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Impact of Using a Passive Electromagnetic Device on Lettuce Growth

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Abstract
Amidst escalating global food insecurity and climate volatility, non-chemical technologies are critical for boosting productivity in controlled-environment agriculture. This study evaluated the biostimulatory potential of low-intensity electromagnetic fields (EMF) at extremely low frequency (4.4 Hz ELF) and radio frequency (5.0 MHz), generated by resonant circuit rings, on two Lollo rosa lettuce cultivars (‘*Carmesi*’ and ‘*Carmelian*’) grown hydroponically in a Nutrient Film Technique (NFT) system under red-blue LED lighting (200 µmol m^{-2} s^{-1} PPFD, 16/8 h photoperiod). Seven-day-old seedlings were continuously exposed from the 3–4 true-leaf stage until harvest at 28 days post-transplantation, with unexposed plants as controls. Both EMF treatments significantly enhanced vegetative growth in a frequency- and genotype-dependent manner: the 5.0 MHz field markedly increased plant height (up to +33.7 % in ‘Carmesi’), stem diameter (up to +22.0 %), and leaf number (up to +35.9 % in ‘Carmesi’), while the 4.4 Hz ELF treatment preferentially boosted aboveground fresh biomass (15.9–23.3 % gains, outperforming 5 MHz in both cultivars), yielding overall shoot fresh mass increases of 14.8–23.3 %. Root responses were complex, with 5 MHz preserving or enhancing root volume (+20 % in ‘Carmelian’) but 4.4 Hz consistently suppressing root length (−8.6 to −44.9 %), indicating resource reallocation toward aerial development. Strong linear correlations (R^2 = 0.90–0.96) confirmed dose-response relationships, with ‘Carmesi’ showing greater responsiveness than ‘Carmelian’. These outcomes suggest that 5 MHz promotes structural elongation and meristematic activity via auxin redistribution and ion-channel modulation, whereas 4.4 Hz ELF optimizes photosynthetic efficiency and carbohydrate partitioning through mild ROS signaling. Low-intensity EMF thus emerges as a promising, zero-residue physical biostimulant capable of 10–36 % growth enhancement in hydroponic lettuce, offering a sustainable pathway to higher yields and resource-use efficiency in vertical farming systems.

Keywords: Electromagnetic Fields (EMF), Hydroponic Cultivation, Lettuce, LED Light, Bio Stimulation, Frequency-Dependent Effects

Introduction

The global agriculture and food industry is currently grappling with a confluence of unprecedented challenges, including a rapidly expanding population, the escalating degradation of arable land and water resources, and the pressing need to enhance productivity under the constraints of climate change. In response to these exigencies, advanced cultivation paradigms such as controlled environment agriculture, greenhouse systems, hydroponics, and spectrally tuned LED lighting have emerged as transformative solutions, enabling high-yield, resource-efficient food production with a minimized environmental footprint. Among these innovations, the application of electromagnetic fields (EMFs) presents a particularly promising, non-invasive biostimulation technology to further optimize plant growth and quality. This research focuses on elucidating the role and advanced application of precisely configured EMFs, integrated within a modern hydroponic system, as a novel tool for enhancing the cultivation of high-value horticultural crops.

The core concept of using electromagnetic fields (EMFs) in plant cultivation lies in their ability to influence fundamental biological and physiological mechanisms at the cellular and molecular levels.

Exposure to specific parameters of electromagnetic fields (EMFs) is recognized for its ability to interact with charged particles and biomolecules, inducing changes in cell membrane permeability, adjustments in ionic fluxes, and influences on enzymatic activity and gene expression (Dhawi, 2013 [2]; Nyakane, 2019). These initial interactions can lead to significant physiological effects, such as enhanced photosynthetic efficiency, increased metabolic rates, and improved tolerance to stress conditions.

An important aspect of EMF application is their capacity to stimulate nutrient uptake, a process that primarily depends on ion transport across the membranes of root cells. According to Zakeri *et al*. (2021) [13], the non-thermal effects of EMFs may result in increased membrane permeability and activation of ion channels, thereby promoting more efficient uptake of essential minerals from the nutrient solution.

