The Effects of Weak Static Magnetopriming on Seed Germination and Plant Growth

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Abstract

Magnetotropism is a growing area of study, as it has shown to increase the growth and resilience of plants to external abiotic stressors. Establishing new cost-effective production methods that can contribute to the ongoing success of agricultural production is important, thus weak static/permanent magnets and their impact on seed germination and plant mass are further investigated in this study. The purpose of this study is to examine the impact of a low magnetic field preseed treatment of four types of seeds (bell peppers, cucumbers, zucchini, and wheatgrass) on seed germination and plant mass. The seeds and plants were subjected to an ex-vitro quantitative analysis after emergence and 14 days of development. Seeds were magnetized using 4x100 Gauss magnets for 1 minute, 1 hour, and 3 hours, and it was hypothesized there would be a small, but measurable increase in seed germination and plant mass. After 14 days, comparisons were made between the control and treatments on seed germination percentage and fresh plant mass. The plant's masses were compared across trials using a one-way ANOVA to test for statistical significance. Overall, this study did not support our hypothesis ($p>0.05$), however, it is believed that the static magnets used were too weak relative to other studies which did obtain a significant result.

Keywords: Magnetism; ion content; seed pre-treatment; germination; plant growth

1. Introduction

The challenge of increasing crop yield with the added pressure of climate change has driven scientists to test alternative possible methods to increase plant resilience to various external stressors. The topic of magnetotropism, which is the effect of magnetic fields on plants, has been gaining steady interest from plant scientists as a preventative treatment against droughts and climate disruptions. Numerous recent studies have shown that the magnetized pre-treatment (magnetopriming) of some seeds increases both seed germination and growth (Sarraff, 2020; Bukhari et al,. 2021; da Silva JA, 2015; Podleśna, 2019). However, all of these studies used electromagnets specifically designed to produce strong magnetic fields oscillating at ranges of x10-100 times larger than permanent and static magnetic fields of cheaper household magnets. However, one study (Katarina et al., 2017) did specify the use of very intense static magnetic fields (SMF) when treating maize and soybeans and observed a positive effect from SMF treatments on germination and salinity stress resilience. Another study (Thomas et al., 2013) performed a similar experiment with chickpeas and noted an increase in α-amylase activity which is known to catalyze seed germination. Now that it has been established that a static magnetic field can influence the biological mechanisms of a plant, the next step would be to determine why this occurs, and how low a SMF can be utilized effectively by the agricultural industry.

The exact mechanism through which magnetic fields positively influence plants remains undetermined, but it is likely to vary by plant species. It is also important to note that not all plants demonstrate this upregulation when exposed to a SMF (Turker et al., 2007; Nagy et al., 2004), with some results even showing downregulation of chlorophyll concentration in some plants. However, the plants used in this study are all believed to experience an overall upregulation. One of the main mechanisms magnetopriming is believed to benefit plants in general is by an increase in water intake followed by an increase in enzyme activity. Enzymes require water to carry out their biological functions and use it both as a substrate (ex. hydrolysis) or product (ex. esterolysis), and also to maintain its natural conformation (Rezaei et al., 2007). Furthermore, enzyme function below a determined hydration threshold of around 0.2 g/protein typically renders enzymes inactive due to their inflexibility when dried (Kurkal, 2005). It has been demonstrated through theoretical calculations that a magnetic field could contribute to increases in ion current density across a seed's cellular membrane, therefore influencing the osmotic pressure in favor of water moving into the cell (Reina et al., 2001). As previously mentioned, enzyme activity, especially α-amylase, is found to be upregulated in seeds exposed to a magnetic field, whether it be static or oscillating. The enzymes α -amylase and β-amylase play a crucial role in seed germination by converting stored starch into usable energy by the seed. Therefore, the magnetic field's effect on osmotic pressure would provide a larger volume of solvent more quickly to the seed's germination enzymes.

The studies mentioned all demonstrated significant results from either large static magnetic fields, or large electromagnetic fields. Not all plant activity measured was upregulated, but any observable downregulation implies an influence from SMFs nonetheless. The purpose of this study was to determine if it is possible to obtain any significant measurable impact on seed germination and 14 day plant dry mass using much weaker permanent (static) magnets. I hypothesize that magnetopriming seeds with weaker permanent magnets will induce a small but measurable effect on seed germination and 14 day plant mass. If seed germination and plant growth is positively impacted by magnetopriming of seeds, then we should expect to observe an increase in seed germination and 14 day plant mass after doing so.

2. Materials and Methods

2.1 Experimental set-up

Two bags of Pro-Mix Premium Potting Mix (9 L) were emptied onto a sanitized surface and mixed thoroughly by hand with gloves. The soil was spread thinly and given 48 hours to allow for any moisture to evaporate at 21 degrees Celsius. Next, biodegradable pots (175 mL) were organized into 4 groups of 12 and each was filled with 160 g of the dried soil.

