JUATIKA
JURNAL AGRONOMI TANAMAN TROPIKA
VOL. 8 No. 2 May 2026

DOI :https://doi.org/10.36378/juatika.v8i2.5481
eissn 2656-1727
pissn 2684-785X
pages : 712 – 718

REVIEW ARTICLE Open Access

Stomatal Index and Chlorophyll Content of Soybean (*Glycine max* (L.) Merr.) Plants in Response to Induction by a 0.3 mT Magnetic Field

Fahrizal Sahdan[1,*], Dwijowati Asih Saputri[1], Shinta Anisya[1]

Abstract

Soybean productivity in Indonesia remains low, necessitating environmentally friendly innovations such as magnetic field induction to enhance plant physiological performance and support national food security. Therefore, this study focuses on the effects of a 0.3 mT MF with exposure durations of 0, 10, 20, and 30 minutes on the stomatal index and chlorophyll content, as well as the relationship between the two, in the Denasa 1 soybean variety. This study employed a completely randomized design (CRD) with four treatments and four replicates. Stomatal measurements were taken 30 days after planting using the replica method and a light microscope, while chlorophyll content was analyzed using the Arnon spectrophotometric method. The results showed that a 0.3 mT magnetic field significantly increased the stomatal index, with the highest value observed at a duration of 30 minutes; however, it did not affect the chlorophyll a, b, or total content. These findings indicate that the magnetic field is more responsive to leaf anatomical morphology than to chlorophyll biosynthesis, suggesting that the plant's physiological response is specific to certain parameters. The key advantage of this finding is that magnetic field treatment can selectively modify stomatal characteristics without affecting chlorophyll content, making it a targeted, chemical-free, and environmentally friendly technology for enhancing plant adaptation. Farmers, seed producers, and agricultural practitioners are recommended to consider exposing seeds to a 0.3 mT magnetic field for 30 minutes before planting as a sustainable seed treatment method. Further research is needed to evaluate its effects on photosynthetic performance, environmental stress tolerance, and field yield productivity.

Keywords: Denasa 1, Extremely Low Frequency, Food Security, Photosynthesis, Vegetative Growth

1. Introduction

Food security is an urgent global challenge, in line with Sustainable Development Goals (SDGs), specifically Goal 2: Zero Hunger, which emphasizes the importance of sustainably increasing agricultural productivity (Juansa et al., 2025); therefore, the development of scientific technologies to support sustainable agricultural systems is essential. One of the key national food commodities is soybean (*Glycine max* (L.) Merr.) (Saputra et al., 2023), which serves as the primary source of plant-based protein for meeting public nutritional needs and as a raw material for various food products (Haryani & Nindyarani, 2026). However, soybean productivity in Indonesia has not yet met domestic demand (Ardian et al., 2024), with production in 2022–2023 at only 314.246 tons compared to a need of 3.2 million tons, making imports still necessary (Putri et al., 2024; Soesanto, 2022).

One of the main limiting factors is abiotic stress, such as drought, which disrupts plant growth and physiology (Mailidarni & Djafar, 2025). Drought causes stomata to close to limit water loss, but at the same time inhibits the entry of CO_2 into leaf tissues, thereby reducing the rate of photosynthesis and limiting the production of photosynthates for vegetative growth. Consequently, drought inhibits stomatal activity, reduces chlorophyll synthesis, and suppresses photosynthetic efficiency and

*Correspondence: fahrizalsahdan22@gmail.com
1) Universitas Islam Negeri (UIN) Raden Intan Lampung - Jl Letnan Kolonel H. Endro Suratmin, Sukarame, Kota Bandar Lampung, Lampung 35131, Indonesia

overall growth (Gulo & Nurhayati, 2023). In the long term, disruptions in stomatal function can reduce biomass accumulation, pod number, seed weight, and yield, thereby contributing to low soybean productivity.

Previous research has shown that the stomatal index and chlorophyll content are frequently used as physiological indicators to assess a plant's ability to perform photosynthesis and adapt to environmental conditions. The stomatal index is the ratio of the number of stomata to the total number of epidermal cells. This parameter is important for assessing a plant's adaptation to its environment and the efficiency of photosynthesis (Bestari & Riawan, 2024). The higher the index, the more optimal the CO_2 uptake, resulting in more efficient photosynthesis (Mudhor & Oktavia, 2025). Meanwhile, chlorophyll captures light energy to convert it into chemical energy, making it a primary indicator of a plant's photosynthetic capacity (Chamidah et al., 2024).

With advances in technology in the field of plant physiology, extremely low frequency magnetic fields have begun to be studied as a physical treatment that has the potential to influence plant biological activity in an environmentally friendly manner without leaving chemical residues. Magnetic field (MF) induction has been reported to affect the growth and physiological parameters of other plants through increased metabolic activity, growth rate, and enzymatic response, although the effects are highly dependent on the intensity, duration of induction, and the plant species studied (Sefanda et al., 2025). The application of magnetic fields to plants has been shown to influence plant physiological performance by altering ion and enzyme activity within cells, while also modifying the rate of electron movement, which plays a role in enhancing plant cell metabolism, increasing germination rates, root and shoot growth, cell division, and the uptake of water and nutrients (Anggraeni et al., 2024; Putri et al., 2024; Sarraf et al., 2020).