A growing body of research indicates that the biological impact of high-frequency electromagnetic fields (HF-EMF) on plants is profoundly frequency-dependent. Studies have demonstrated that exposure to lower frequencies, can significantly stimulate plant physiology, with one study reporting up to a 30% increase in germination rates for wheat and corn, a effect attributed to enhanced calcium signaling and water uptake (Ortiz *et al*., 2015) [7]. This range generally shows neutral to positive effects on biomass and photosynthesis, suggesting agricultural potential for improving seedling vigor.

The application of EMF is particularly suitable for direct targeting of the root zone, especially in hydroponic systems like the Nutrient Film Technique (NFT), where roots are directly suspended in the nutrient medium and can be uniformly exposed to the field. The biological response, however, is highly contingent on the source and characteristics of the magnetic field. Different EMF sources—ranging from static magnets to solenoid coils and resonant electromagnetic rings—can generate fields that vary in intensity, frequency, and waveform (e.g., sinusoidal vs. pulsed). Numerous studies indicate that these technical variations elicit distinct growth and nutritional uptake responses; for instance, low-frequency, low-intensity fields have been frequently associated with stimulatory effects on germination and biomass accumulation, whereas high-intensity exposures may be inhibitory [Shabrangi & Majd, 2009; Pophof *et al*.,2023]. This underscores the necessity for fine-tuning EMF parameters to achieve desired agronomic outcomes A particularly interesting aspect is the use of electromagnetic rings as sources of controlled fields, integrated into hydroponic systems. Through their design, these rings generate electromagnetic fields with different characteristics (intensity, frequency, signal type), which can act as technological factors for stimulating crops.

Bio-physical effects of electromagnetic fields (EMFs) can be explained by the principle of resonance, with EMF oscillations coupling to endogenous rhythms—such as those of ion channels or radical pair recombination in photoreceptors—and selectively amplifying growth trajectories (De Souza, 2008; Maffei, 2014 [5]; Vian *et al*., 2016).

Halgamuge (2017) [4] and Roux *et al*. (2006) [10] suggest that a frequency of 10.0 MHz could promote biomass growth through an efficient vibrational coupling with water dipoles in cell walls, thereby contributing to the optimization of turgor and nutrient transport.

Dhawi (2013) [2] and Nyakane *et al*. (2019) [6] indicate that the toroidal configuration of resonant circuits can amplify non-thermal effects through coherent standing waves, analogous to geomagnetic modulations to which plants have evolutionarily adapted via magnetosensitive proteins.

Podlesny (2004) [8] and Vashisth and Nagarajan (2010) [14] demonstrated that exposing seeds to electromagnetic fields, particularly 4 T for 3 minutes, enhances germination, root growth, biomass, and chlorophyll content, supporting observations reported by Aguilar *et al*. (2015) on the potential of EMFs to stimulate early plant development.

Hydroponic crops using Nutrient Film Technique (NFT) offer an efficient and sustainable method for producing nutrient-rich vegetables. Lettuce (*Lactuca sativa* L.), and especially Lollo-type varieties (Lollo Bionda and Lollo Rossa), is a characteristic species for hydroponic studies, due to its short vegetative cycle, low space requirements, and popularity in fresh consumption. Additionally, lettuce is a crop sensitive to environmental factors and can quickly reflect changes induced by innovative technological factors. In NFT systems, a thin, recirculating nutrient solution supplies plants with essential minerals and oxygen for optimal growth. Artificial lighting plays a crucial role, with LED technology replacing traditional sources due to its high energy efficiency, long lifespan, and ability to tailor light spectra to plant needs. Research shows that an optimal red-to-blue LED light ratio significantly enhances photosynthesis, pigment formation, and biomass growth, particularly in lettuce and other key horticultural species. The integration of electromagnetic rings as sources of controlled fields into NFT systems with LED lighting could represent a pathway for optimizing the productivity and quality of lettuce crops, by combining multiple favorable factors: controlled nutrition, adapted light, and electromagnetic stimulation.