The experiment consisted of a total of 3 treatments: Seeds magnetized for 60 seconds, 1 hour, 3 hours, and the untreated control. Each of the 3 treatments consisted of 3 biodegradable pots with a predetermined number of seeds as shown in Figure 1.

Different numbers of seeds were used across the 4 species of plants used. For *Capsicum annum* (bell peppers), one replicate contained one seed (12 plants total), for *Cucurbita Pepo* (zucchinis) and *Cucumis sativus* (cucumbers), one replicate contained two seeds (24 plants total) and for *Triticum aestivum* (wheatgrass), one replicate contained nine seeds (108 plants total). The number of seeds chosen for each plant type was based on the predicted final size obtained after the 14 day experimental period. Wheatgrass was given significantly more seeds per trial because of their small size in relation to each other.

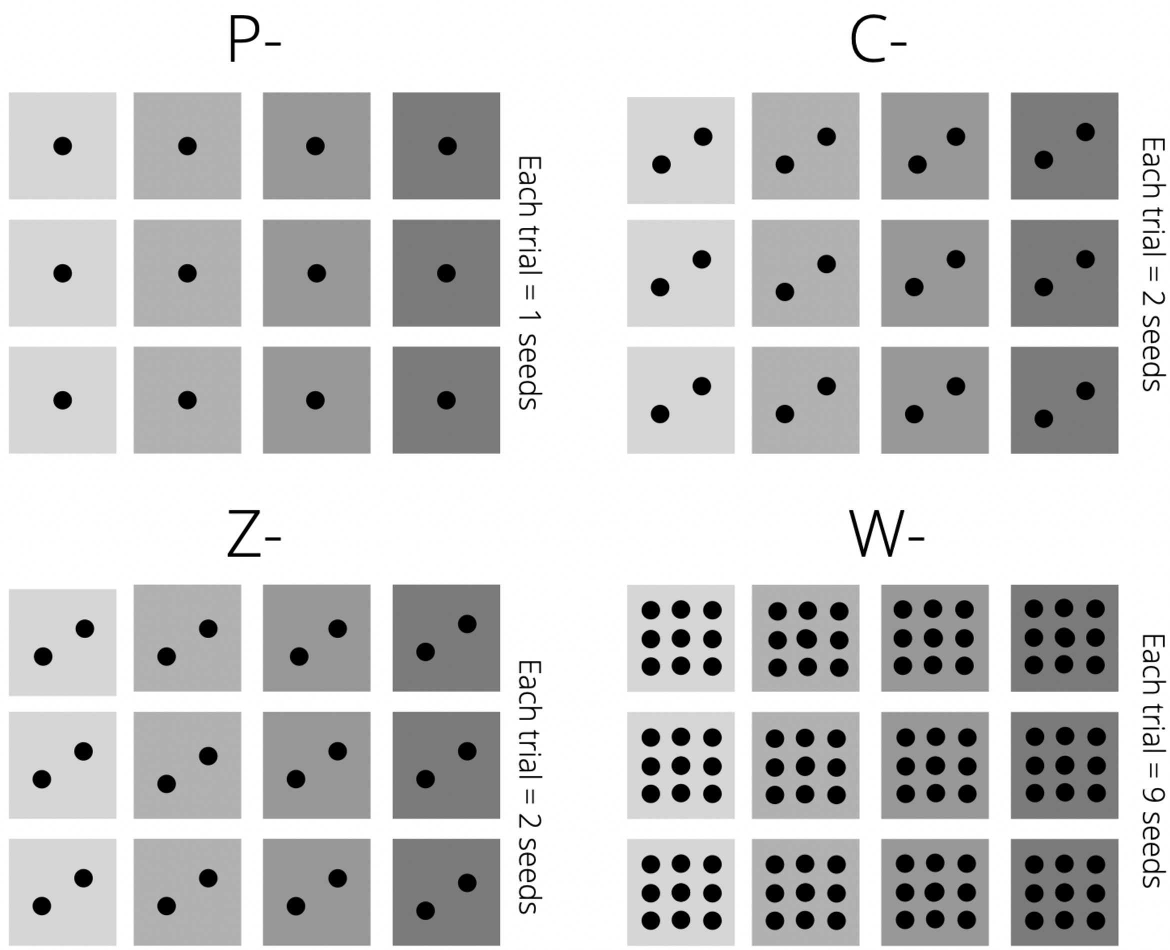


Figure 1 - Diagram representing the seed placement of the experiment. “P-" is the pepper trial, “C-” is the cucumber trial, “Z-” is the zucchini trial, “W-” is the wheatgrass trial. Each seed type had 12 pots in total, with each column (set of 3 pots) representing 3 trials of the same treatment. The first column in each (the lightest shade column) represents the untreated control, the second vertical column represents the 1 minute pre-treatment, the third for the 1 hour pre-treatment, and the last (the darkest column) represents the 3 hour pretreatment. The black dots represent the number of seeds in each trial for each seed type.

