Published: (November, 2025), Pages: 1–5

Original Research

Effects of Extremely Low-Frequency Electromagnetic Fields on Early Growth of *Brassica rapa* var. *rapa*

Igor Nelson[1]

[1] VortexLab,Independent Research Laboratory, Portugal Coimbra, Portugal

Abstract

Extremely low-frequency electromagnetic fields have been reported to influence plant physiology, but the effects of different field configurations remain poorly understood. This study investigated the impact of weak ELF electromagnetic fields on early growth of *Brassica rapa* var. *rapa* seedlings, comparing solenoidal and bifilar pancake coil configurations at frequencies of 7.83 Hz and 528 Hz. Seeds were germinated under controlled environmental conditions and exposed to alternating fields for 60 minutes per day over five consecutive days. Germination rates were not significantly affected by any treatment. However, all field-exposed groups exhibited enhanced shoot elongation compared to unexposed controls. Although the bifilar groups showed slightly higher mean shoot elongation, statistical analysis did not reveal significant effects of frequency or coil topology. These results indicate that weak low-frequency electromagnetic fields can enhance early vegetative development in *Brassica rapa* var. *rapa*. Future studies incorporating multiple species, additional physiological characterization and more profound exposure characterization are warranted to elucidate the underlying mechanisms and generalizability of these effects.

Keywords: Low-frequency EMF exposure, Schumann resonances, Plant growth, *Brassica rapa* var. *rapa* , Bioelectromagnetics, Shoot elongation

1. Introduction

Biological systems have evolved in constant interaction with natural electromagnetic fields, including solar radiation, the geomagnetic field, and the Earth's extremely low-frequency (ELF) oscillations (Nelson 2025). These fields are persistent environmental factors that have been present throughout the evolution of life and are known to influence various physiological processes. The Earth's ionosphere cavity supports the Schumann resonance spectrum (fundamental mode around 7.83 Hz and higher harmonics), a naturally occurring ELF background generated by global lightning activity, which has been discussed as a potential synchronizing environmental factor for biological rhythms (Nelson 2025; Cherry 2002; Volland 1995).

Several reviews report that weak ELF exposures can modulate ion transport, membrane potential, and intracellular Ca^{2+} signaling in various cell types, though these effects are generally small and often dependent on exposure parameters and biological context (Pall 2013; Panagopoulos et al. 2015; Tian 2023). Despite decades of research, the precise biophysical mechanisms remain incompletely understood.

Experimental studies have reported modest biological effects at or near Schumann's main mode (7.83 Hz), such as modulation of intracellular calcium and changes in human EEG coherence. In addition, several in vitro studies have suggested potential effects on cancer cell proliferation and signaling: for example, exposure to this frequency been shown to influence the growth of human breast cancer cells (Wang et al. 2021), and 7.83 Hz square-wave fields can inhibit B16F10 melanoma cell growth via L- and T-type calcium channels (Wang et al. 2020; Tang et al. 2019). However, results remain preliminary and not always reproducible.

Since plants are stationary and highly sensitive to environmental conditions, they serve as excellent models for studying non-thermal effects of electromagnetic fields (Vian et al. 2016).

Accumulating evidence points in the direction that non-ionizing electromagnetic fields can affect plant germination, growth, photosynthetic performance, and secondary metabolism (Vian et al. 2016; Galland and Pazur 2018; Roux et al. 2006). However, the amplitude and reproducibility of these effects vary considerably depending on field strength, frequency, and plant species (Vian et al. 2016; Maffei 2014).

Other than 7.83 Hz, the frequency 528 Hz is typically discussed in the context of acoustic (sound) rather than electromagnetic stimulation. Although popularized as a "healing frequency," empirical data are limited. One controlled human study found that listening to music tuned to 528 Hz reduced salivary cortisol and increased oxytocin compared with 440 Hz music (Akimoto 2018). Another experiment using cultured human astrocytes reported increased cell viability and decreased oxidative stress following 528 Hz sound exposure (Babayi and Riazi 2017). In rodents, prolonged 528 Hz auditory exposure is known to be associated with reduced anxiety-like behaviors and altered neuroendocrine markers (Babayi Daylari et al. 2019).

These findings pertain to acoustic bioeffects, not to ELF electromagnetic interactions, but motivate broader exploration of frequency-specific biological effects.

