic field treatment

Perform seed treatment starting from wetting with water to germination. The position of the seed stalk is arranged in the direction of the magnetic force line. The direction of the magnetic field is set parallel to the direction of the earth's magnetic field. Treatment of seeds using a magnetic field was carried out at a room temperature of 27℃. The treatment used a MFD of 0.0 - 0.5mT, treatment time of 20 minutes per day, and implementation of 5 days. The treatment time of 20 minutes makes the effect of changing water and seed temperature negligible. The flow of alternating current in the coil makes the impedance of the coil increase, resulting in a change in electrical energy into heat energy. Previous studies reported that treatment with a MFD of 1.2 - 3.75 mT, a frequency of 20 Hz, and a treatment time of 5-40 minutes on the water caused a significant temperature increase when the treatment time was 33-37 minutes [25]. Excess heat has the potential to damage the seeds that are being grown.

2.4 Planting

Seven days after the completion of the treatment, the grown sesame seeds were planted in polybags. The size of the Polybag used is 30 cm in diameter and 20 cm in height. Before planting, polybags filled with pure soil without fertilizer with pH 7.0. The temperature of the environment where planting is 23-29℃, while the humidity is 80-85%. The plants in the Polybag are watered once a day and done in the morning. Watering is done with a water volume of 25 mL at 1-14 days old and 240 mL when the plants are more than 14 days old for one plant. Plants were given NPK fertilizer with the same size for each sample when they were 10, 20, 30, and 40 days after planting in polybags. The fertilizer weights were 3, 5, 6, and 6 grams of each plant, respectively. After the plant is 30 days old, then 10^7conidia/mL of *F. oxysporum* are injected into the plant stems. Plants injected with *F. oxysporum* were one group from each group treated with a MFD of 0.0-0.5 mT.

2.5 Measurement

Calculation of the emergence time of sprouts starts from wetting the seeds. When the plants are 7, 21, 35, and 49 days after being transferred to polybags, the stems' height is measured. Measurement of chlorophyll content was carried out based on Mackinney's work and measured the absorbance using a UV-Vis Spectrophotometer [26]. Chlorophyll contents were measured when the plants were 58 days old, namely on the third leaf from the bottom. The absorbance measurements were carried out at 645 nm and 663 nm wavelengths of light. Flowering age is calculated from the time of planting in polybags until the beginning of flower buds. Weighing the weight of the fruit is done when the size of the fruit does not have changed. Weighing the fruit's weight is done when the fruit is still fresh, that is, immediately after picking.

3. RESULTS AND DISCUSSION

3.1 Emergence time of sprouts

Figure 1 is a graph of the emergence time of the sesame seeds treated with a MFD of 0.0 - 0.5 mT. The graph shows that treatment using a magnetic field during seed wetting will shorten the emergence time of sprouts from 2.97±0.04 days to 2.44±0.14 days when given a magnetic field with a MFD of 0.1 mT. The shortest emergence time of sprouts occurred in the seeds treated with a MFD of 0.3 mT, namely 2.23±0.19 days. Treatment with a MFD of 0.4 and 0.5 mT made the emergence time of sprouts longer than treatment with a MFD of 0.3 mT. The statistical test showed that the treatment using a magnetic field had a significant effect on the emergence time of sprouts ($p \leq 0.05$).

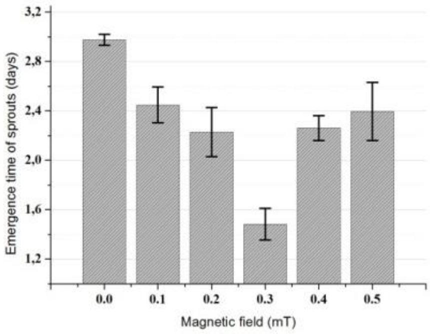

Figure 1. Emergence time of sprouts

3.2 Stem height

Table 1 is the sesame stem height data after 7, 21, 35, 49 days and treated with a MFD of 0.0 - 0.5 mT. Sesame stem was treated with a higher magnetic field than without treatment, where the height of the stems at the age of 7.0 days was 4.31±0.49 cm (with a MFD of 0.1 mT) and 3.95±0.03 cm, respectively. Optimum stem height when treated with a MFD of 0.3 mT, namely 5.59±0.38 cm and 93.6±4.10 cm at the age of 7 and 49 days, respectively. The percentage difference in the height of the bar at 49 days between the untreated and treated with a 0.3 mT magnetic field is 10.77%. Thus, in general, seeds treated with magnetic fields had higher stems than untreated seeds.