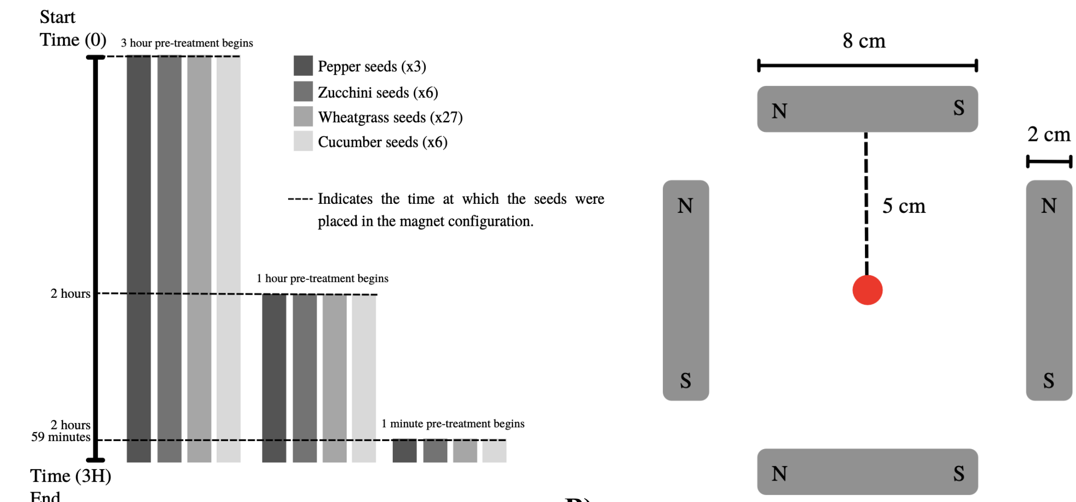
Seeds were evenly spread on a sanitized surface and only intact seeds were picked for the experiment. Of the hand-picked seeds, all were placed in a sanitized styrofoam cup and 4 groups of 27 seeds were then chosen from it at random to ensure no bias across trials. Western family distilled water (4L) was used at room temperature (21 degrees Celsius) to water all plants. On the first day, 7.5 mL of water was applied only one time to each pot. Subsequently, all pots were given 7.5 mL of water twice daily (for a total of 15 mL). Pots were watered as evenly as possible using a spoon to pour directly on the surface of the soil.

2.2 Magnetization pre-treatments

The dimensions of the magnets used were 30 x 10 x 60 mm rectangular neodymium magnets that were rated at 10 micro-teslas (μT), or 100 Gauss (G) in magnetic field strength $\vec{B}$. This measurement describes the vector field required to allow for an accurate estimate on the motion of a point charge, as predicted by the Lorentz force. Four bar magnets (with matching poles facing the same direction) were taped to the surface in a square configuration as illustrated in Figure 2B.

To determine the approximate strength of the magnetic field within the center region, I modeled the magnet as an electric dipole, consisting of two oppositely charged point charges separated by the distance L. It is important to note that no magnetic monopoles are known to exist, however, modeling the magnet as infinitesimal point charges allows for a sufficient result if we keep magnetic moment **m** constant.

The vector fields exist through a linear superposition, thus they add linearly as and the approximate field at a distance of 5cm is 400 Gauss. Seeds were placed in the center of this configuration of magnets for their allotted magnetopriming times, as represented by the time graph in figure 2.



A) B)

Figure 2 - A) A bar graph representing when the seeds were magnetoprimed ensure they all finished at the same time and thus could be planted at the same time. The first four bars represent all 4 seed types that were magnetoprimed for 3 hours. At 2 hours into their treatment, an identical

sheet of seeds was placed on top of the previous one to begin their 1 hour treatment. At 2 hours and 59 minutes from the start, a third identical sheet of seeds was placed on top to begin their 1 minute treatment. When the timer reached 3 hours, the magnets were removed and the seeds were potted in their respective pots immediately. **B)** Configuration and spacing of permanent magnets used to magnetoprime the seeds.

After seeds were treated by the magnetic field, they were immediately placed into pots following the seed configuration as per Figure 1. Seeds were placed approximately 1 inch deep into the un-packed soil (except for peppers, which were placed ½ inch deep). Seeds were buried and 7.5 mL of water was applied to the surface and the experiment commenced. Pots were placed in direct sunlight in the configuration of Figure 1 for 14 days and watered twice daily with 7.5 mL of distilled water.

2.3 Data Collection

After 14 days, dry soil was carefully removed from all biodegradable pots, leaving the above ground plant material and roots and any associated wet soil that remained attached. Next, the intact plants and associated soil were carefully removed from the pot and rinsed thoroughly using distilled water in a sanitized bowl until no dirt remained on the roots. Plants were pat dried using a paper towel and placed on a sheet of parchment paper and labeled to keep them identifiable based on their treatment. After allowing 1 hour to air dry, the plants were weighed on a Dimo's/ Labtronics 600g x 0.1g digital scale.

2.3.1 Statistical Analysis

Germination index (GI) is a measure of percentage and speed of a plant developing from a seed to a spore. It is calculated at the end of this experiment:

$$GI = \left(\frac{g}{p}\right) \times 100\% \quad (1)$$

Where,

p = The number of seeds planted in the trial

g = The number of seeds that germinated.