Several mechanisms have been proposed to explain how weak ELF fields might influence biological systems, including modulation of voltage-gated ion channels, resonance with calcium-binding kinetics, and effects on reactive oxygen species and redox signaling (Pall 2013; Binhi and Rubin 2020). Although none

Author for correspondence: Igor Nelson, Email: igornelson5@hotmail.com

© Igor Nelson, VortexLab ; available on bioRxiv

are conclusively demonstrated, such hypotheses guide alternative experimental designs.

It is important to note that Quaternionic extensions of Maxwell's equations permit mathematical solutions describing longitudinal components, but such modes remain controversial and unverified experimentally (Arbab 2022). Tesla patented a bifilar coil winding (US 512,340, 1894) which he described as enabling higher capacitance and reduced self-induction (Tesla 1894). While some later authors have speculated that Tesla's bifilar coil design might relate to longitudinal electromagnetic modes, there is no direct evidence or primary source confirming that interpretation.

In this study, 'scalar' refers strictly to the bifilar pancake coil geometry used in some exploratory literature, not to any verified distinct electromagnetic mode.

Interestingly, a small number of exploratory studies have reported biological responses to bifilar- or caduceus-coil-generated electromagnetic fields. Rein (Rein 1989) described early experiments suggesting that non-Hertzian 'scalar' electromagnetic fields might influence immune-system activity. In a subsequent theoretical contribution, Rein (Rein 1990) proposed a connection between non-Hertzian 'scalar' energy and conventional electromagnetic energy in biological systems. More recently, Rein (Rein 2012) reported immuno-enhancing effects from longitudinal electromagnetic fields generated by a caduceus coil. While these observations are intriguing, they have not been replicated under rigorous, independent conditions, the underlying physical mechanisms remain speculative, and the broader literature on electromagnetic-field bioeffects does not currently provide a robust, reproducible basis for such effects.

In this context, the present study investigates the influence of extremely low-frequency electromagnetic and bifilar ('scalar') field configurations at 7.83 Hz and 528 Hz on seed germination, shoot growth in *Brassica rapa* var. *rapa*. The effects of frequency and coil geometry on early vegetative development were evaluated by comparing solenoidal and bifilar coil topologies under identical environmental conditions. The selected frequencies (7.83 Hz and 528 Hz) represent, respectively, a natural ELF background resonance and a common "healing" frequency with reported psychophysiological effects.

2. Materials and Methods

2.1. Overview

Turnip greens (*B. rapa* var. *rapa*) seeds were germinated under controlled environmental conditions. Five groups (n = 30 per group) were maintained under identical conditions of natural light, temperature, and humidity throughout the experiment. Seeds were germinated on cotton disks placed in plastic cups, each sample initially watered with 4 mL of water on the first day and 1 mL of water per day on the following 4 days.

The experimental groups were exposed to alternating electromagnetic fields (AC) for 60 minutes per day over five consecutive days at 7.83 Hz (EMF and 'scalar') and 528 Hz (EMF and 'scalar'). All samples were kept on the same shelf throughout the experiment; during exposure periods, the experimental groups were positioned on their respective active coils, while the control group remained on the shelf approximately 4 m away from the coils. Frequencies of 7.83 Hz and 528 Hz were selected due to prior reports of biological relevance.

Samples were rotated within the same positions throughout the experiment, ensuring that each group passed through all positions to minimize positional bias. After five days, shoot length (cm) was measured using a millimetric ruler with an estimated precision of ± 1 mm, accounting for curvature and handling variability. Mean shoot length per group was calculated from germinated seedlings for statistical comparison.

2.2. Coil Configurations

Two continuous alternating current sinusoidal signals were generated using Audacity software (Audacity Team, open-source audio editor), respectively at 7.83 Hz and 528 Hz. Each frequency was supplied independently to a dedicated TDA2050-based audio amplifier. The amplifiers were connected through 3.5 mm audio jack outputs from a computer and each powered by its own power supply.

Electromagnetic Setup (Solenoidal Coil)

The first field source was a solenoidal-type coil wound with 0.20 mm enamelled copper wire, with an approximate total wire length of 100 m. The coil was wound around a circular former with an inner diameter of 5.2 cm, an outer diameter of 6.5 cm, and a coil height of 0.9 cm. The measured DC resistance of the coil was approximately 79 Ω. From the measured resistance and the resistivity of copper at 20°C, the estimated number of turns was approximately $N \approx 790$.

