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Full Length Article

Application of a Time-Changing Magnetic Field to Increase Tomato Growth and Resistance to *Fusarium oxysporum* f. spp. *lycopersici*

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Abstract

This study aimed to accelerate the growth of tomatoes and increase their resistance to the attack of *Fusarium oxysporum* f. spp. *lycopersici* through application of a time-changing megnetic field. The research sample was tomato seeds of the Timoty F1 variety. The treatment was carried out using a time-changing magnetic field (MF) with a frequency of 100 Hz and a magnetic flux density (MFD) of 0.0–0.5 mT. Treatment was carried out for 10 min every day and repeated for five days. The results showed that treatment with MFD 0.3 mT made the time of emergence of germination, percentage of seed germination, and early flowering to be optimum. Treatment with a MFD of 0.2 mT made the plants to grow faster and more resistant to the attack of the *F. oxysporum* f. spp. *lycopersici*. Treatment using MF with a MFD of 0.2 and 0.3 mT made tomato plants resistant to *F. oxysporum* f. spp. *lycopersici*, which usually grows. Treatment using a time-varying MF requires a low MFD, thus minimizing side effects.

Keyword: Flower; Growing; Magnetic field; Stem; Tomato

Introduction

Tomatoes are a commodity needed by humans in both their processed form and unprocessed form. Tomatoes contain various phytochemicals and the most well-known are locotenins, carotenoids, phenolics, antioxidants, moderate amounts of vitamin C and small amounts of vitamin E (Hedges and Lister 2005). A large number of phytochemicals that are beneficial to the human body makes the need for tomatoes continue to increase. Various efforts, therefore, have been made to increase their production but are often constrained by climate change, pests and diseases (Guner *et al.* 2009). These factors can cause a decrease in the production of tomatoes quantitatively and qualitatively and can cause crop failure (Hanssen *et al.* 2010; Bhandari *et al.* 2021). One of the diseases often encountered in tomato plants is the pathogen *F. oxysporum* f. spp. *lycopersici* (López-Zapata *et al.* 2021).

F. oxysporum is a soil-borne fungal pathogen that is one of the factors in the decrease in tomato production (Michielse and Rep 2009). The fungus that mainly attacks tomato plants is *F. oxysporum* f. spp. *lycopersici* (Abdel-Fattah 2012; Naqvi *et al.* 2019). *F. oxysporum* f. spp. *lycopersici* can survive long in the soil in the form of chlamydospores (Hou *et al.* 2020). The pathogen *F. oxysporum* can cause great harm to plants that are susceptible to the environment (Farahani-Kofoet *et al.* 2020). Under optimal infection conditions, yield reduction is up to 90% (Mostafa *et al.* 2022). Specifically, the fungus attacks susceptible plants through natural wounds and openings created by emerging roots (Zhang *et al.* 2021). In fact, several methods have been available to control diseases caused by *F. oxysporum* f. spp. *lycopersici*. However, farmers generally prefer to use synthetic pesticides because they are more efficient and profitable. The use of synthetic pesticides has an impact on human health, the environment and food safety (Poudel *et al*. 2020; Ali *et al.* 2021). The synthetic pesticides used generally contain synthetic chemicals such as organochlorines, carbonates and organophosphates. Therefore, finding an efficient control method with minimal side effects is necessary. Many studies have also been carried out on the effects of MFs on plant growth and development. The MF treatment is one method that can be used to promote plant growth as it is an environmentally friendly method with low side effects.

Several previous research reported that the stationary magnetic field (MF) treatment affected maize (Florez *et al.* 2007), wheat (Pietruszewski and Kania 2010) and lentils (Aladjadjiyan 2010). Previous research also reported that the MF treatment could affect cell membrane characteristics, cell reproduction, cell metabolism and plant characteristics such as mRNA quality, gene expression, protein synthesis and enzyme activity (Hozayn *et al.* 2010). The MF affects the structure of the cell membranes, thereby increasing the permeability and ion transport, which

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ultimately affects the metabolic pathway. Therefore, it can be said that the MF treatment affects plant growth and productivity (Souza *et al.* 2005). Optimal plant growth indicates the plants are growing healthy. Healthy plants are potentially more resistant to *F. oxysporum* f. spp. *lycopersici* attack. In addition, the magnitude of the interaction force between the MF and seeds is influenced by the MF gradient (Tao *et al.* 2020). Therefore, this study used a MF changing with time to get more optimum results. The aim of this study is to determine the effect of changing MFs on the time of emergence of sprouts, percentage of germination, growth of stems, time of emergence of flowers and resistance to the attack by the pathogen *F. oxysporum* f. spp. *lycopersici*.