Although various studies have examined the effects of MF on seed germination, vegetative growth, productivity, and physiological parameters of plants, information regarding their effects on leaf anatomical characteristics, particularly stomatal indices and their relationship with chlorophyll content in soybean plants, remains limited. Furthermore, the response of the Denasa 1 soybean variety to 0.3 mT MF induction during the pre-planting stage has not been widely reported. Therefore, this study focuses on the effects of a 0.3 mT MF with exposure durations of 0, 10, 20, and 30 minutes on the stomatal index and chlorophyll content, as well as the relationship between the two, in the Denasa 1 soybean variety. This study is expected to broaden our understanding of the anatomical and physiological responses of plants to environmentally friendly MF induction technology to support increased soybean production.

2. Material and Methods

This experimental study was conducted from December 2025 to February 2026 at the Basic Biology and Microbiology Laboratory, Faculty of Science and Technology, Universitas Islam Negeri Raden Intan Lampung, and in Kampung Beringin, Bandar Lampung City (5.415044° S, 105.328931° E), at an altitude of approximately 147 m above sea level (asl). A one-factor completely randomized design (CRD) was used, involving a 0.3 mT MF induction with four treatment levels, namely P0 (0 minutes), P1 (10 minutes), P2 (20 minutes), and P3 (30 minutes) on Denasa 1 soybean seeds, where each treatment was repeated four times and measured in duplicate, resulting in a total of 32 seeds. The seeds were physically selected based on their integrity, absence of damage, and uniform size, then sterilized with 1% NaClO for 1 minute (Muarifa et al., 2024), rinsed three times with distilled water, and soaked for 15 minutes for initial imbibition before germination (Tirono & Hananto, 2023).

The soaked seeds were placed in 35 mL thin-walled tubes containing 5 mL of distilled water to ensure uniform MF distribution during induction at 0.3 mT (Tirono & Hananto, 2023). After induction, the seeds were planted in 30 × 30 cm polybags filled with lithosol soil, labeled with the treatment, and planted 5 cm deep from the surface of the medium. Watering was performed every morning with a volume of 25 mL during the first 1–14 days, then increased to 250 mL thereafter, to maintain optimal moisture (Rohmandhoni, 2022; Susanti & Yuliana, 2024). Stomatal samples were collected once at 30 days after sowing, between 9:00 and 10:00 AM (Sultana et al., 2024). Stomatal slides were prepared using the replica method, which involves coating the underside of the leaf with clear nail polish (Prastika et al., 2023), drying for 5–10 minutes (Cambaba & Kasi, 2022), applying a clear adhesive, peeling it off gently, and then placing it on a microscope slide (Astari & Lestari, 2024). Observations were conducted using a Nikon 119c light microscope at 40x magnification. Stomatal cells and intact epidermal cells were counted manually using ImageJ software in each field of view. The stomatal index is calculated as the ratio of the number of stomata to epidermal cells, so it depends not only on the absolute number of stomata but is also influenced by the number of epidermal cells (Bestari & Riawan, 2024). The stomatal index formula follows (Wallis, 1965):

$$\textbf{Indeks Stomata (\%)} = \frac{\mathbf{S}}{\mathbf{S+E}} \times \mathbf{100}$$

Notes:
S = Number of stomata per field of view
E = Number of epidermal cells per field of view

Chlorophyll content was measured using 30 day old leaves. The cleaned leaves were then cut into small pieces in preparation for extraction (Alif et al., 2023). A 1 g sample was macerated with 80% acetone in a 1:10 ratio for 3 × 24 h (Aprila et al., 2024; Satya et al., 2025). The sample was placed in a cuvette up to the specified mark, and the absorbance values were measured using a UV-Vis spectrophotometer at wavelengths of 645 nm and 663 nm based on the Arnon (1949) method. The chlorophyll a, b, and total content were then calculated using the following formula:

$$\textbf{Klorofil a (mg/L)} = (12{,}7 \times OD\ 663) - (2{,}69 \times OD\ 645)$$

$$\textbf{Klorofil b (mg/L)} = (22{,}9 \times OD\ 645) - (4{,}68 \times OD\ 663)$$

$$\textbf{Klorofil Total (mg/L)} = (20{,}2 \times OD\ 645) + (8{,}02 \times OD\ 663)$$

Note: OD = *Optical Density*

The data obtained were tabulated using Microsoft Excel 2019 and subsequently analyzed using the one-way ANOVA (analysis of variance) method via SPSS version 29 (Statistical Package for the Social Sciences). If the analysis results showed significant differences between groups, the analysis was continued with Duncan's Multiple Range Test (DMRT) to identify which groups differed significantly, with a significance level of α = 5%.