A higher germination index implies a more successful harvest.

Germination rate (GR) is a measure of the rate of germination in a seed:

$$Germination\,rate\,(GR) \;=\; \sum_{i-1}^{j} \frac{n_i}{D_i} \qquad (2)$$

Where,

n = The number of seeds that germinated during day *i*

D = The *i*th day

A higher germination rate can imply a more successful harvest.

The combined mass of the plants per trial was obtained and compared to determine if any noticeable differences between the 3 magnetopriming treatments occurred. The p-value was set to 0.05 and a one-way ANOVA was performed to determine whether or not any of the results were statistically significant.

3. Results

No peppers germinated throughout the entire experiment. All pots containing pepper seeds were carefully examined to find 0 germinated seeds over the 14 day period. Thus, any statistical analysis of the pepper seed data is not possible and no conclusions can be made with respect to the impact of weak magnetopriming on the germination or biomass of pepper plants.

3.1 Germination Index (GI) results

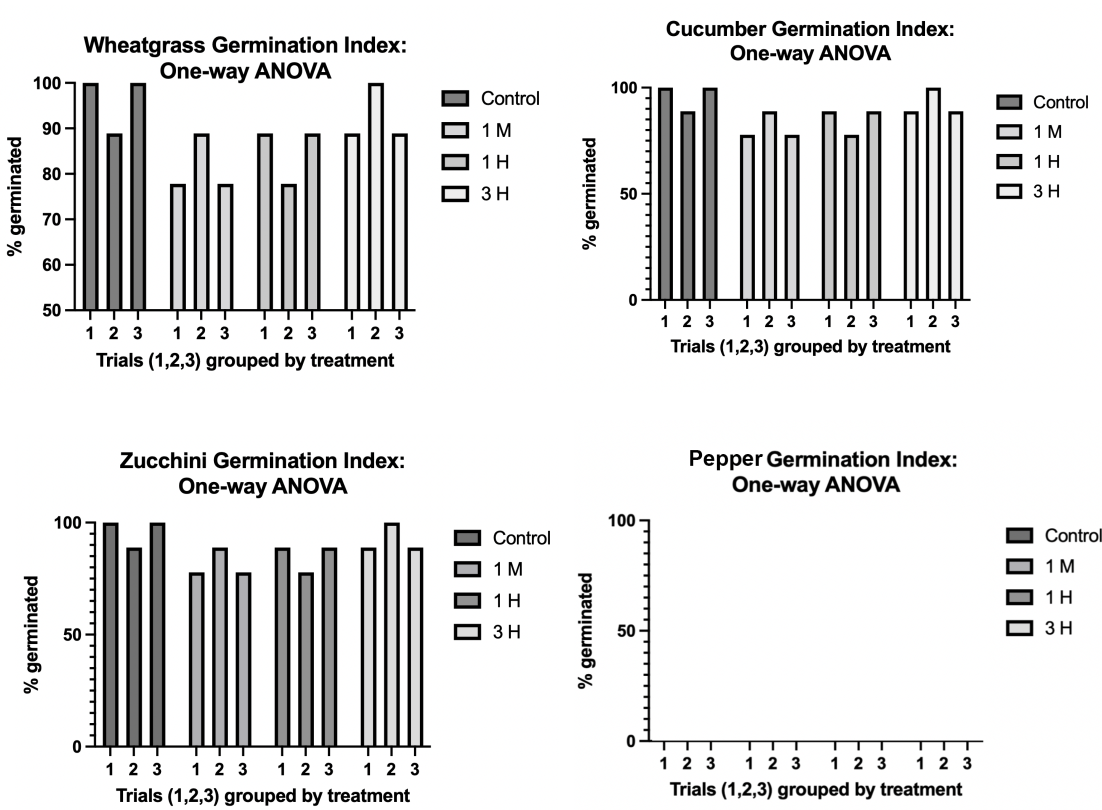


Figure 3 - Bar graphs comparing the germination percentage across trials and treatments for each seed. The p-alpha value was set to 0.05 across all treatments. Wheatgrass (N=27 per trial) one-way ANOVA result yielded p=0.077. Cucumber's (N=2 per trial) ANOVA result yielded p=0.2869. Zucchini's (N=2 per trial) one-way ANOVA result yielded p=0.1927. Pepper's (N=1 per trial) one-way ANOVA test was not undertaken due to lack of any data.

The p-value for all four plants was initially set to α=0.05 to indicate whether the results were due to change or treatment significance. The wheatgrass, cucumber, and zucchini all yielded p>0.05. The one-way ANOVA was inconclusive for the pepper plants as there was a 0% germination index for all treatments.