Materials and Methods

Magnetic field source

The MF used to treat tomato seeds was sourced from the Helmholtz coil. In this research, two Helmholtz coils were used and both were arranged parallel to each other with a distance of 0.2 m. Each coil was then connected to a direct current source with a current that changed with time. The frequency of change was 100 Hz, resulting in a MF that varied with time with a frequency of change of 100 Hz.

Sample preparation

The tomato seeds used as samples were the Timoty F1 variety produced by PT. East-West Seed Indonesia. *F. oxysporum* f. spp. *lycopersici* isolates were obtained from the Southeast Asian Regional Center for Tropical Biology (SEAMEO BIOTROP) laboratory in Bogor-Indonesia. The weight of tomato seeds was chosen with almost the same weight, which was between 0.0025–0.0035 milligrams per seed. Samples were then made into 12 groups, each of which had 20 seeds or replications.

Treatment using a magnetic field

Seeds that met the criteria were soaked in distilled water for 15 min. Then, the seeds were randomly grouped according to the treatment group and placed on a seedling tray filled with planting media. The treatment using a MF was carried out with a MFD from 0.0 mT to 0.5 mT. Each group was treated using the MF for 10 min a day and the treatment was repeated for five days. The treatment time was 10 min, done to avoid heating the water used to soak the seeds. Previous studies reported that in the treatment with 1.2–3.75 mT MFD, frequency of 50 Hz and duration of 30 min, the water temperature increased significantly (Ayrapetyan *et al.* 2006), which eventually could damage the seeds.

Planting

Seeds that had been sown and were seven days old from wetting were transferred to seedling polybags that had been filled with a mixture of soil and humus growing media in a ratio of 3:1. Plants were watered daily to maintain moisture. After the plants were ten days old from transplanting to seedling polybags, then the plants were transferred to 30 × 30 cm polybags filled with planting media. Each polybag was filled with one plant, and the distance between polybags was 10 cm. The planting medium used was a mixture of soil, manure and roasted husks in a ratio of 1:1:1, which had been mixed evenly. Plants were watered once a day every day in the morning. Watering was done with a water volume of 25 mL for 1–14 day-old plants and 240 mL when the plants were more than 14 days old per one plant. Plants were fertilized using NPK fertilizers once a week with a dose of 15 grams of NPK fertilizers dissolved in 5 L of water. Afterwards, 240 mL was poured into each polybag. The planting site had an environmental temperature of 21–31°C and 79–82% air humidity.

Plant infection with *F. oxysporum*

After the treatment using a MF was completed and the sprouts had grown roots, the following six groups of samples were taken to be infected with *F. oxysporum* f. spp. *lycopersici*. *F. oxysporum* f. spp. *lycopersici* infection is administered at 10^{-7} conidia/mL dilution. Plant infection was carried out by the root watering inoculation method using a micropipette of 1.0 mL per plant.

Statistical analysis

Data on the time of emergence of germination, number of germination, growth of stems, and time of onset of flower emergence were analyzed using Analysis Of Variance (ANOVA) statistics to examine the difference in mean between treatment groups. The significance of the differences from each subsequent treatment was tested using the Duncan Multiple Range Test (DMRT).

Results

Sprouts emergence time

Treatments using a MF in the water used to soak the seeds can change some of its properties, such as pH, electrical resistivity, viscosity and inhibition of calcite formation, so the ability to soak the seeds increases. Therefore, the treatment using a MF at the time of seed germination could speed up the appearance of sprouts in tomato seeds. Table 1 shows that the time of emergence of seed germination without the MF treatment was 71.39 ± 1.07 h after immersion, while seeds treated with the MFD 0.1 mT were 55.65 ± 3.01 h. The treatment using a MF with a MFD of 0.3 mT resulted in an optimum sprout emergence time of 28.8 ± 4.15 h after immersion or 42.59 h faster than without the MF treatment. The results of the statistical analysis of the ANOVA test followed by the DMRT test showed that the treatment using a MF had a significant effect on the time of emergence of sprouts in tomato seeds with $P \leq 0.05$.