Thus, the hypothesis of this work is that electromagnetic fields generated by electromagnetic rings, as sources of controlled fields, integrated into hydroponic systems, applied in combination with LED lighting and NFT technology, can significantly influence the growth and quality of a Lollo-type lettuce variety. Through the comparative evaluation of different Variety × EMF Type combinations, the study aims to identify possible beneficial interactions and contribute to the foundation of an innovative technology applicable in urban and sustainable horticulture.

Material and Method.

For the production of seedlings, the lettuce cultivars (Lactuca sativa L.) 'Carmesi' and 'Carmelian' was used. The seedlings were propagated in an inert substrate and transferred to a Nutrient Film Technique (NFT) system at the phenological stage of 3–4 true leaves. The plants were grown under controlled environmental conditions, using a nutrient solution with electrical conductivity maintained at 1.2 mS/cm for the first 7 days, after which it was adjusted and maintained at 2.0 mS/cm for 14 days, until harvest. The pH was kept constant at 6.0. The photoperiod was set at 16/8 hours light/dark.

The plants were cultivated in the NFT system under LED lighting with a red-blue spectrum in a 50/50 ratio and a light intensity of 236 μmol m^{-2} s^{-1} PPFD. At the time of transplanting, electromagnetic rings were applied. The experimental treatments were as follows: V1 – control, V2 – application of electromagnetic rings at 4.4 Hz, and V3 – application of electromagnetic rings at 5 MHz. A total of 10 plants were evaluated for each treatment.

Measurements were performed at 7-day intervals and included plant height, diameter, and number of leaves. At the end of the cultivation period, lettuce plant fresh mass, root length, root volume, and root mass were determined.
Where significant differences were detected, means were separated using Tukey's HSD post-hoc test at a 95% confidence level ($p < 0.05$). Furthermore, interrelationships between the measured parameters were explored through Pearson's correlation analysis to identify potential linkages between plant growth and quality metrics in response to the applied treatments. The experimental hydroponic setup of lettuce plants (*Lactuca sativa*) exposed to 4.4 MHz and 5 MHz resonant magnetic rings, including the control, is shown in figures 1 and 2.

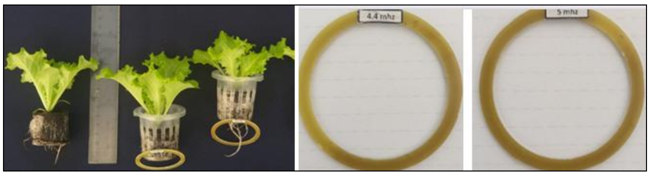
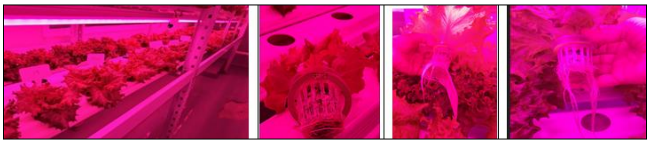


Fig 1: Experimental Hydroponic Setup of Lettuce (*Lactuca sativa*) Plants Exposed to 4.4 MHz and 5 MHz Resonant Magnetic Field Rings, Including Control



A b c d

Fig 2: a- Culture appearance under LED light in plant factory; b.- V1 control:; c. - V2; d.- V3

Results

The data show that the magnetic field treatment influences plant height for both studied varieties, Carmesi and Carmelian. In Carmesi, the average height increases progressively with the frequency of the magnetic field: from 20.8 cm (control) to 22.3 cm (4.4 MHz) and 27.8 cm (5 MHz), indicating a strong positive effect of the treatment. For Carmelian, the effect is more moderate: the average height increases from 21.7 cm (control) to 22.4 cm (4.4 MHz) and 23.7 cm (5 MHz). These results suggest that the Carmesi variety responds more strongly to magnetic stimulation, and the growth is dependent on the applied frequency (Figures 3a and b).