3.2 Plant mass results

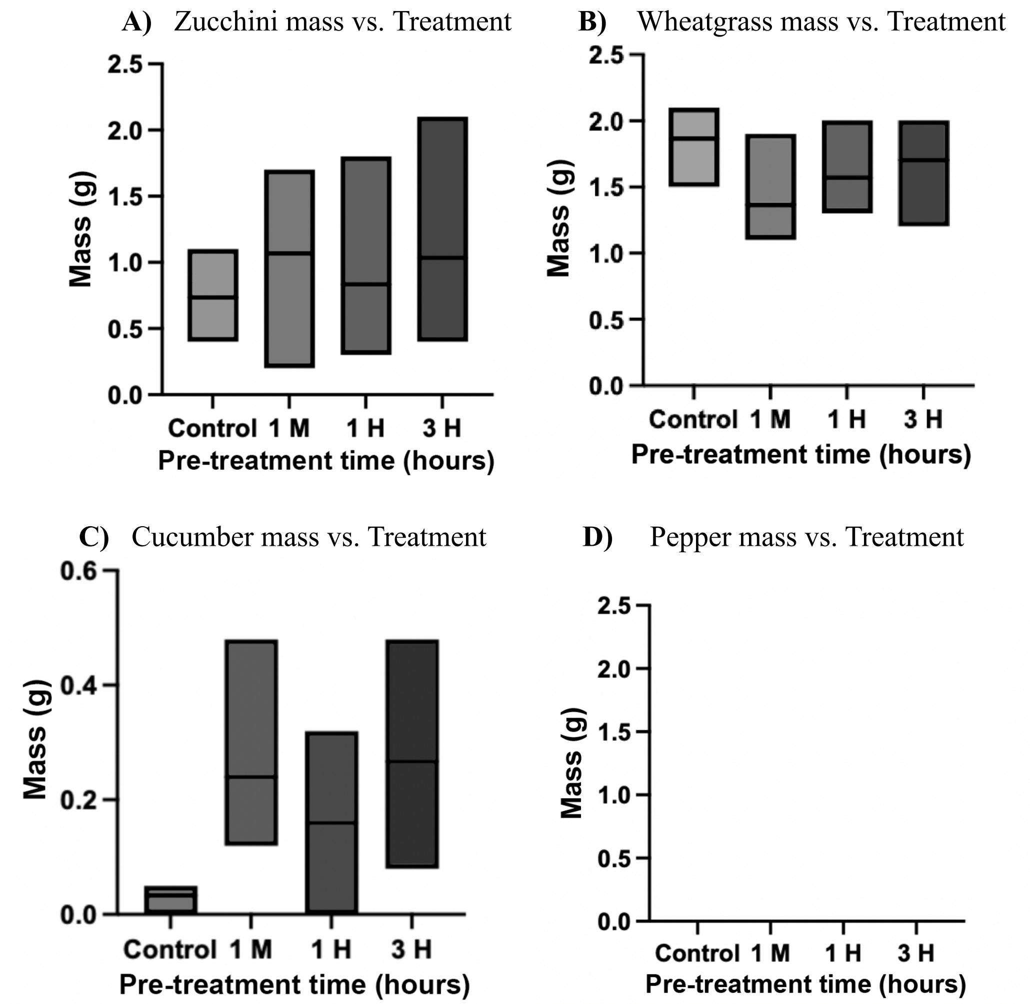


Figure 4 - **A)** The mass range of the zucchini plants per treatment. The control's masses ranged from 0.4-1.1g, the 1-minute (1M) treatment masses ranged from 0.2-1.3g, the 1-hour (1H) treatment masses ranged from 0.3-1.8g, and the 3-hour (3H) treatment masses ranged from 0.4-2.1g. **B)** The mass range of the wheatgrass per treatment. The control's masses ranged from 1.5-2.1g, the 1-minute treatment masses ranged from 1.1-1.9g, the 1-hour treatment masses ranged from 1.3-2.0g, and the 3-hour treatment masses ranged from 1.2-2.0g. **C)** The mass range of the cucumber plants per treatment. The control's mass was 0.05g, the 1-minute treatment masses ranged from 0.12-0.48g, the 1-hour treatment masses ranged from 0.16-0.32g, and the 3-hour treatment masses ranged from 0.08-0.48g. **D)** No peppers germinated during the experiment, so the mass of the plants is 0g for all trials.

The p-value for all four plants was initially set to α=0.05 to indicate whether the results were due to change or treatment significance. The zucchini plants had an average mass per treatment similar to each other, thus p=0.93. The cucumber plants showed more variation in their masses per treatment, however not a linear one as expected, and p=0.37. The wheatgrass also showed little variation in their masses, and p=0.52. The one-way ANOVA was inconclusive for the pepper plants as there was a 0% germination index for all treatments.

4. Discussion

For seed germination index (GI) comparisons, all treatments across all seed types were greater than the set alpha value of 0.05, thus implying a true null result. With a large amount of certainty, we then fail to reject the null hypothesis that 4x100 Gauss magnets used for magnetopriming would increase the germination index for cucumbers, zucchini, and wheatgrass. The pepper result remains inconclusive.