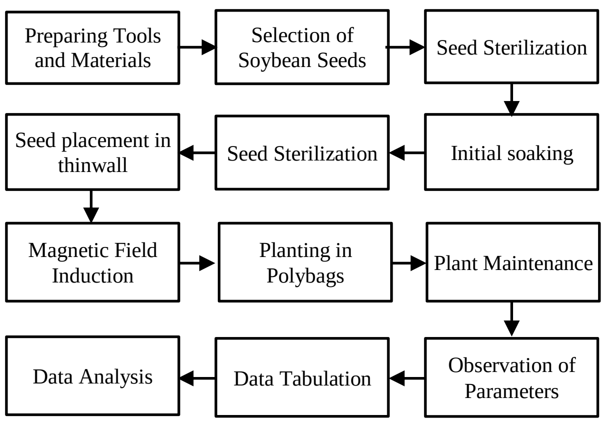

Figure 1. Research Flow Diagram

3. Results and Discussion

The results indicate that a MF of 0.3 mT, with varying exposure durations, had different effects on the two observed parameters: the stomatal index and chlorophyll content of Denasa 1 soybean leaves. A significant response was detected in the stomatal index, whereas chlorophyll content (a, b, and total) was relatively stable and showed no significant differences among treatments, as evidenced by the data presented in Tables 1 and 2. In this study, these differing response patterns indicate that MF at specific intensities and durations tend to influence leaf anatomy more than the biochemical processes of photosynthetic pigment synthesis.

The data in Table 1 show a gradual increase in the stomatal index, indicating physiological stimulation resulting from exposure to a 0.3 mT MF. Duncan's test results show that the 20 and 30-minute treatment durations fall into the same group and differ significantly from the control and the 10-minute treatment. The 30-minute duration showed optimal results in increasing the stomatal index of Denasa 1 soybean leaves, a difference also visually evident in Figure 2. through an increase in the number of stomata per unit of field of view.

Table 1. Stomatal Index (%) of Denasa 1 Soybean Leaves at 30 Days After Sowing

Treatment	Stomatal Index (%)
P0 (Control)	20,88 ± 0,34 a
P1 (10 Minutes)	21,71 ± 0,54 b
P2 (20 Minutes)	22,79 ± 0,53 c
P3 (30 Minutes)	22,84 ± 0,48 c

Note: Values are presented as the mean ± standard deviation (SD). Different letters in the same column indicate significant differences based on the DMRT test ($P < 0.05$). Data were obtained from 4 replicates and 4 duplicated treatments, resulting in a total of 32 plants observed. Stomatal observations were conducted on three leaves per plant, resulting in 96 preparations.

Stomata are microscopic pores in the epidermal layer that form through cell differentiation and are controlled by guard cells (Nendissa et al., 2025). The opening of stomata allows for gas exchange (CO_2 in, O_2 and H_2O out). Each plant has different types of stomata, depending on the plant species. This diversity in stomatal types can be observed in the arrangement and number of epidermal cells surrounding the guard cells, or in the epidermal cells located very close to the guard cells (Aulia et al., 2023). The stomatal type in soybean plants is anomositic (ranunculaceous), in which the stomata are surrounded by epidermal cells that have a polygonal shape and irregular size. These characteristics are also evident in the photomicrograph in Figure 2, which shows the stomatal structure under each treatment.

The stomatal index of Denasa 1 soybean leaves in this study ranged from 20.88% in the control to 22.84% in the treatment exposed to a MF for 30 minutes. These results indicate an increase of 1.96 percentage points, or approximately 9.39%, compared to the control. This increase aligns with the findings of Setyasih et al. (2013), who reported a 12.25% increase in the stomatal index from 48.505% to 54.445% following a 0.3 mT MF treatment on tomato plants. Similarly, Agustrina et al. (2020) found that exposure to a 0.2 mT MF increased the stomatal index from 20.87% to 29.93%, representing a 43.41% increase in red chili plants. The significant differences in response between studies are thought to be related to differences in plant species, MF intensity, duration of exposure, and environmental conditions during growth.