The coil was powered by a regulated DC supply rated at 2 V, 4.5 A and driven with a sinusoidal signal amplified by a TDA2050-based power amplifier. Two excitation frequencies were applied: 7.83 Hz and 528 Hz.

The voltage and current delivered to the coil were measured using a true RMS ammeter and an oscilloscope. At 7.83 Hz, the applied signal measured 14.3 V_{pp} and 0.317 A, while at 528 Hz, the measurements were 10.10 V_{pp} and 2.37 A, respectively.

The magnetic field was measured with a MAG3110 sensor at 7.83 Hz and was found to be approximately 1 mT at the location of the sample. Note that the sensor is not capable of measuring the magnetic field at 528 Hz.

The electric field was measured using a copper plate connected to an Arduino and was estimated to be approximately 33 V/m at 7.83 Hz and 29 V/m at 528 Hz at the sample location.

'Scalar' Setup (Bifilar Pancake Coil)

The second configuration consisted of a bifilar flat spiral (pancake) coil constructed with 1.0 mm diameter enamelled copper wire. The coil was wound as 25 turns clockwise and 25 turns counterclockwise, forming a mirrored bifilar structure. The outer diameter of the finished coil was 12.2 cm, and its measured DC resistance was approximately 0.4 Ω.

The coil was powered by an independent DC power supply rated at 2 V, 4.0 A and driven with a sinusoidal signal amplified by a TDA2050-based power amplifier. Two excitation frequencies were applied: 7.83 Hz and 528 Hz.

At 7.83 Hz, the applied signal measured 14.0 V_{pp} and 0.33 A, while at 528 Hz, the measurements were 9.8 V_{pp} and 2.40 A, respectively.

The magnetic field was found to be approximately 0.15 mT at 7.83 Hz an the location of the sample.

The electric field was approximately 8 V/m at 7.83 Hz and 23 V/m at 528 Hz at the sample location.

2.3. Results and Analysis

2.3.1. Germination Analysis

For all groups, a total of 30 seeds were planted.

As shown in Table 1, germination outcomes were analyzed separately from shoot-length measurements. A chi-square test of independence was performed on the 5×2 contingency table (germinated vs. non-germinated across groups), showing no significant difference in germination rates among treatments ($\chi^2(4) = 6.45$, $p = 0.168$). All expected cell counts were greater than 5, confirming the validity of the chi-square approximation.

These results indicate that exposure to the electromagnetic or 'scalar' fields did not significantly affect seed germination rate under the tested conditions, suggesting that subsequent differences observed in shoot growth are unlikely to result from differential germination success.

Table 1. Germination counts and chi-square test (assumed $n_{\text{planted}} = 30$ per group).

Group	n_{planted}	$n_{\text{germinated}}$	% germination
Control	30	25	83.3%
7.83 Hz EMF	30	24	80.0%
7.83 Hz 'Scalar'	30	27	90.0%
528 Hz EMF	30	20	66.7%
528 Hz 'Scalar'	30	21	70.0%

Chi-square test: $\chi^2(4) = 6.45$, $p = 0.168$ (no significant difference).

Data were analyzed using independent-samples t-tests (with unequal variances not assumed). Analyses were restricted to germinated seeds (sample sizes as shown in Table 2). Normality was evaluated using the Shapiro–Wilk test. All experimental groups except the control showed no significant deviation from normality ($p > 0.05$). Because the control group showed a departure from normality (Shapiro–Wilk $p = 0.008$), Welch's two-sample t-tests were used (robust to unequal variances and sample sizes) to compare mean shoot lengths, and confirmed all significant results using nonparametric Mann–Whitney U tests. Means $\pm$ SD, normality p-values, and both parametric and nonparametric comparisons against the control group are reported.

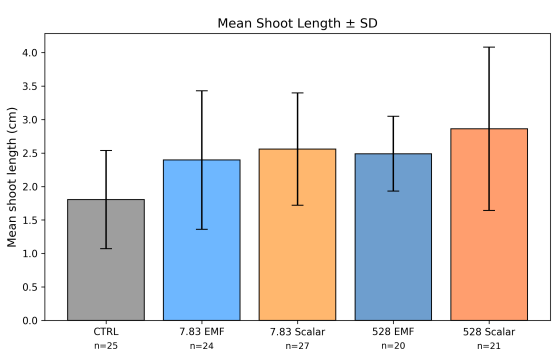

Figure 1. Mean shoot length (cm) for each experimental group. Error bars represent standard deviations. Sample sizes are shown above each bar (n = number of germinated seedlings). Groups correspond to: Control, 7.83 Hz EMF, 7.83 Hz 'Scalar', 528 Hz EMF, and 528 Hz 'Scalar'.