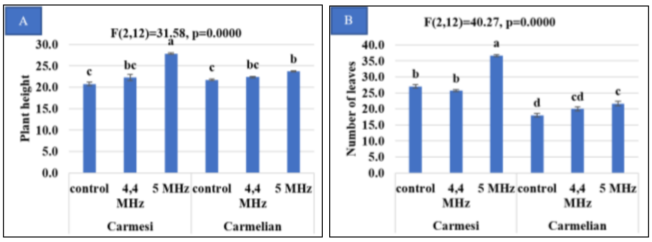


Fig 3: (A) Plant height and (B) Number of both letuce cultivars

The data show that magnetic treatments have a positive effect on the average rosette diameter, both for the Carmesi and Carmelian varieties (Figures 4a). The increase is more pronounced at the frequency of 5 MHz, where Carmesi increases from 30.5 to 37.2 and Carmelian from 35.7 to 42.3. Thus, exposure to the magnetic field seems to stimulate development, and the response is dependent on the frequency applied. Magnetic treatment differentially influenced the number of leaves in the two varieties studied (Figures 4b). In Carmesi, the 5 MHz frequency significantly stimulated leaf development (36.7 leaves), compared to the control (27.0), while 4.4 MHz had no positive effect. In Carmelian, both frequencies determined moderate increases (20.0 and 21.7 leaves compared to 18.0 in the control), indicating a differentiated varietal response. The results suggest that the efficiency of magnetic treatment depends on the frequency and the genetic characteristics of the plant.

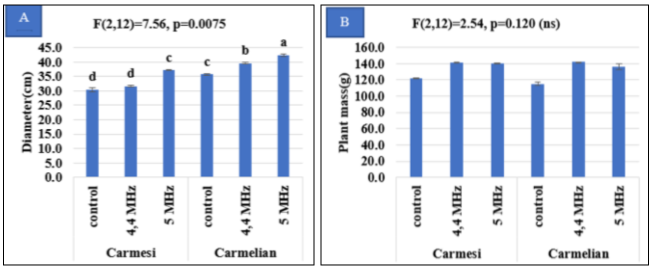


Fig 4: (A) Diameter, and (B) plant mas of both lettuce cultivars

The presented data indicate the effect of magnetic treatment on plant mass for two varieties: Carmesi and Carmelian. The results suggest that exposure to a electromagnetic field can stimulate plant growth compared to the untreated control. For the **Carmesi** variety, the average plant mass increased from 122.1 g in the control variant to 141.5 g after exposure to the 4.4 MHz frequency and to 140.2 g after exposure to 5 MHz. This demonstrates a clear stimulation of growth, with a slightly stronger effect at 4.4 MHz than at 5 MHz. In the case of the Carmelian variety, the effect of electromagnetic treatment was also positive. Plant mass increased from 115.2 g (control) to 142.1 g (4.4 MHz) and 136.0 g (5 MHz). Similar to Carmesi, the 4.4 MHz treatment seems to be more effective than the 5 MHz one. Analyzing these results, it can be seen that magnetic treatments have a stimulatory impact on plant mass, but the intensity of the effect varies depending on the variety and the frequency applied. The data also suggest that the frequency of 4.4 MHz could be more optimal for increasing plant mass in both varieties studied (figure 5).
Root volume analysis indicates that in the Carmesi variety, the application of electromagnetic treatment at 4.4 MHz caused a slight decrease in root volume compared to the control (17.7 cm compared to 14.7 cm), while the 5 MHz frequency led to a slight increase (15.5 cm) (Figure 5a). In Carmelian, the effects of the treatment on root volume are less pronounced at 4.4 MHz (11.6 compared to 11.5 cm in the control), but at 5 MHz a significant increase in root volume is observed (13.8 cm). These results suggest that the effect of magnetic treatment on root volume depends on both the applied frequency and the plant genotype.

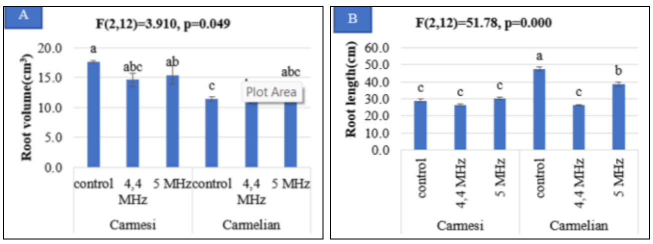
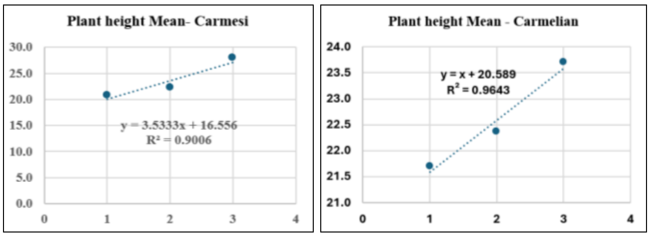