For overall plant mass, all treatments across all seed types also resulted in an ANOVA p-value greater than 0.05. Thus, we fail to reject the null hypothesis that 4x100 Gauss magnets used for magnetopriming would increase the overall plant mass for cucumbers, zucchini, and wheatgrass. The pepper result remains inconclusive.

A possible explanation for the lack of action from the pepper seeds could simply be improper storage or transportation. The fact that not 1 of the 12 seeds germinated at all over a two week period causes suspicions to arise unrelated to plant care during the actual experiment. While it's true bell peppers do take the longest to germinate of the 4 seeds, natural variation in germination rates should have caused a noticeable change in at least one of the twelve planted seeds. Since all seeds looked identical to when they were planted using ex-vitro comparison, and because they did not swell regardless of being watered for 14 days, it is more than likely that this batch of seeds was defective. Something as simple as rough handling with seed bags can damage the seed coats and embryos. Furthermore, high heat or high humidity can also significantly decrease seed germination.

To avoid situations like this, it is usually possible to order seeds from your base institution’s biological laboratory where external factors like this are kept to a minimum. This is a factor that should be accounted for when deciding to order seeds from Amazon for a scientific study. If it is unavoidable, performing a germination test prior to the experiment to test the viability of the seed would expose potential problems like this before the experiment commences.

It is important to reiterate that the experiment's non-significant results are not representative of all magnetopriming treatments as a whole. The magnets used were not only permanent and static, but they were significantly weaker than the ones used in numerous other studies (Sarraff, 2020; Bukhari et al,. 2021; da Silva JA, 2015; Podleśna, 2019) all of which demonstrated significant results. The fact that enzyme regulation was not specifically tested can be noted as a limitation to this study. It is possible that the weak magnetic field may have altered osmotic pressure, but only to a fraction of the amount it needed to to produce significant results in the wheatgrass, cucumber, and zucchini seeds.

Future experimentation using a longer experimental time (>14 days) could provide more definitive data on the pretreatment's effect on longer term plant growth rather than only on primarily germination and initial growth. For example, on average zucchini plants take 45-55 days to fully mature. If taken to full maturity another study may be done to determine differences in fruit size or flowering are observed. Furthermore, since some research indicates magnetopriming lessens the damaging effects of droughts, a longer experimental time would also allow for this to be studied.

Magnetopriming is a chemical-free, relatively inexpensive, and peer-reviewed method to increase overall health of some plants, however, only when done with a sufficiently large magnetic field. The results of this study suggest that it is insufficient to use static neodymium magnets to achieve the same effects of plant longevity as suggested by the results of others' experiments.

5. Conclusion

The purpose of this study was to determine if there would be an observable effect on germination and growth index across different plants exposed to a weak static magnetic field. It was determined that no obvious differences were noticed, and this was likely due to the low magnetic strength since numerous other studies have seen positive results.

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Data Availability

Data on the parameters from this study is available upon request from the author.

Conflicts of Interest

The author declares no conflict of interest.

References

Abdollahi, F., Niknam, V., Ghanati, F., Masroor, F., & Noorbakhsh, S. N. (2012). Biological effects of weak electromagnetic field on healthy and infected lime (Citrus aurantifolia) trees with phytoplasma. TheScientificWorldJournal, 2012, 716929. https://doi.org/10.1100/2012/716929

Abdel-Fattah Hassan Selim, Mohamed Fathi El-Nady, Physio-anatomical responses of drought stressed tomato plants to magnetic field, Acta Astronautica, Volume 69, Issues 7–8, 2011, Pages 387-396, ISSN 0094-5765, https://doi.org/10.1016/j.actaastro.2011.05.025. (https://www.sciencedirect.com/science/article/pii/S0094576511001640)

Aksenov SI, Bulychev AA, Grunina TIu, Turovetskiĭ VB. Vliianie nizkochastotnogo magnitnogo polia na aktivnost' ésteraz i izmenenie pH u zarodysha v khode nabukhaniia semian pshenitsy [Effect of a low-frequencey magnetic field on esterase activity and change in pH in wheat germ during swelling of wheat seeds]. Biofizika. 2000 Jul-Aug;45(4):737-45. Russian. PMID: 11040986.

Ananta Vashisth, Shantha Nagarajan, Effect on germination and early growth characteristics in sunflower (Helianthus annuus) seeds exposed to static magnetic field, Journal of Plant Physiology, Volume 167, Issue 2, 2010, Pages 149-156, ISSN 0176-1617, https://doi.org/10.1016/j.jplph.2009.08.011.

Ijaz, Babar & Jatoi, Shakeel & Ahmad, Dawood & Masood, Mehraj & Siddiqui, sadar-uddin. (2012). Changes in germination behavior of wheat seeds exposed to magnetic field and magnetically structured water. AFRICAN JOURNAL OF BIOTECHNOLOGY. 11. 10.5897/AJB11.2927.