All field-exposed groups exhibited significantly greater shoot elongation than the unexposed control ($p < 0.05$). The strongest effect, mean increase of 59% relative to control (p = 0.0015), was observed under 'scalar' field exposure at 528 Hz (mean increase $\approx 59\%$ relative to control).

Table 2. Descriptive and inferential statistics for shoot length across treatments.

Group	Mean (cm)	SD	n	Shapiro p	t (vs CTRL)	Welch p	Mann–Whitney p
Control	1.80	0.73	25	0.008	–	–	–
7.83 Hz EMF	2.40	1.04	24	0.464	-2.30	0.0265*	0.031*
7.83 Hz 'Scalar'	2.56	0.84	27	0.185	-3.46	0.0011**	0.002**
528 Hz EMF	2.49	0.56	20	0.411	-3.57	0.0009**	0.001**
528 Hz 'Scalar'	2.86	1.22	21	0.696	-3.48	0.0015**	0.002**

2.3.2. Combined-group comparisons

To test whether the observed effects were associated with coil topology (EMF vs 'scalar') or with stimulation frequency (7.83 Hz vs 528 Hz), groups were combined accordingly and compared. Combined EMF samples (7.83 Hz and 528 Hz pooled; $n = 44$) had mean shoot length 2.439 ± 0.844 cm, while combined 'scalar' samples (pooled; $n = 48$) had mean 2.692 ± 1.023 cm. Shapiro–Wilk tests on the pooled samples indicated no departure from normality (EMF $p = 0.794$, 'scalar' $p = 0.865$), so Welch's two-sample t-test was applied and confirmed using Mann–Whitney U tests. No significant difference was observed between EMF and 'scalar' configurations (Welch $p = 0.198$, Mann–Whitney $p = 0.206$).

Similarly, pooled 7.83 Hz samples (EMF+'scalar'; $n = 51$) had mean 2.482 ± 0.931 cm, and pooled 528 Hz samples (EMF+'scalar'; $n = 41$) had mean 2.680 ± 0.963 cm. Normality was not rejected for the pooled frequency groups (7.83 Hz $p = 0.159$, 528 Hz $p = 0.862$). Welch's test and Mann–Whitney test both indicated no significant difference between frequencies (Welch $p = 0.322$, Mann–Whitney $p = 0.402$).

These results indicate that neither coil topology (EMF vs 'scalar') nor stimulation frequency (7.83 Hz vs 528 Hz) produced robust differences in mean shoot length when data were pooled across the other factor.

Table 3. Comparison of combined groups: EMF vs 'Scalar' and 7.83 Hz vs 528 Hz.

Group	Mean (cm)	SD	n	Shapiro p	Welch p	Mann–Whitney p
EMF (7.83 + 528)	2.439	0.844	44	0.794	0.1977	0.2064
'Scalar' (7.83 + 528)	2.692	1.023	48	0.865		
7.83 Hz (EMF + 'Scalar')	2.482	0.931	51	0.159	0.3223	0.4023
528 Hz (EMF + 'Scalar')	2.680	0.963	41	0.862		

3. Discussion

This study investigated the effects of weak ELF electromagnetic and 'scalar' fields on early growth of *B. rapa* var. *rapa*. Results demonstrate that while germination percentages were not significantly affected by any treatment, all field-exposed groups exhibited enhanced shoot elongation relative to the unexposed control. This finding supports the idea that weak ELF electromagnetic fields can modulate early vegetative growth under controlled environmental conditions.

Interestingly, the bifilar ('scalar') coil configurations tended to produce larger shoot elongation values compared to the corresponding EMF-only setups, despite having lower measured electric and magnetic field intensities, although these differences were not statistically significant when data were pooled. For example, at 7.83 Hz, the solenoid coil generated approximately 1 mT and 33 V/m, while the bifilar pancake coil produced only 0.15 mT and 6 V/m. These observations suggest that factors beyond simple field strength—potentially related to coil topology, field uniformity, or interactions with plant bioelectrical properties may play a role in the observed growth enhancement.

Neither coil topology (EMF vs. 'scalar') nor stimulation frequency (7.83 Hz vs. 528 Hz) produced statistically significant differences in shoot length when data were pooled, indicating that the overall effects of frequency or topology are subtle and likely context-dependent.