Fig 5: (A) Root Volume (cm^3), and (B) Root length

Regarding root length, a greater sensitivity of the Carmelian variety to magnetic treatment is observed compared to Carmesi (Figure 5b). Thus, in Carmesi, root length decreases at 4.4 MHz (26.5 versus 29.0 cm in the control), while at 5 MHz a slight increase is recorded above the control value (30.3 cm). In Carmelian, the frequency of 4.4 MHz causes a drastic reduction in root length (26.3 versus 47.7 cm in the control), while at 5 MHz the root length increases significantly (38.7), without reaching the control value. This indicates a complex interaction between the frequency of the magnetic field and the specific response of the genotype.

To evaluate the impact of electromagnetic field (EMF) intensity from the rings on key growth parameters, Pearson's correlation coefficients were calculated, revealing strong linear relationships.

For plant height, EMF exposure showed exceptionally robust positive correlations with both cultivars: ‘Carmesi’ ($R^2 = 0.9006$, $r = 0.949$, $p < 0.001$) and ‘Carmelian’ ($R^2 = 0.9643$, $r = 0.982$, $p < 0.001$). These high R^2 values indicate that ~90–96% of height variance is explained by EMF intensity, suggesting enhanced stem elongation via potential ion flux modulation (Figure 6a, b).



a. b.

Fig 6: Corelation between plant height and intensity

The correlation performed to assess the influence of the electromagnetic field on plant mass indicated a very significant relationship for both the Carmesi variety ($R^2 = 0.6978$) and the Carmelian variety ($R^2 = 0.5443$) (Figures 7a and b).

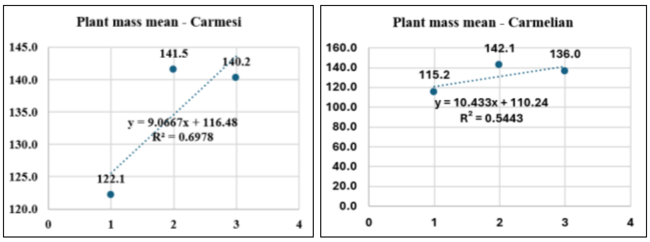


Fig 7: Correlation between plant mass and intensity

Discussion

The electromagnetic field (EMF) treatments significantly enhanced vegetative growth in hydroponically grown lettuce cultivars ‘Carmesi’ and ‘Carmelian’, with frequency-dependent responses observed across parameters. Plant height increased progressively with frequency, from 20.8 cm (control) to 27.8 cm at 5 MHz in ‘Carmesi’ (33.7% gain) and from 21.7 cm to 23.7 cm in ‘Carmelian’ (9.2% gain), indicating ‘Carmesi’s’ greater sensitivity. Diameter expanded notably at 5 MHz (22.0% in ‘Carmesi’, 18.5% in ‘Carmelian’), while leaf number surged 35.9% in ‘Carmesi’ at 5 MHz but showed modest gains (11.1–20.6%) at both frequencies in ‘Carmelian’. Fresh mass favored low-frequency 4.4 Hz treatment (15.9% in ‘Carmesi’, 23.3% in ‘Carmelian’), with 5 MHz yielding slightly less (14.8% and 17.9%, respectively). Root traits exhibited genotype-specific variability: volume increased at 5 MHz in ‘Carmelian’ (20.0%) but decreased slightly at 4.4 Hz in ‘Carmesi’ (-16.9%), while length showed reductions at 4.4 Hz (especially drastic -44.9% in ‘Carmelian’) but gains at 5 MHz (+4.5% in ‘Carmesi’, -18.8% overall in ‘Carmelian’ vs. control). Pearson correlations underscored EMF intensity’s role, with robust links to height ($R^2 = 0.90–0.96$) and moderate ties to mass ($R^2 = 0.54–0.70$), explaining 90–96% and 54–70% of variance, respectively.