Kurkal, V., Daniel, R. M., Finney, J. L., Tehei, M., Dunn, R. V., & Smith, J. C. (2005). Enzyme activity and flexibility at very low hydration. *Biophysical Journal*, *89*(2), 1282–1287. https://doi.org/10.1529/biophysj.104.058677

Maffei M. E. (2014). Magnetic field effects on plant growth, development, and evolution. Frontiers in plant science, 5, 445. https://doi.org/10.3389/fpls.2014.00445

Nagy, P., & Fischl, G. (2004). Effect of static magnetic field on growth and sporulation of some plant pathogenic fungi. *Bioelectromagnetics*, *25*(4), 316–318. https://doi.org/10.1002/bem.20015

Radhakrishnan R. (2019). Magnetic field regulates plant functions, growth and enhances tolerance against environmental stresses. Physiology and molecular biology of plants : an international journal of functional plant biology, 25(5), 1107–1119. https://doi.org/10.1007/s12298-019-00699-9

Rezaei K, Jenab E, Temelli F. Effects of water on enzyme performance with an emphasis on the reactions in supercritical fluids. Crit Rev Biotechnol. 2007 Oct-Dec;27(4):183-95. doi: 10.1080/07388550701775901. PMID: 18085461.

Sarraf, M.; Kataria, S.; Taimourya, H.; Santos, L.O.; Menegatti, R.D.; Jain, M.; Ihtisham, M.; Liu, S. Magnetic Field (MF) Applications in Plants: An Overview. *Plants* 2020, *9*, 1139. https://doi.org/10.3390/plants9091139

Shine MB, Guruprasad KN, Anand A. Enhancement of germination, growth, and photosynthesis in soybean by pre-treatment of seeds with magnetic field. Bioelectromagnetics. 2011 Sep;32(6):474-84. doi: 10.1002/bem.20656. Epub 2011 Mar 4. PMID: 21381047.

da Silva JA, Dobránszki J. Magnetic fields: how is plant growth and development impacted? Protoplasma. 2016 Mar;253(2):231-48. doi: 10.1007/s00709-015-0820-7. Epub 2015 May 8. PMID: 25952081. https://pubmed.ncbi.nlm.nih.gov/25952081/

Statscan confirms Canada's crop production down in 2021. (n.d.). Retrieved April 1, 2022, from https://www.agcanada.com/daily/statscan-confirms-canadas-crop-production-down-in-2021

Sunita Kataria, Lokesh Baghel, K.N. Guruprasad, Pre-treatment of seeds with static magnetic field improves germination and early growth characteristics under salt stress in maize and soybean, Biocatalysis and Agricultural Biotechnology,Volume 10, 2017, Pages 83-90, ISSN 1878-8181, https://doi.org/10.1016/j.bcab.2017.02.010.

Thomas, S., Anand, A., Chinnusamy, V. *et al.* Magnetopriming circumvents the effect of salinity stress on germination in chickpea seeds. *Acta Physiol Plant* 35, 3401–3411 (2013). https://doi.org/10.1007/s11738-013-1375-x

Paponov, I. A., Fliegmann, J., Narayana, R., & Maffei, M. E. (2021). Differential root and shoot magnetoresponses in Arabidopsis thaliana. Scientific reports, 11(1), 9195. https://doi.org/10.1038/s41598-021-88695-6

Podleśna, A., Bojarszczuk, J. & Podleśny, J. Effect of Pre-sowing Magnetic Field Treatment on Some Biochemical and Physiological Processes in Faba Bean (*Vicia faba*L. spp. *Minor*). *J Plant Growth Regul* 38, 1153–1160 (2019). https://doi.org/10.1007/s00344-019-09920-1

Appendix [Condensed]

Data on the parameters from this study is available upon request from the author.

Materials

Seed Type	Seed Brand	Obtained from
Wheatgrass seed	Everland Organic Red Hard Wheatberries	Amazon Canada
Bell pepper seed	Oh! Canada Seeds Non-GMO Vegetable Seed Pack	Amazon Canada
Cucumber Seed	Oh! Canada Seeds Non-GMO Vegetable Seed Pack	Amazon Canada
Zucchini seed	Oh! Canada Seeds Non-GMO Vegetable Seed Pack	Amazon Canada

Data Collections

Dry Mass Measurements

Example of one of the tables given below. Tables on zucchini, peppers, and cucumbers can be made available upon request from the author.

Wheatgrass plants

Sample (W -)	Mass* (g)	Germination %	Average GI	Total Mass (g)	Est. Ind. mass (g)	Errors
C1	1.5	9/9 = 100%	26/27 = 96.3 %	5.6	0.215	∅
C2	2.1	8/9 = 88.9%				∅
C3	2.0	9/9 = 100%				∅
1M - 1	1.1	7/9 = 77.8%	22/27 = 81.9 %	4.1	0.186	∅
1M - 2	1.9	8/9 = 88.9%				∅
1M - 3	1.1	7/9 = 77.8%				∅
1H - 1	1.4	8/9 = 88.9%	23/27 = 85.2 %	4.7	0.204	∅
1H - 2	1.3	7/9 = 77.8%				∅
1H - 3	2.0	8/9 = 88.9%				∅
3H - 1	2.0	8/9 = 88.9%	25/27 = 92.6 %	5.1	0.204	∅
3H - 2	1.9	9/9 = 100%				∅
3H - 3	1.2	8/9 = 88.9%				∅

* Mass is the combined mass of all seeds that germinated in that particular trial.