Table 1: Data on the emergence of sprouts and the number of germinated seeds

Magnetic field (mT)	Emergence time of sprouts (hour)		Number of germinated seeds (%)	
0.0	71.38 ± 1.07	a	66.67 ± 2.89	a
0.1	55.65 ± 3.01	b	88.33 ± 5.77	b
0.2	48.73 ± 4.15	b	95.00 ± 5.00	bc
0.3	28.80 ± 1.20	c	100.00 ± 0.00	c
0.4	48.49 ± 4.24	b	91.67 ± 2.89	bc
0.5	50.97 ± 4.05	b	90.00 ± 5.00	bc

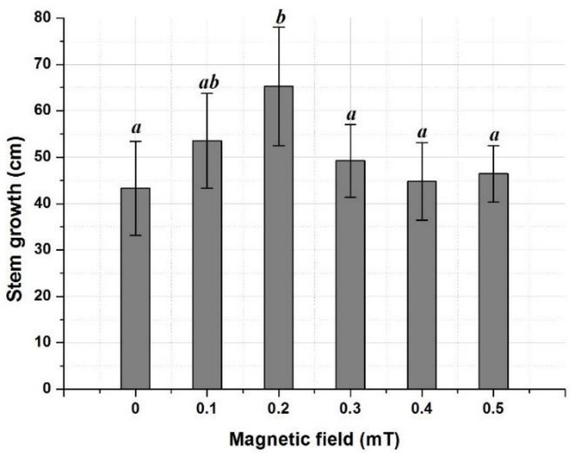

Fig. 1: Growth of stems at the age of 6-30 days due to MF treatment

Number of germinated seeds

Table 1 shows the treatment effect using a MF on the number of germinating seeds. Without the MF treatment, the number of germinated seeds was (66.67 ± 2.89%). Meanwhile, the treatment using a MF with 0.1 mT MFD made the number of seeds germinate as much as (88.33 ± 5.77%). Meanwhile, the treatment using a MFD of 0.3 mT made the number of seeds germinate to the optimum, which was (100 ± 0.00%). The statistical analysis results showed that the treatment which used a MFD of 0.1, 0.2, 0.3, 0.4 and 0.5 mT had a significant effect ($P \leq 0.05$) on the number of germinating seeds. However, the mechanism of the interaction of MFs with seeds is not widely known; several theories have reported changes in embryos' biochemical or enzyme activity which affect seed growth.

Plant stem growth

Not infected with *F. oxysporum*: The MF treatment at the time of seed germination had an effect on stem growth, which made the height of tomato stems different for each treatment group. Fig. 1 shows tomato stem growth from 6 days to 30 days after planting into 30 × 30 cm polybags. The growth of tomato stems that were not treated with the MF was 43.27 ± 10.10 cm. On the other and the treatment using a MF with an 0.1 mT MFD made tomato stems increase in height by 53.51 ± 10.25 cm. Optimal stem growth occurred in seeds treated with 0.2 mT MFD, which was 65.28 ± 12.80 cm. The results of the statistical analysis showed that the treatment using a MFD of 0.2 mT had a significant effect on the growth of tomato plant stems ($P \leq 0.05$), while in the MFD of 0.1 mT, 0.3, 0.4 and 0.5 mT the effect was not significant. The insignificant effect occurs because the MFD and frequency influence the interaction effect of the MF with plant cells. At a low MF the effect is too small, while a large MF will decrease cell metabolism.