Table 1. Sesame plant height after 7, 21, 35, and 49 days

Magnetic Field (mT)	Stem height (cm) at age (days)			
	7	21	35	49
0	3.95±0.03	13.74±0.77	39.50±1.22	84.50±1.27
0.1	4.31±0.49	14.74±0.51	44.90±1.92	84.80±2.82
0.2	4.78±0.34	15.23±0.77	46.10±2.16	91.30±3.96
0.3	5.59±0.38	16.29±0.61	48.80±2.20	93.60±4.10
0.4	4.42±0.24	14.58±0.45	42.60±2.95	89.10±2.07
0.5	4.12±0.85	14.11±0.68	41.50±2.09	86.50±4.00

Table 2. Sesame plant height after 7, 21, 35, and 49 days infected with *F.oxysporum*

Magnetic Field (mT)	Stem height (cm) at age (days)			
	7	21	35	49
0	3.92±0.33	13.83±0.37	32.30±2.39	37.10±9.05
0.1	4.38±0.27	14.77±1.12	34.00±2.09	43.60±6.11
0.2	4.74±0.42	15.28±0.63	35.50±2.37	49.10±9.67
0.3	5.56±0.74	16.25±0.65	41.40±1.39	68.70±6.20
0.4	4.49±0.33	14.53±0.34	33.90±1.43	47.60±4.48
0.5	4.15±0.29	14.17±0.47	32.80±1.52	42.90±7.84

This condition is thought to be caused by changes in DNA. Where treatment of magnetic fields increases deoxyribonucleic acid (DNA) repair [27]. Magnetic fields influence DNA and RNA synthesis [28]. Magnetic fields in the very low frequency (ELF) and radiofrequency (RF) ranges activate the cellular stress response, inducing protection of stress response genes [29]. The effect of magnetic field treatment on DNA is influenced by MFD and treatment time, so that each MFD has a different effect. Treatment with a MFD of 0.5 mT, a frequency of 50 Hz for 2 hours in 5 days will cause DNA degradation [30]. Fourteen days of exposure to magnetic fields had the potential to cause DNA damage, but none was found in the 2 hours and 5-day exposures [31].

DNA changes due to treatment using magnetic fields make sesame plants more resistant to pests, especially *F. oxysporum*. One form of resistance is shown by the stems of plants that grow taller than those without magnetic field treatment. Table 2 shows that the height of the plant stems without magnetic field treatment at the age of 49 days is 37.1±9.05 cm, while with a 0.1 mT magnetic field treatment is 43.6±6.11 cm. The treatment with a MFD of 0.3 mT obtained the optimum stem height of 68.7±6.20 cm and gradually lower in the treatment with a MFD of 0.4 mT and 0.5 mT.Treatment using a magnetic field made the stems of plants able to grow from 42 days to 49 days, while those that were not treated were getting shorter in size because the plants wilted.