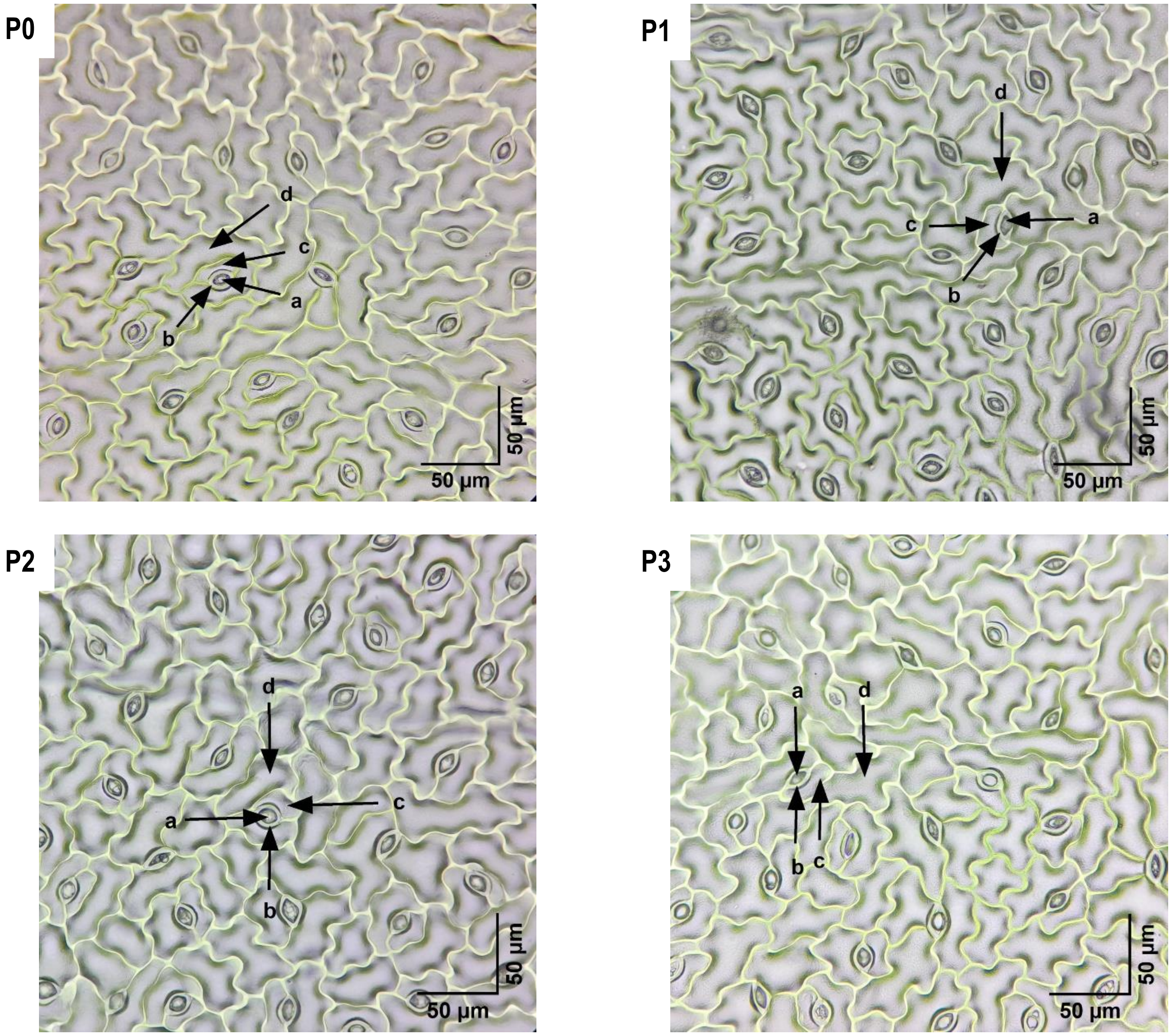

Figure 2. Photomicrograph of stomatal openings on the abaxial surface of a soybean leaf of the Denasa 1 variety at 30 DAS, magnification 40x. Note: P1 = 0 minutes; P1 = 10 minutes; P2 = 20 minutes; P3 = 30 minutes; a = stomatal aperture; b = guard cell; c = adjacent cell; d = epidermis

Physiologically, an increase in the stomatal index can be attributed to the influence of MF on ion activity and cell membrane dynamics. Stomata form through a process of epidermal cell differentiation controlled by hormonal signals and ion balance, particularly Ca^{2+} and K^+. According to a report by Ullrich & Apell (2021), exposure to a MF affects ion movement across the membrane through changes in electrical potential and ion pump activity. Ca^{2+} rapidly increases intracellular concentrations in response to growth factors, triggering protein phosphorylation and kinase activation that drive the cell cycle and cell division (Kurniawan, 2015), including the formation of guard cells. Thus, MF likely act as a physical stimulus that modulates leaf epidermal development processes.

Additionally, an increase in the stomatal index can be interpreted as a form of plant adaptation to increased photosynthetic capacity (Nendissa et al., 2025). The stomatal index is calculated as the percentage of stomata relative to the total epidermal cells, reflecting the relative density of stomata. A higher stomatal index has the potential to increase CO_2 diffusion into the mesophyll tissue, thereby supporting the photosynthetic process (Bestari & Riawan, 2024). In this context, exposure to a MF can improve plant physiological efficiency through the optimization of gas exchange. These findings are consistent with previous studies reporting that magnetic treatment of seeds can enhance plant growth parameters and physiological activities, including stomatal conductance and photosynthetic rates (Katsenios et al., 2020; Tirono, 2022).