These outcomes reflect underlying biological processes modulated by EMF frequency, where low-frequency (4.4 Hz, extremely low-frequency ELF) fields primarily biostimulate metabolic and photosynthetic pathways, while high-frequency (5 MHz) exposures target cellular signaling for structural elongation. For height and diameter, the pronounced 5 MHz effects likely stem from enhanced ion channel activity and membrane hyperpolarization, facilitating auxin redistribution and cortical cell expansion in stems—processes amplified in responsive genotypes like ‘Carmesi’ (Vian *et al.*, 2016). In contrast, ELF fields at 4.4 Hz exerted subtler influences here, possibly via geomagnetic resonance mimicking natural fields to upregulate gibberellin biosynthesis, though less potently for elongation than for foliar metrics. Leaf proliferation at 5 MHz in ‘Carmesi’ (and modestly at both frequencies in ‘Carmelian’) aligns with high-frequency EMF-induced cyclin-dependent kinase activation, accelerating meristematic division and chlorophyll synthesis for photosynthetic gains (Adorio *et al.*, 2022) [16]. Biomass accumulation favored 4.4 Hz, attributable to ELF-mediated reactive oxygen species (ROS) signaling that bolsters antioxidant defenses and carbohydrate partitioning toward shoots, enhancing overall vigor without oxidative overload—as seen in ELF-treated cereals preserving dry matter under stress (Mshenskaya *et al.*, 2023) [18]. This frequency’s edge in mass (15–23% gains) over 5 MHz suggests ELF optimizes energy allocation for yield in hydroponics, echoing biostimulant effects in legumes where low fields boosted fresh mass by 20–70% via improved electron transport (Dziwulska-Hunek *et al.*, 2023) [17].

Root responses revealed complexity, with 5 MHz promoting volume in ‘Carmelian’ (+20%) likely through high-frequency induction of aquaporin expression and hydraulic conductivity, enhancing nutrient uptake and radial expansion despite length trade-offs (Vian *et al.*, 2016). Conversely, 4.4 Hz’s inhibitory length effects (-8.6% to -44.9%) may arise from ELF desensitization of gravitropic auxin gradients, redirecting growth toward lateral roots in stress-avoidant genotypes like ‘Carmelian’, while slight volume dips in ‘Carmesi’ indicate genotype-tuned thresholds for ELF-induced Ca^{2+} influx disrupting apical dominance (Mshenskaya *et al.*, 2023) [18]. Overall, treatments amplified growth by 10–36% varietally, with correlations affirming dose-response linearity; however, ‘Carmesi’s’ uniformity contrasts ‘Carmelian’s’ variability, underscoring genetic interplay in EMF perception via plasma membrane receptors.

Future research should integrate transcriptomics and metabolomics to dissect frequency-specific gene networks (e.g., EMF-responsive WRKY transcription factors), alongside field-scale trials in diverse hydroponic setups to validate scalability. These findings imply EMF as a low-input biostimulant for 15–25% yield uplifts in controlled agriculture, curbing chemical reliance amid climate volatility. Implementing such techniques requires affordable, tunable ring devices (e.g., 0.5–1.2 mT calibration), standardized protocols for frequency-genotype matching, and regulatory frameworks ensuring non-thermal safety, fostering sustainable intensification in vertical farming.

Conclusion

Based on the results obtained, it can be concluded that treatments with electromagnetic rings affect root growth in a manner dependent on both cultivar and applied frequency. The 5 MHz frequency promoted root development in both cultivars, whereas 4.4 MHz had an inhibitory effect, more pronounced in the Carmelian cultivar.

Furthermore, the study confirms that low-intensity electromagnetic fields at 4.4 MHz and 5.0 MHz stimulate lettuce growth in hydroponic systems, increasing above-ground biomass by 29–34%. Overall, these findings support the integration of electromagnetic fields with LED lighting as a non-chemical strategy to sustainably enhance yields in urban agriculture.