3.3 Chlorophyll content

Figure 2 is the content of chlorophyll-*a* and chlorophyll-*b* of sesame leaves at 58 days. The highest chlorophyll content was obtained from plants treated with a magnetic flux density of 0.3 mT, where the chlorophyll-*a* content was 10.79±0.39 mg/L and chlorophyll-*b* was 4.56±0.33 mg/L. The lowest chlorophyll content was obtained from plants that were not treated using a magnetic field, namely chlorophyll-a of 6.39± 0.23 mg/L and chlorophyll-b of 0.65±0.21 mg/L. Overall, the chlorophyll content of sesame leaves in plants treated with a MFD of 0.1-0.5 mT was higher than in untreated plants. Therefore, treatment with a MFD of 0.1-0.5 mT and a frequency of 50 Hz has a significant effect on the chlorophyll content in the leaves of sesame plants ($p \leq 0.05$). This condition occurs because the magnetic field can increase the energy in distributing the atoms, causing the acceleration of metabolism [23]. The increased ion mobility and ion absorption due to the magnetic field treatment resulted in better growth stimulation. This condition makes it easier for plants to carry out photosynthesis [32].

The magnetic field treatment increased the chlorophyll content of sesame plants infected with *F. oxysporum*. Figure 3. is data on the chlorophyll content of sesame leaves infected with *F. oxysporum* at 30 days. The highest chlorophyll content was found in plants treated with a MFD of 0.3 mT, chlorophyll-*a* of 8.06±0.19 mg/L, and chlorophyll-*b* of 3.16±0.07 mg/L. The chlorophyll content decreased again after being treated with a MFD of 0.4 mT and 0.5 mT. The results of statistical tests showed that the magnetic field treatment had a significant effect on the chlorophyll content of sesame leaves infected with *F. Oxysporum* ($p \leq 0.05$).

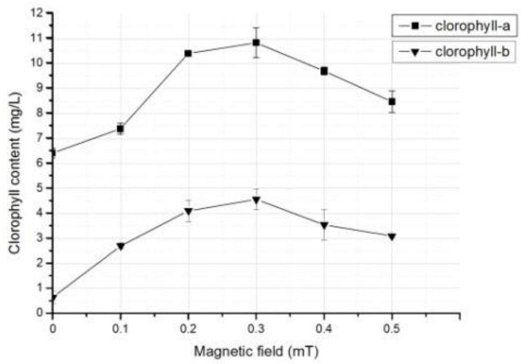

Figure 2. Chlorophyll content without *F. oxysporum* infection

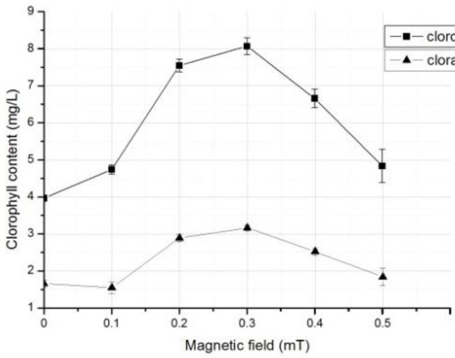

Figure 3. Chlorophyll content with *F. oxysporum*

3.4 Flowering age

Magnetic field treatment can accelerate plant metabolism, thereby accelerating the flowering start time compared to untreated plants, as shown in Figure 4. The fastest flowering time was the plants treated with a MFD of 0.3 mT, namely at the age of 51.4±0.55 days, whereas without treatment, flowering began at the age of 54±1.22 days. Statistical analysis showed that magnetic field treatment had a significant effect on flowering time with $p \leq 0.05$. The same condition occurred in plants infected with *F. oxysporum*, where the flowering time of plants treated with magnetic fields was faster than those that were not treated, as shown in Figure 5. However, the difference in flowering time was not significant, except for plants treated with a MFD of 0.3 mT, where the plants flowered at the age of 52±0.71 days. whereas without treatment to flowering at 54±1.00 days. Plant infection with *F. oxysporum* does not affect the flowering time of the sesame plant but affects the number and freshness of the flowers.