In contrast to the stomatal index, the levels of chlorophyll a, chlorophyll b, and total chlorophyll did not show significant differences among treatments. In the statistical analysis, all treatments fell into the same letter group, as shown in Table 2. This indicates that the application of a 0.3 mT MF for durations ranging from 0 to 30 minutes did not significantly affect the chlorophyll biosynthesis pathway in the leaves of 30 DAS Denasa 1 soybean plants.

Table 2. Chlorophyll content (mg/L) of Denasa 1 soybean leaves at 30 DAS

Treatment	Chlorophyll content (mg/L)		
	Chlorophyll A	Chlorophyll B	Total Chlorophyll
P0 (Control)	30,54 ± 0,10 a	59,03 ± 0,29 a	89,54 ± 0,39a
P1 (10 Minutes)	30,52 ± 0,08 a	59,11 ± 0,12 a	89,60 ± 0,20a
P2 (20 Minutes)	30,56 ± 0,18 a	59,18 ± 0,19 a	89,60 ± 0,37a
P3 (30 Minutes)	30,55 ± 0,06 a	59,08 ± 0,30 a	89,60 ± 0,34a

Note: Values are presented as the mean ± standard deviation (SD). Identical letters in the same column indicate no significant difference based on the DMRT test ($P < 0.05$). Data were obtained from 4 replicates and 4 duplicated treatments, resulting in a total of 32 plants observed.

Chlorophyll is the primary green pigment responsible for absorbing light energy and converting it into organic compounds through photosynthesis; as such, it plays a crucial role in promoting the production of assimilates to fill the pods and reduce the occurrence of empty pods (Syahfitri Harahap et al., 2025). This process is significantly influenced by genetic factors, the availability of nitrogen and magnesium, and light conditions (Chamidah et al., 2024). Physically, chlorophyll absorbs light at specific wavelengths (primarily blue at 430–450 nm and red at 640–680 nm) while reflecting green light (around 500–600 nm), and can emit light through long-wavelength red fluorescence when excess energy is released (Wahyuni & Setiarso, 2022). There were no significant changes in chlorophyll content in this study, as shown in Table 2. The application of a 0.3 mT MF for 0–30 minutes had no significant effect on chlorophyll biosynthesis in 30-day-old Denasa 1 soybean leaves. The levels of chlorophyll a, chlorophyll b, and total chlorophyll were relatively stable across treatments. These results differ from the study by Saputra et al. (2025), who reported that the application of an ELF MF was able to increase the chlorophyll a, b, and total content in the 11-minute 42-second treatment of rice leaves in the vegetative phase by 31.40%, 18.59%, and 49.98% compared to the control treatment, which were 28.07%, 13.10%, and 41.16%. Similarly, Dumayanti et al. (2021) found that a 0.2 mT MF tended to increase the chlorophyll content of red chili plants infected with *Fusarium oxysporum*, with values for chlorophyll a, b, and total of 13.06%, 9.52%, and 22.06% compared to the control treatment, which were 12.172%, 8.84%, and 20.60%. These differences in response are likely due to variations in plant species, MF characteristics, duration of exposure, and the plants' physiological sensitivity to MF induction.

In this study, chlorophyll stability indicates that the 0.3 mT treatment did not cause physiological disruption to the photosynthetic system, yet it was not strong enough to increase pigment accumulation. Interestingly, although the stomatal index increased, chlorophyll content remained stable. This suggests that an increase in CO_2 diffusion potential through the stomata is not automatically followed by an increase in light absorption capacity by chlorophyll. The number of stomata increases in plants as an adaptive mechanism to optimize CO_2 exchange, while the photosynthetic system continues to function normally and in balance. Chlorophyll content in leaves can serve as a reliable indicator for evaluating metabolic imbalances between photosynthetic processes and production outcomes, particularly under water-deficient conditions. This implies that if chlorophyll levels remain stable, photosynthetic metabolism and biomass production proceed in harmony (Song & Banyo, 2011).

Overall, the results of the study indicate that exposure to a 0.3 mT MF for 30 minutes effectively increased the stomatal index of soybean leaves but did not have a significant effect on chlorophyll content. These results indicate that MF stimulation has a greater effect on the development and differentiation of epidermal cells involved in stomatal formation than on the chlorophyll biosynthesis pathway. Thus, MF treatment has the potential to be applied as a pre-planting technique to enhance plant adaptability through modification of leaf anatomical characteristics. The lack of effect on chlorophyll content may be due to differences in the physiological mechanisms regulating these two parameters.

Stomatal formation is associated with epidermal cell division and differentiation, which are relatively more responsive to MF exposure during early growth stages, whereas chlorophyll biosynthesis involves more complex processes and likely requires higher exposure intensity or duration to produce a measurable response. These findings are consistent with a study by Atmaja (2018), which reported that a 0.2 mT MF had no significant effect on the stomatal index or chlorophyll content in chili plants. In addition, it can be influenced by genetic variation, environmental conditions such as temperature, humidity, and light intensity, as well as the growth stage at the time of observation; thus, changes in the stomatal index are not always accompanied by changes in chlorophyll content (Syarifuddin et al., 2021). This is consistent with the statement by Alfiah et al. (2025), that the morphological and pigmentation characteristics of leaves are strongly influenced by environmental conditions, particularly water availability, nutrient availability, and light intensity.