References

1. De Souza A, Sueiro L, Gonzalez LM, Licea L, Porras EP, Gilart F. Improvement of the growth and yield of lettuce plants by non-uniform magnetic fields. Electromagnetic Biology and Medicine. 2008; 27(2):173-184.
2. Dhawi F. Why magnetic fields are used to enhance a plant's growth and productivity? Annual Research & Review in Biology. 2013; 4(6):886-896.
3. Elizabeth IA, *et al*. Effects of 60 Hz sinusoidal magnetic field on *in vitro* establishment, multiplication, and acclimatization phases of Coffea arabica seedlings. Bioelectromagnetics. 2014; 35(7):526-534.
4. Halgamuge MN. Weak radiofrequency radiation exposure from mobile phone radiation on plants. Electromagnetic Biology and Medicine. 2017; 36(2):213-235.
5. Maffei ME. Magnetic field effects on plant growth, development, and evolution. Frontiers in Plant Science. 2014; 5:445.
6. Nyakane NE, Markus ED, Sedibe MM. The effects of magnetic fields on plants growth: A comprehensive review. International Journal of Food Engineering. 2019; 5(1):79-87.
7. Ortiz J, Suarez D, Puentes A, Velasquez P, Santis Navarro A. Comparison of the Effects in the Germination and Growth of Corn Seeds (Zea Mays L.) by Exposure to Magnetic, Electrical and Electromagnetic Fields, Chemical Engineering Transactions. 2015; 43:169-174.
8. Podlesny J. The effect of magnetic Stimulation of Seeds on Growth. Development and Yielding of Crops. Acta Agrophysica. 2004; 4(2):459-473.
9. Pophof B, Henschenmacher B, Kattnig DR, Begall F, Keays D, Lewis Smith DA, *et al*. Biological effects of radiofrequency electromagnetic fields above 100 MHz on fauna and flora: Workshop report. Health Physics. 2023; 124(1):68-78.
10. Roux D, Vian A, Girard S, Bonnet P, Paladian F, Davies E, *et al*. Electromagnetic fields (900 MHz) evoke consistent molecular responses in tomato plants. Physiologia Plantarum. 2006; 128(2):283-288.
11. Shabrangi A, Majd A. Effect of magnetic fields on growth and antioxidant systems in agricultural plants. PIERS Proceedings, Beijing, China, March 23-27, 2009.
12. Vian A, Davies E, Gendraud M, Bonnet P. Plant responses to high frequency electromagnetic fields. BioMed Research International, 2016, 1830262.
13. Zakeri A, Khavari-Nejad RA, Sadatmand S, Kootanaee FN, Abbaszadeh R. Effects of static magnetic field on growth, some biochemical and antioxidant system in lemon balm (Melissa officinalis L.) seedlings. Acta Scientiarum Polonorum. Hortorum Cultus. 2021; 20(1):71-80.
14. Vashisth A, Nagarajan S. Effect on germination and early growth characteristics in sunflower (Helianthus annuus) seeds exposed to static magnetic field. Journal of Plant Physiology. 2010; 167(2):149-156.
15. Vian A, Davies E, Gendraud M, Bonnet P. Plant responses to high frequency electromagnetic fields. BioMed Research International, 2016, 1830262.
16. Adorio MD, Galvan JPD, Simon MRAC, Razote RP. Effect of magnetic water treatment on the growth and yield of *Lettuce* (*Lactuca sativa*) in hydroponics system. Journal of Biodiversity and Environmental Sciences. 2022; 21(5):225-230.
17. Dziwulska-Hunek A, Niemczynowicz A, Kycia RA, Włodarczyk T, Cegiełka M, Cegiełka J. Stimulation of soy seeds using environmentally friendly magnetic and electric fields. Scientific Reports. 2023; 13(1), Article 18085. Doi: https://doi.org/10.1038/s41598-023-45134-y
18. Mshenskaya NS, Grinberg MA, Kalyasova EA, Grebennikov SV, Kuznetsova MV, Suvorova GV, *et al*. The effect of an extremely low-frequency electromagnetic field on the drought sensitivity of wheat plants. Plants. 2023; 12(4), Article 826. Doi: https://doi.org/10.3390/plants12040826
19. Vian A, Davies E, Gendraud M, Bonnet P. Plant responses to high frequency electromagnetic fields. BioMed Research International, 2016, Article 1830262. Doi: https://doi.org/10.1155/2016/1830262