* "Est. Ind. mass" is the estimated individual mass of each plant that germinated in that particular trial.

Calculations

Germination Index (GI)

$$GI = \left(\frac{g}{p}\right) \times 100\%$$

Where,

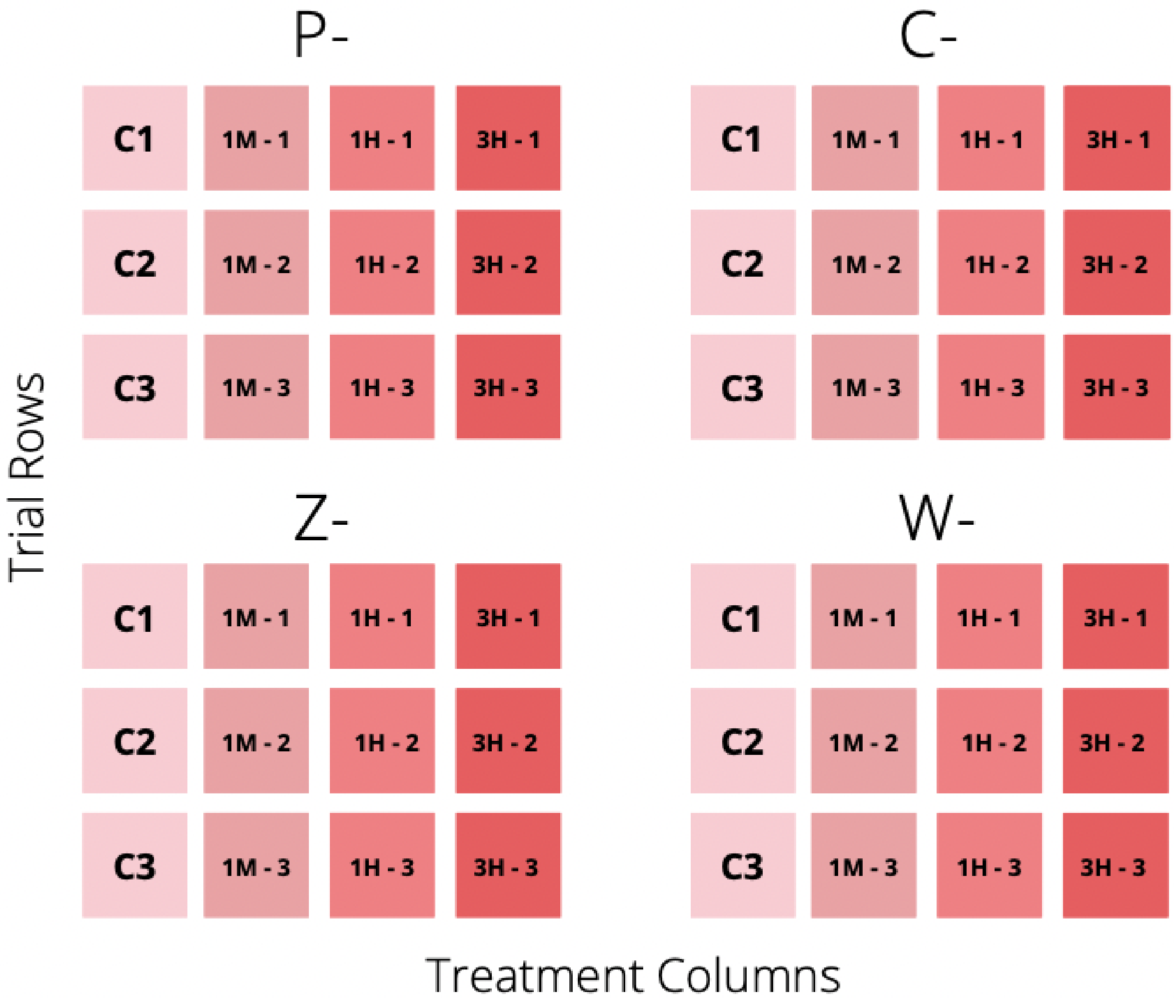
p = The number of seeds planted in the trial

g = The number of seeds that germinated.

Calculated germination index for each plant (across all trials):

Zucchini	Cucumber	Wheat grass	Peppers
p = 24 g = 18 GI = (18/24)(100) = 75%	p = 24 g = 15 GI = (15/24)(100) = 62.5 %	p = 108 g = 98 GI = (98/108)(100) = 88.9%	p = 12 g = 0 GI = (0/12)(100) = 0%

Naming Convention



P- = Pepper
C- = Cucumber
Z- = Zucchini
W- = Wheat grass

3H = 3 hour pre-treatment
1H = 1 hour pre-treatment
1M = 1 minute pre-treatment
C# = Control