4. Conclusion

The increase in the stomatal index was not accompanied by changes in chlorophyll content, indicating that the plant's physiological response to MF induction is specific to certain parameters. The significance of this finding is that MF treatment can selectively modify stomatal characteristics without affecting chlorophyll content, thus potentially serving as a targeted, chemical-free, and environmentally friendly technology to enhance plant adaptability. Farmers, seed producers, and agricultural practitioners are recommended to consider using a 0.3 mT MF exposure for 30 minutes prior to planting as a sustainable seed treatment method to support soybean plant growth and adaptation.

References

Agustrina, R., Manullang, H. M., Irawan, B., Wahyuningsih, S., & Sumardi, S. (2020). Produksi cabai merah (*Capsicum annuum* L.) dari benih yang diinduksi medan magnet 0,2 mT dan diinfeksi jamur *Fusarium* sp. *Jurnal Biologi Papua, 12*(1), 50–58. https://doi.org/10.31957/jbp.1063

Alif, A. A., Gusmiaty, G., Akzad, M. B., Rahim, I., & Larekeng, S. H. (2023). Isolasi cendawan rhizosfer pelarut fosfat pada jabon merah (*Neolamarckia macrophylla*) provenans Kabupaten Sidrap, Sulawesi Selatan. *Jurnal Galung Tropika, 12*(1), 109–118. https://doi.org/10.31850/jgt.v12i1.1046

Anggraeni, F. K. A., Herlia, N. F., Subagya, M. R., Rohmah, I. A., Lestari, D. A., & Mahmudi, K. (2024). Kajian pengaruh paparan medan magnet pada pertumbuhan tanaman tomat. *Optika: Jurnal Pendidikan Fisika, 8*(2), 266–274. https://doi.org/10.37478/optika.v8i2.4188

Aprila, N. A., Ulfa, A. M., & Susanti, D. (2024). Perbandingan aktivitas antibakteri ekstrak etanol dan aseton limbah kulit bawang putih (*Allium sativum* L.) terhadap pertumbuhan bakteri *Staphylococcus aureus*. *Jurnal Ilmiah Wahana Pendidikan, 10*(1), 647–655. https://doi.org/10.5281/zenodo.10469632

Ardian, A., Deviona, D., & Nathisa, D. (2024). Pengujian beberapa varietas kedelai (*Glycine max* L.) pada kondisi cekaman kekeringan. *Jurnal Pertanian Agros, 26*(1), 5245–5262. http://dx.doi.org/10.37159/jpa.v26i1.3978

Arnon, D. I. (1949). Copper enzymes in isolated chloroplasts. Polyphenoloxidase in *Beta vulgaris*. *Plant Physiology, 24*(1), 1–15. https://doi.org/10.1104/pp.24.1.1

Astari, A., & Lestari, E. (2024). Korelasi kerapatan stomata daun terhadap tingkat kejadian penyakit bulai (*Peronosclerospora philippinensis*) pada tanaman jagung. *Journal Agroecotech Indonesia (JAI), 3*(1), 32–44. https://dx.doi.org/10.37159/jpa.v26i1.3978

Atmaja, T. A. (2018). *Pengaruh paparan medan magnet 0,2 mT terhadap pertumbuhan vegetatif benih cabai merah (Capsicum annuum L.) yang diinfeksi Fusarium sp.* [Skripsi, Universitas Lampung]. https://digilib.unila.ac.id/32463/

Bestari, I. A. P., & Riawan, I. M. O. (2024). Keanekaragaman anatomi epidermis daun dan indeks stomata jepun cenana *Plumeria alba* var. Cendana berdasarkan lingkungan tumbuhnya di Bali Utara. *Jurnal Biologi UNAND, 12*(2), 106–113. https://doi.org/10.25077/jbioua.12.2.106-113.2024

Cambaba, S., & Kasi, P. D. (2022). Karakteristik struktur anatomi stomata beberapa spesies tanaman mangrove di Pantai Labombo Kota Palopo. *Cokroaminoto Journal of Biological Science, 4*(2), 8–15.