Infected with *F. oxysporum* f. spp. *Lycopersici*: Treatments using a MF during seed germination affected the growth of tomato plant stems infected with the pathogen *F. oxysporum* f. spp. *lycopersici*. Fig. 2 is a graph of the growth of tomato plant stems at the age of 6–30 days after being transferred to 30 × 30 cm polybags and after being previously treated with a MF and infected with the pathogen *F. oxysporum* f. spp. *lycopersici*. Plants not treated with a MF experienced a stem growth of 41.19 ± 10.19 cm. Meanwhile, the growth of stems of tomato plants treated using a MFD of 0.1 mT was 46.29 ± 9.66 cm. Optimal plant stem growth occurred in plants treated with a MF with a 0.2 mT MFD, 51.09 ± 7.93 cm. This growth indicates that the treatment using a MF with a 0.2 mT MFD can still make tomato plants grow even though they are exposed to the attack of the *F. oxysporum* f. spp. *lycopersici* pathogen. Statistical analysis showed that the treatment using a MF with an MFD of 0.2 mT had a significant effect ($P \leq 0.05$) on stem growth.

Plant stem height comparison

Fig. 3 shows the stem height of tomato plant with the infection of *F. oxysporum* f. spp. *lycopersici* and without infection. Plants infected with *F. oxysporum* f. spp. *lycopersici* had lower stems than those not infected. The attack of the pathogen *F. oxysporum* f. spp. *lycopersici* significantly reduced the growth of tomato plant stems, resulting in shorter stems. The treatment using a MF with a MFD of 0.1 and 0.2 mT could increase the growth of stems of plants infected with *F. oxysporum* f. spp. *lycopersici* so that the stems were taller than the stems of the plants that were not treated and not infected with *F. oxysporum* f. spp. *lycopersici*. The height of the plants not treated with a MF and not infected with *F. oxysporum* f. spp. *lycopersici* was 52.24 ± 10.65 cm, while the plants that were infected with *F. oxysporum* f. spp. *lycopersici* and treated with a MFD of 0.1 and 0.2 mT had the stem height of 53.19 ± 6.44 cm and 57.88 ± 8.89 cm, respectively. The 0.1 and 0.2 mT MF treatments made tomato plants resistant to the attack of the pathogen *F. oxysporum* f. spp. *lycopersici*.

The growth pattern of plant stems

Not infected with *F. oxysporum* f. spp. *lycopersici:* Fig. 4 shows the growth pattern of tomato plants at the age of 6–30 days, starting from the transfer of the plants to polybags

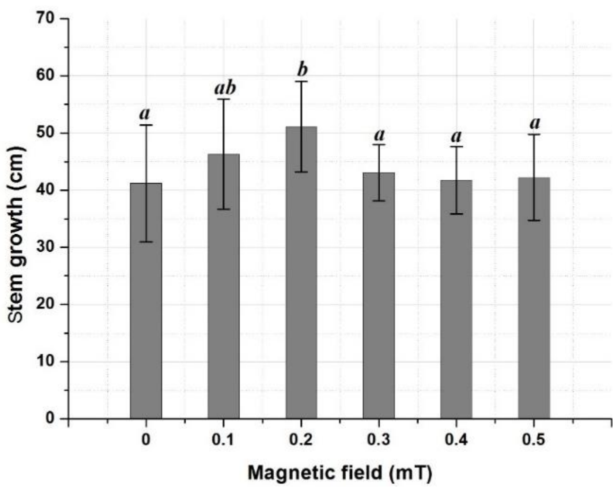

Fig. 2: Growth of tomato stems aged 6-30 days with MF treatment during seeding and infected with *F. oxysporum* f. spp. *lycopersici* after root growth

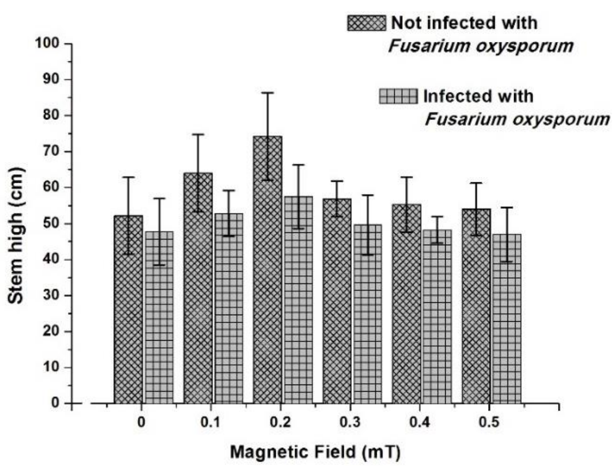

Fig. 3: Stem height of tomato plants that were not infected and infected with *F. oxysporum* f. spp. *lycopersici* the age of 30 days after transplanting into polybag 30 × 30 cm