The mechanisms underlying these growth effects remain unclear. Given the low power levels and negligible temperature increase of the applied fields, the observed differences are unlikely to be thermal in origin. Potential explanations include modulation of ion transport, changes in membrane polarization, or resonance-like interactions near the 7.83 Hz Schumann frequency, consistent with previous studies reporting biological responses to weak ELF fields Nelson (2025); Pall (2013); Binhi and Rubin (2020). Further investigations with higher replication, individual plant imaging, and additional physiological measurements (e.g., chlorophyll content, root growth, or gene expression) are needed to clarify the mechanisms and confirm the preliminary observations reported here.

Overall, the present findings suggest that weak ELF exposures can enhance early vegetative development in *B. rapa* var. *rapa*, and that coil configuration may influence the magnitude of this effect. While the biological significance and reproducibility of these results require further study, they provide a foundation for future research exploring the influence of weak electromagnetic fields on plant development.

The exposure magnitudes and durations in this study were consistent with or lower than those used in prior plant research. For example, previous studies investigating ELF effects on seed germination and early growth often applied magnetic fields ranging from 0.1 to 5 mT for 30–120 minutes per day (Vian et al. 2016; Sarraf et al. 2020). In our experiments, the solenoidal coil generated approximately 1 mT at 7.83 Hz, while the bifilar coil produced 0.15 mT. Exposure durations of 60 minutes per day over five consecutive days fall within the lower-to-mid range of previous protocols, suggesting that the observed growth effects occurred at relatively modest field intensities and durations.

Several limitations of the current study should be acknowledged. The experiment involved a single plant species, limiting generalizability to other species. Sample sizes were modest, and no blinding was applied during measurements, introducing potential bias. Additionally, although care was taken to position control samples away from active coils, ambient electromagnetic fields in the laboratory could have contributed to background exposure.

4. Conclusions

The aim of this study was to investigate the effects of different electromagnetic frequencies and field types on the early growth of *B. rapa* var. *rapa*.

Germination percentage was not affected by any of the treatments.

All examined field-exposed groups showed increased shoot elongation relative to the control group, supporting the hypothesis that weak ELF electromagnetic fields can enhance early plant growth under controlled environmental conditions.

Due to the low power levels and negligible temperature increase of the applied fields, the observed differences are unlikely to be thermal in origin.

Although both setups operated at similar frequencies and used comparable power supplies, they exhibited markedly different electromagnetic properties. The solenoid coil generated a magnetic field of approximately 1 mT and an electric field of 33 V/m at 7.83 Hz, whereas the bifilar pancake coil produced a magnetic field of 0.15 mT and an electric field of 6 V/m, roughly 6.6 and 5.5 times weaker, respectively. Interestingly, despite the lower field intensities, the bifilar pancake coil generally promoted greater plant growth. This trend warrants further controlled investigation, as the underlying mechanism is not currently understood.

Neither coil topology (EMF vs. 'scalar') nor stimulation frequency (7.83 Hz vs. 528 Hz) produced robust differences in growth metrics, indicating that the observed effects may be subtle or mediated by complex interactions not captured in this study.

Further studies with higher replication and more detailed imaging are needed to confirm these preliminary observations and clarify the underlying mechanisms.

5. Future Work

To build on the findings reported here, future studies should incorporate electromagnetic shielding and real-time field mapping to isolate the contribution of coil geometry more rigorously. Increasing replication and including multiple plant species will help assess the generalizability of ELF and 'scalar' field effects. Additional physiological and molecular endpoints such as chlorophyll content, root development, or gene expression, should be measured to clarify the mechanisms underlying growth modulation. Longer-term experiments may also determine whether early vegetative development enhancements translate into differences in mature plant development or yield.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work the author used ChatGPT (GPT-5, OpenAI, 2025) in order to assist with background research and to improve English writing and readability. After using this tool/service, the author reviewed and edited the content as needed and takes full responsibility for the content of the published article.

Competing Interests

The author has no financial interests, commercial affiliations, or conflicts of interest to disclose.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Akimoto, T. e. a. (2018). Effects of 528 hz music on the endocrine system and autonomic function. *Health*, 10(3):115–122.

Arbab, A. I. (2022). Electrodynamics with quaternionic mass. *arXiv:2202.03200 [physics.gen-ph]*. Preprint.