Chamidah, A., Afrilia, H. C., Ahmad, M. G., & Arisandi, D. (2024). Isolasi klorofil A dan analisis aktivitas antioksidan dari mikroalga *C. vulgaris*. *Jurnal Pengolahan Hasil Perikanan Indonesia, 27*(11), 1006–1020. https://doi.org/10.17844/jphpi.v27i11.57470

Dumayanti, E., Agustrina, R., Setiawan, W. A., Ernawiati, E., Yulianty, Y., & Chrisnawati, L. (2021). Resistance of red curly chili (*Capsicum annuum* L.) sprouts to *Fusarium oxysporum* infection from seeds induced by 0.2 mT. *Jurnal Ilmiah Biologi Eksperimen dan Keanekaragaman Hayati (J-BEKH), 8*(1), 14–22. https://doi.org/10.23960/jbekh.v8i1.167

Gulo, D. K., & Nurhayati, N. (2023). Proses fisiologis pembentukan protein kedelai pada kondisi tanaman mengalami cekaman kekeringan. *Tabela Jurnal Pertanian Berkelanjutan, 1*(1), 15–18. https://doi.org/10.56211/tabela.v1i1.167

Haryani, A., & Nindyarani, A. K. (2026). *Ragam polong, kacang, dan biji sebagai sumber lemak dan protein nabati unggulan sepanjang zaman (Jilid 2)*. Penerbit Andi.

Juansa, A., Maulana, A. W., Lubis, M. M., Wijaya, A. A., Minarsi, A., Sugama, D., Ayu, I. W., Rianty, E., & Murwanti, R. (2025). *Ketahanan pangan: Swasembada pangan dan implikasinya terhadap pertumbuhan ekonomi di Indonesia*. PT Star Digital Publishing.

Katsenios, N., Sparangis, P., Kakabouki, I., & Efthimiadou, A. (2020). Influence of pulsed electromagnetic field as a pre-sowing treatment on germination, plant growth and yield of broad beans. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 48*(3), 1398–1412. https://doi.org/10.15835/nbha48311989

Kurniawan, S. N. (2015). Intracellular Ca^{2+} homeostasis. *MNJ (Malang Neurology Journal), 1*(1), 36–45. https://doi.org/10.21776/ub.mnj.2015.001.01.7

Mailidarni, N., & Djafar, T. (2025). *Fisiologi tumbuhan: Proses, mekanisme, dan adaptasi*. Elfarazy Media Publisher.

Muarifa, I. R. D. A., Hasanah, A., Nagifea, F. Y., Ariyanto, S., Anggraeni, F. K. A., & Mahmudi, K. (2024). Analisis pengaruh gelombang elektromagnetik extremely low frequency pada sektor pertanian. *Future Academia: The Journal of Multidisciplinary Research on Scientific and Advanced, 2*(3), 171–177. https://doi.org/10.61579/future.v2i3.108

Mudhor, M. A., & Oktavia, I. (2025). Perbandingan jumlah dan kerapatan stomata pada tanaman C3, C4, dan CAM menggunakan metode cetakan cat kuku. *Jurnal Penelitian Inovatif, 5*(3), 2667–2674. https://doi.org/10.54082/jupin.1808

Nendissa, J. I., Riry, J., Patty, J., Amba, M., Wahditiya, A. A., & Lating, R. J. (2025). Pengaruh konsentrasi dan frekuensi POC biofouling tiram mutiara terhadap kerapatan stomata hotong (*Setaria italica* (L.)). *Media Pertanian, 10*(2), 132–144. https://doi.org/10.37058/mp.v10i2.16433

Nur Alfiah, L., Abdillah, K., & Zaimah, Z. (2025). Morphological characteristics of leaf color and leaf shape of soybean variety Anjasmoro (*Glycine max* (L.) Merr.) under water stress. *Jurnal Agronomi Tanaman Tropika (JUATIKA), 7*(1). https://doi.org/10.36378/juatika.v7i1.3988

Prastika, D., Sarjani, T. M., Mahyuni, S. R., Hariani, I., Ramadhan, D. A., Rezeki, S., Tiara, R., Hendrik, E., Aulia, R., & Amalia, T. (2023). Identifikasi tipe stomata anggota suku Myrtaceae di Kota Langsa. *Jurnal Sains dan Edukasi Sains, 6*(1), 20–27. https://doi.org/10.24246/juses.v6i1p20-27

Putri, M. K., Kurnia, S. I., Sudarti, S., & Mahmudi, K. (2024). Study pustaka: Pengaruh paparan medan magnet extremely low frequency (ELF) dalam bidang pertanian pada pertumbuhan fisik tanaman. *Optika: Jurnal Pendidikan Fisika, 8*(1), 59–68. https://doi.org/10.37478/optika.v8i1.3460

Putri, S. W., Wagiono, W., & Subardja, V. O. (2024). Respon kombinasi dosis pupuk bokashi kotoran ayam dan tiga varietas kedelai terhadap pertumbuhan dan hasil tanaman kedelai (*Glycine max* L. Merr.). *Jurnal Ilmiah Hijau Cendekia, 9*(1), 73–78. https://doi.org/10.32503/hijau.v9i1.4619

Rohmandhoni, A. D. (2022). *Pengaruh intensitas paparan medan magnet extremely low frequency (ELF) terhadap pertumbuhan dan produktivitas kedelai (Glycine max L. Merr.)* [Disertasi doktor, Universitas Islam Negeri Maulana Malik Ibrahim]. http://etheses.uin-malang.ac.id/id/eprint/36244