measuring 30 × 30 cm and treated using a MF. At the age of 6–24 days, the growth between plants treated with a MF and those not treated was not significantly different. At the age of 27–30 days, the growth of the plants treated using a MFD of 0.2 mT was faster than other plants. Meanwhile, in the treatment using a MFD of 0.3, 0.4 and 0.5 mT, the plant height conditions until 30 days were almost the same as the plants without treatment using a MF. Therefore, 0.2 mT MFD had the potential to be used to accelerate tomato stem growth.

The cause of increased stem growth at the age of more than 24 days due to treatment with a MFD of 0.2 mT is not widely known. However, MF treatment could change enzyme content and increase hormone content. Therefore, it is suspected that an increase in the number of hormones that accelerate stem growth occurs after the plant is over 24 days old.

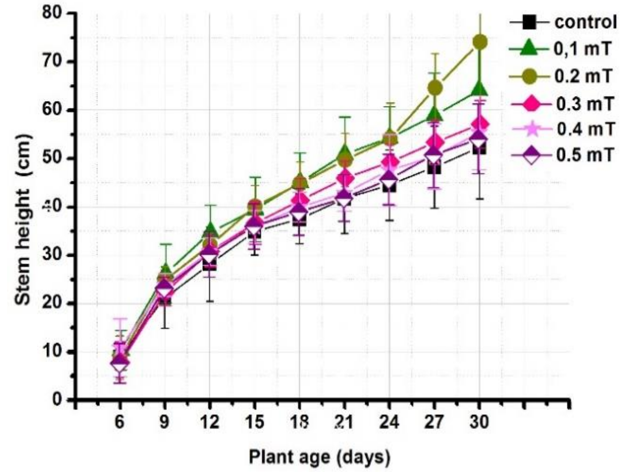

Fig. 4: The growth pattern of tomato stems aged 6-30 days due to 0-0.5 mT MF treatment

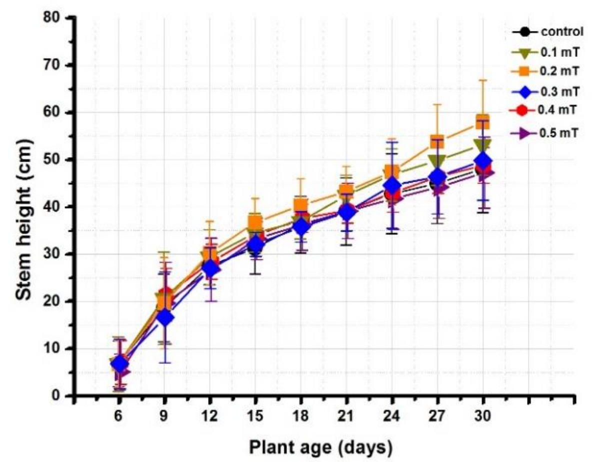

Fig. 5: The growth pattern of tomato stems aged 6–30 days due to MF treatment of 0–0.5 mT and infected with the pathogen *F. oxysporum* f. spp. *lycopersici*

infection with *F. oxysporum* f. spp. *lycopersici*.

Infected with *F. oxysporum* f. spp. *lycopersici*: Fig. 5 shows the growth pattern of the plants treated using a MF and infected with the pathogen *F. oxysporum* f. spp. *lycopersici*. At the age of 6–30 days, plant stems still grew, although their growth was slower than that of the plants that were not infected with the pathogen *F. oxysporum* f. spp. *lycopersici*. The treatment using a MFD of 0.2 mT made plants grow faster at the age of 27–30 days compared to the group of plants treated using other MFDs. Meanwhile, the treatment using a MFD of 0.5 mT made the growth of the plant stems slower than that of the plants that were not treated using a MF, which was as high as 47.3 ± 7.55 cm at the age of 30 days, while the growth without treatment was 48.08 ± 9.23 cm. Therefore, a 0.2 mT MFD treatment made the plant maintain stem growth even though it was infected