Babayi, T. and Riazi, G. H. (2017). The effects of 528 hz sound wave to reduce cell death in human astrocyte primary cell culture treated with ethanol. *Journal of Addiction Research and Therapy*, 2017:1–5.

Babayi Daylari, T., Riazi, G. H., Pooyan, S., Fathi, E., and Hedayati Katouli, F. (2019). Influence of various intensities of 528 hz sound-wave in production of testosterone in rat's brain and analysis of behavioral changes. *Genes & Genomics*, 41(2):201–211.

Binhi, V. N. and Rubin, A. B. (2020). Molecular gyroscopes, biological water, and quantum effects of weak magnetic fields. *Biophysical Reviews*, 12:1031–1041.

Cherry, N. J. (2002). Schumann resonances, a plausible biophysical mechanism for the human health effects of solar and geomagnetic activity. *Natural Hazards*, 26:279–331.

Galland, P. and Pazur, A. (2018). Magnetic field effects on plant growth, development, and evolution. *Frontiers in Plant Science*, 9:181.

Maffei, M. E. (2014). Magnetic field effects on plant growth, development, and evolution. *Frontiers in Plant Science*, 5:445.

Nelson, I. (2025). Exploring the influence of schumann resonance and electromagnetic fields on bioelectricity and human health. *Electromagnetic biology and medicine*, 44(3):348–358. doi:10.1080/15368378.2025.2508466.

Pall, M. L. (2013). Electromagnetic fields act via activation of voltage-gated calcium channels to produce beneficial or adverse effects. *Journal of Cellular and Molecular Medicine*, 17(8):958–965.

Panagopoulos, D. J., Johansson, O., and Carlo, G. L. (2015). Mechanism for action of electromagnetic fields on cells. *Biochemical and Biophysical Research Communications*, 460:97–102.

Rein, G. (1989). Effect of non-hertzian electromagnetic scalar waves on the immune system. *J. U.S. Psychotronics Assoc.*, 2:15.

Rein, G. (1990). Non-hertzian scalar energy and electromagnetic energy: the biological connection. In Ellswick, S., editor, *Proc. International Tesla Soc.*, Colorado Springs, CO. International Tesla Soc.

Rein, G. (2012). Immuno-enhancing effects of longitudinal em fields generated from a caduceus coil. In *Proc. Society for Scientific Exploration*, New York.

Roux, D., Vian, A., Girard, S., Bonnet, P., Paladian, F., Davies, E., and Ledoigt, G. (2006). Electromagnetic fields (900 mhz) evoke consistent molecular responses in tomato plants. *Physiologia Plantarum*, 128:283–288.

Sarraf, M., Kataria, S., Taimourya, H., Santos, L. O., Menegatti, R. D., Jain, M., Ihtisham, M., and Liu, S. (2020). Magnetic field (mf) applications in plants: An overview. *Plants*, 9(9):1139.

Tang, J. Y., Yeh, T. W., Huang, Y. T., Wang, M. H., and Jang, L. S. (2019). Effects of extremely low-frequency electromagnetic fields on b16f10 cancer cells. *Electromagnetic Biology and Medicine*, 38(2):149–157.

Tesla, N. (1894). Coil for electro-magnets.

Tian, F. e. a. (2023). Extremely low-frequency magnetic fields modulate intracellular calcium signaling: A review. *Environmental Research*, 230:115401.

Vian, A., Davies, E., Gendraud, M., and Bonnet, P. (2016). Plant responses to high frequency electromagnetic fields. *BioMed Research International*, 2016:1830262. FEMU ID: 29052; EMF-Portal URL: https://www.emf-portal.org/en/article/29052.

Volland, H., editor (1995). *Handbook of Atmospheric Electrodynamics, Volume I*. CRC Press, Boca Raton, FL, 1st edition.

Wang, M. H., Chen, K. W., Ni, D. X., Fang, H. J., Jang, L. S., and Chen, C. H. (2021). Effect of extremely low frequency electromagnetic field parameters on the proliferation of human breast cancer. *Electromagnetic Biology and Medicine*, 40(3):384–392.

Wang, M. H., Jian, M. W., Tai, Y. H., Jang, L. S., and Chen, C. H. (2020). Inhibition of b16f10 cancer cell growth by exposure to the square wave with 7.83±0.3 hz involves l- and t-type calcium channels. *Electromagnetic Biology and Medicine*, 40(1):150–157.