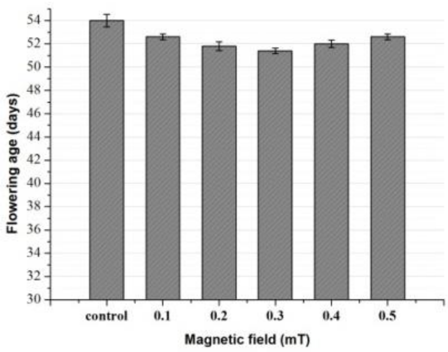

Figure 4. Time to start flowering without *F. oxysporum* infection

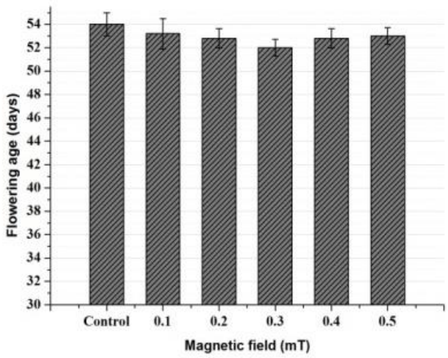

Figure 5. Time to start flowering with *F. oxysporum* infection

3.5 Fruit weight

The fruit is picked from the tree when the fruit does not change in size. The fruit is weighed immediately after being picked from the tree or fresh. Figure 6 is a graph of the weight of the sesame fruit per seed treated with magnetic fields and without being treated. The weight of the sesame fruit treated with a MFD of 0.1- 0.5 mT is heavier than the untreated ones. The untreated fruit weight was 1.37±0.10 grams, while the fruit treated with a MFD of 0.1 mT was 1.64±0.08 grams. Plants treated with a MFD of 0.3 mT weight 2.55±0.14 grams or 1.86 times the weight compared to those not treated using a magnetic field. The results of statistical analysis showed a significant difference in fruit weight between plants without magnetic field treatment and those that were treated ($p \leq 0.05$).

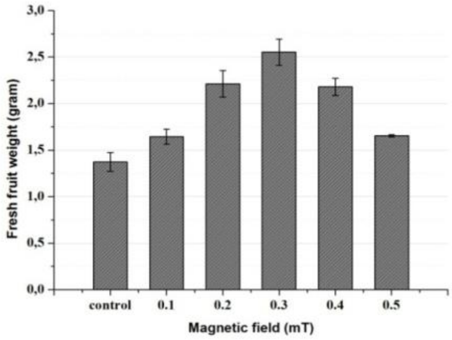

Figure 6. Fruit weight without *F. oxysporum* infection

F.oxysporum infection makes sesame plant growth disturbed, thus disturbing the weight of the fruit produced. Magnetic field treatment makes sesame plants more able to withstand pests so that the fruit weight is higher than untreated plants, as shown in Figure 7. Treatment with a MFD of 0.1, 0.4, and 0.5 mT did not significantly affect the weight of the sesame fruit infected with *F. oxysporum*. Meanwhile, those treated with a MFD of 0.2 mT and 0.3 mT had a significant effect ($p \leq 0.05$). In the treatment with a MFD of 0.3 mT, the optimum fruit weight was 0.77±0.10 grams, while the untreated plants had a fruit weight of 0.36 grams.

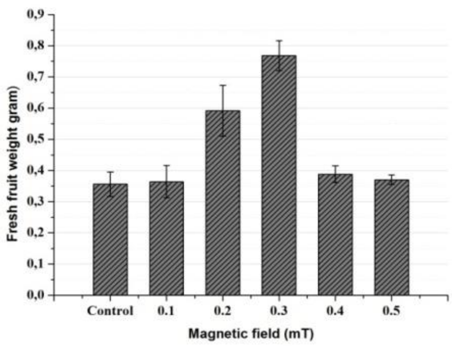

Figure 7. Fruit weight of plants infected with the pathogen *F. oxysporum*

3.6 Discussion

In this study, treatment with a MFD from 0.1 mT to 0.3 mT made the sprouts grow faster, increased stem height, more chlorophyll content, shorter flowering time, heavier fruit weight, and resistance to *F. oxysporum* increased compared to control. Treatment with a MFD of 0.4-0.5 mT began to decrease compared to treatment with 0.3 mT. Therefore, treatment with a MFD of 0.3 mT provided optimal plant growth and resistance to *F. oxysporum.* Treatment with magnetic fields on seeds immersed in water causes shifting and polarization of the water atoms, thereby changing the physicochemical properties of water, including decreasing surface tension and increasing its viscosity [19]. The magnetic field treatment on the seeds causes the enzyme activity in the embryo to increase [33]. The interaction force of the magnetic field with seed and water can be expressed by [34]:

$$\Delta F = \Delta \varkappa_o \mathrm{V}\, H\, \nabla H \tag{4}$$

where, $\Delta\varkappa_o$ is the change in the magnetic susceptibility of water or material, *V* is the volume of the material, *H* is the magnetic field, and ∇H is the magnitude of the magnetic field gradient.

Eq. (4) shows that the magnetic field interaction force is influenced by the magnetic field intensity (*H*) and the change in the magnetic field ∇H. Therefore, water can immerse the seeds with changes in density due to exposure to magnetic fields. Previous studies reported that changes in the relative water mass uptake by seeds increased from 0.7 to 0.79 with a stationary magnetic field treatment of 0-10 mT for 8 hours [35]. Treatment using magnetic fields makes it easier for the planted seeds to absorb water [36]. The emergence time of each of the respective magnetic flux densities is different, whereas increasing the moisture pressure progressively inhibits seed germination [37].

In this study, the magnetic field oscillates with a frequency of 50 Hz, so a low MFD is required for seed treatment. Changing magnetic fields are a solution for using low magnetic flux densities [38]. Previous studies have reported that treatment using a MFD of 150 mT for 72 hours can shorten the emergence time of potato seed sprouts from 31.8 days to 14.0 days [39].

After the sprouts have grown, the magnetic field treatment can prolong the life of the free radical ions by inducing unpaired electron-triplet transitions that cause oxidative stress [21, 33], which affects cell reproduction, cellular metabolism, gene expression, and enzyme activity [40]. This condition makes the plant stems grow faster so that the sesame plant stems are treated with a higher magnetic field than without being treated. Previous studies reported that treatment with a MFD of 0.33T increased plant height from 4.18 cm to 5.25 cm at four weeks of age [41]. Differences in stem height between plants treated with magnetic fields and without treatment also occurred in plants infected with *F. oxysporum*. Magnetic field treatment increases the occurrence of chemical reactions that positively affect plant photochemical activity, respiration ratio, and enzyme activity [21]. Previous studies have reported that static magnetic field treatment with a magnetic flux density of 50 mT increased chlorophyll content, while 100 mT tended to decrease [42]. Identical reports suggest that magnetic fields significantly enhance all photosynthetic pigments [43]. The chlorophyll content is closely related to plant health, where the higher the chlorophyll content, the better the plant health [44]. Therefore, the plants treated with the magnetic field could withstand *F. oxysporum* wilt better than the untreated ones. This is indicated by higher plant stems, more chlorophyll content, faster flowering time, heavier fruit weight.

Magnetic fields have a very high stimulatory effect on cell multiplication, growth, and development [6], thus triggering faster flowering. Several studies have reported that magnetic field treatment affects productivity [45-47]. This study also showed that the fruit weight produced from plants treated with a magnetic field was higher than that of untreated plants.

In this study, a lower magnetic field and shorter maintenance time are required compared to using a static electric field. The magnetic flux density that resulted in optimum growth and resistance to *F. oxysporum* was 0.3 mT. The drawback is that connecting the Helmholtz coil with a sinusoidal electric current increases the impedance so that the temperature of the coil increases.

4. CONCLUSION

Magnetic field treatment with changing treatment times and a frequency of 50 Hz during seed wetting and germination were effective in accelerating the emergence of sprouts, accelerating growth, improving sesame plant health, and making plants more resistant to *F. oxysporum* wilt. The effective dose was obtained in the treatment with a magnetic flux density of 0.3 mT with a treatment duration of 20 minutes every day for five days. Research has not revealed the use of other magnetic field frequencies, their significance for the total productivity and quality of the sesame yield, and their application to other types of crops. Therefore, further research is still needed.

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