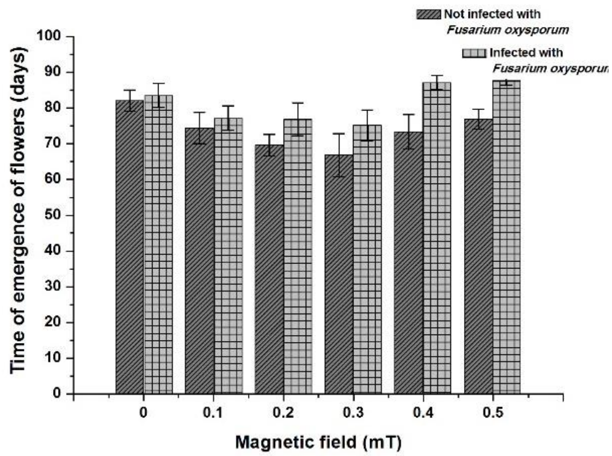

Fig. 6: Time of emergence of flowers from tomato plants due to MF treatment

with the pathogenic *F. oxysporum* f. spp. *lycopersici* disease. Fig. 5 shows that infection from *F. oxysporum* f. spp. *lycopersici* has an effect on stem growth when the plant is over 12 days old.

Flowering time

Fig. 6 shows the effect of the MF on the time of emergence of tomato plant flowers in plants both infected and uninfected by the pathogen *F. oxysporum* f. spp. *lycopersici*. The time of the initial appearance of flowers was calculated from the transfer to a 30 × 30 cm polybag. In plants without being infected with the pathogen *F. oxysporum* f. spp. *lycopersici*, the treatment using magnetic flux densities of 0.1, 0.2, 0.3 and 0.4 mT had an effect of significance ($P \leq 0.05$) on the initial time of flower emergence from tomato plants. The initial time of flower emergence on plants without the treatment using a MF was 82 ± 0.93 days, while the initial time of those treated using 0.1 mT MFD was 74.30 ± 4.40 days. The earliest time for the emergence of the fastest flowers occurred in tomatoes treated with 0.3 mT MFD, which was 66.7 ± 1.90 days or 15.3 days faster than without the treatment using MF. Furthermore, plants infected with *F. oxysporum* f. spp. *lycopersici* had a slower time of flower emergence than those without infection. However, the MF treatment could speed up the initial time of flower emergence. Treatments using magnetic flux densities of 0.1, 0.2 and 0.3 mT could speed up the initial time of flower emergence, while treatments with magnetic flux densities of 0.4 and 0.5 mT could slow down the initial time of flower emergence, as shown in Fig. 6. The initial time of emergence of the earliest flowers occurred in seeds treated with 0.3 mT MFD, *i.e.*, 76.9 ± 1.46 days, while plants that were untreated with the MF took 83.6 ± 1.08 days. Therefore, the earliest time for flower emergence occurred from seeds treated with a 0.3 mT MFD, whether or not they were infected with the pathogen *F. oxysporum* f. spp. *lycopersici*.

Discussion

The MF treatment during seed germination affects the germination yield. Optimum germination was obtained when the plants were treated with a MFD of 0.3 mT. Changes in the germination results occur because the treatment using a MF causes polarization and shifts in the water atoms used to soak the seeds so that the physicochemical properties of water change, including decreased surface tension and increased viscosity (Cai *et al.* 2009). The ability of water to soak the seeds depends on the magnetic flux density. A previous research stated that seeds' mass absorption of water increased from 0.7 to 0.79 due to the treatment using a stationary MF with a MFD of 0–10 mT for 8 h (Reina *et al.* 2001). In addition, the MF treatment led to an increase in enzyme activity in the embryo (Júnior *et al.* 2020). Changes in water absorption and increased enzyme activity in embryos caused the emergence of sprouts to change along with changes in the density of the applied MF. It was also reported that the time of emergence of potato seed germination was faster, from 31.8 days to 14.0 days, due to the treatment using 150 mT MFD for 72 h (Bahadir *et al.* 2020). This result is identical to the results of this present research in whichthe MF treatment between 0.1 mT to 0.5 mT made the sprouting time faster. The treatments with a MFD of 0.4 and 0.5 mT made the number of germinated seeds tend to decrease when compared to the MFD of 0.3 mT. The mechanism of the declining germination tendency is not widely known, but it has been reported that the treatment of a MF in water makes the pH of the water increase (Karkush *et al.* 2019). Germination will decrease if the pH of the water used to soak the seeds is too high (Uguru *et al.* 2012). It has also been reported that exposure to a MF of 0.3 T for 20 min inhibited roots and shoot growth in Lens culinaris cultivars (Shabrangi and Majd 2009).