Saputra, A., Listiana, I., & Saputri, D. A. (2025). Analisis kandungan klorofil pada benih padi tua (*Oryza sativa* L.) yang terpapar medan magnet extremely low frequency (ELF) pada masa pertumbuhan vegetatif. *Bioscientist: Jurnal Ilmiah Biologi, 13*(1), 327–335. https://doi.org/10.33512/jat.v16i2.23001

Saputra, Y., Aliudin, A., & Mulyaningsih, A. (2023). Pengendalian impor kedelai dalam upaya mewujudkan ketahanan pangan nasional di

Kabupaten Serang. *Jurnal Agribisnis Terpadu, 16*(2), 90–97. https://doi.org/10.33512/jat.v16i2.23001

Sarraf, M., Kataria, S., Taimourya, H., Santos, L. O., Menegatti, R. D., Jain, M., Ihtisham, M., & Liu, S. (2020). Magnetic field (MF) applications in plants: An overview. *Plants, 9*(9), 1139. https://doi.org/10.3390/plants9091139

Satya, I. G. M., Putra, G. P. G., & Anggreni, A. A. M. D. (2025). Karakteristik ekstrak kulit tanduk kopi Arabika (*Coffea arabica* L.) sebagai sumber antioksidan pada variasi jenis pelarut dan daya ekstraksi menggunakan microwave-assisted extraction. *Jurnal Rekayasa dan Manajemen Agroindustri, 13*(4), 547–556. https://doi.org/10.24843/JRMA.2025.v13.i04.p06

Sefanda, S. K., Nafilla, V. Z., & Anggara, P. (2025). Exploring the potential of magnetic fields on plant growth as monitoring agricultural success. *Jurnal Agro Indragiri, 10*(1), 1–8. https://doi.org/10.32520/jai.v10i1.3217

Setyasih, N., Agustrina, R., Handayani, T. T., & Ernawiati, E. (2013). *Pengaruh medan magnet 0,3 mT terhadap stomata daun tanaman tomat (Lycopersicum esculentum Mill.)* [Skripsi, Universitas Lampung]. http://repository.lppm.unila.ac.id/id/eprint/41160

Soesanto, L. (2022). *Kompendium penyakit-penyakit tanaman kedelai*. Bumi Aksara.

Song, A. N., & Banyo, Y. (2011). Konsentrasi klorofil daun sebagai indikator kekurangan air pada tanaman. *Jurnal Ilmiah Sains, 11*(2), 166–173. https://doi.org/10.35799/jis.11.2.2011.202

Sultana, S. N., Jo, H., Song, J. T., Kim, K., & Lee, J.-D. (2024). Stomatal density variation within and among different soybean cultivars across various growth stages. *Agriculture, 14*(11), 2028. https://doi.org/10.3390/agriculture14112028

Susanti, A., & Yuliana, A. I. (2024). Pengaruh penambahan dua pupuk hayati terhadap pertumbuhan kedelai pada tanah Litosol. *Exact Papers in Compilation (EPiC), 6*(3), 48–53. https://doi.org/10.32764/epic.v6i3.1233

Syahfitri Harahap, A., Hafiz, M., Mahareni Br Sitepu, S., & Luthfiyyah Nabillah, R. (2025). Increasing three soybean varieties' growth and production by soaking using paclobutrazol. *Jurnal Agronomi Tanaman Tropika (JUATIKA), 7*(1). https://doi.org/10.36378/juatika.v7i1.3924

Syarifuddin, A., Wibowo, F. A. C., Yusuf, S. A., & Sulistyono, A. D. (2021). Hubungan faktor abiotik terhadap jumlah klorofil dan stomata (ekofisiologis) pada tanaman jati (*Tectona grandis* L. f.) di Kabupaten Malang. *Jurnal Penelitian Hutan Tanaman, 18*(1), 51–64. https://doi.org/10.59465/jpht.v18i1.804

Tirono, M. (2022). The use of a time-changing magnetic field to increase soybean (*Glycine max*) growth and productivity. *International Journal of Design & Nature and Ecodynamics, 17*(5), 737–743. https://doi.org/10.18280/ijdne.170511

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

Ullrich, V., & Apell, H.-J. (2021). Electromagnetic fields and calcium signaling by the voltage dependent anion channel. *Open Journal of Veterinary Medicine, 11*(1), 57–86. https://doi.org/10.4236/ojvm.2021.111004

Wahyuni, I. T., & Setiarso, P. (2022). Karakterisasi elektrokimia ekstrak klorofil dari daun salam (*Syzygium polyanthum*) pada pH basa sebagai sensitizer pada dye-sensitized solar cell (DSSC). *ALCHEMY: Journal of Chemistry, 10*(2), 41–47. https://doi.org/10.18860/al.v10i2.14109

Wallis, T. E. (1965). *Analytical microscopy: Its aims and methods in relation to foods, water, spices and drugs*. Little, Brown.