Plant stem growth either without being infected with *F. oxysporum* f. spp. *lycopersici* or with being infected with *F. oxysporum* f. spp. *lycopersici* will be optimum at the 0.2 mT MF treatment. The increase in stem growth occurs because after the seeds germinate, the treatment with the MF causes the lifespan of free radical ions to be longer because it induces unpaired singlet-triplet electron transitions, resulting in oxidative stress (Sahebjamei *et al.* 2007; Júnior *et al.* 2020), cell reproduction, metabolism, cells, enzyme activity, and gene expression (Belyavskaya 2004). These conditions ultimately affect the stem growth of tomato plants so that the stem height varies depending on the applied MFD. This study found that the stem height of tomatoes that received treatment with a MFD of 0.2 mT was 74.24 ± 12.19 cm, while those which did not receive the MF treatment were 52.24 ± 10.65 cm at the age of 30 days after planting into the soil with polybags measuring 30 × 30 cm. Previous studies reported identical conditions, where in the treatment using a MFD of 0.33T the plant height increased from 4.18 cm to 5.25 cm when the plants were four weeks old (Fu 2012). This study also found that the stem height of plants infected with the pathogen *F. oxysporum* f. spp. *lycopersici* varied depending on the magnitude of the MFD applied during seed germination. This indicated that the 0.2 mT MF treatment increased the resistance of tomato plants to *F. oxysporum* f. spp. *lycopersici* pests. Moreover, it has been reported that the treatment using a MF on seeds increased the occurrence of chemical reactions, which had a positive effect on the photochemical activity of the plants, respiration ratio, and enzyme activity (Sahebjamei *et al.* 2007), thereby making the plant healthier. Treatments with magnetic flux densities of 0.3, 0.4 and 0.5 mT made stem growth tend to decrease compared to treatments with a MFD of 0.2 mT. This happens because the MF treatment that changes with time will interact with calcium ions (Ca^{2+}) in protein channels in the cell membrane (Koch *et al.* 2003). The interaction effect of the MF changes with time on the cell depends on the MFD and frequency (Halgamuge *et al.* 2009). The interaction of the MF with cells can increase the rigidity of the cell membrane (Lin *et al.* 2013). It has been reported that the treatment with a 40 mT MF for 10 and 15 min on potatoes harmed the percentage of germination, plant length, number of leaves planted, number of potato tubers per plant and fresh weight of potato tubers per plant and potato tuber diameter (El-Gizawy *et al.* 2016).

Seed treatments using a MF gave a very high stimulatory effect on cell propagation, development, and growth (Maffei 2014), so that it could trigger faster flower emergence. Several previous studies also reported that giving the MF treatment affected plants productivity (Aladjadjiyan 2002; Dardeniz and Yalcin 2007; Jamil *et al.* 2012). Therefore, this study reported that the treatment using a MF with a 0.3 mT MFD made plants flower faster, whether plants were infected with *F. oxysporum* f. spp. *lycopersici* or not.

Conclusion

Seed treatments using a MF that changed with time at the beginning of growth affected the growth of tomato plants and their resistance to *F. oxysporum* f. spp. *lycopersici* attack. Stem growth and resistance to *F. oxysporum* f. spp. *lycopersici* attack were optimum in plants treated with a MFD of 0.2 mT. Each type of plant tended to have a different MF strength to produce optimum growth. In addition, Treatments using a changing MF with time requires a lower magnetic flux density, which has lower side effects.

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Author Contributions

The correspondent author contributed to the process of data collection, data analysis, and script writing.

Conflicts of Interest

Authors declare no conflicts of interest

Data Availability

Data presented in this study will be available on a fair request to the corresponding author.

Ethics Approval

Not applicable to this paper

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