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Harnessing Magnetic Fields for Sustainable Agriculture: A Study on Crop Growth, Yield, and Stress Resistance

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Abstract
Researchers have focused a great deal of emphasis on magnetic field treatment since it is an effective and clean technology with promising applications in agricultural and horticultural improvement. Relevant investigations indicate that the goal of major studies is to apply magnetic field (MF) intervention to enhance the financial attributes of both agriculture and horticulture. For instance, MF improves agricultural output and quality, germination of seeds, seedling development, and cultivation stress endurance. Recently, experts have concentrated on employing magnetized water irrigation to improve plant tolerance to stress from heavy metals. This strategy seeks to improve soil health by allowing plants to acquire heavy metals. The most widely used MF treatment techniques have been thoroughly explained in this review, along with the results of MF intervention on agricultural and horticultural crop varieties. Additionally, fresh opportunities for treating MF and its underlying molecular foundation have been revealed. Currently, there is a barrier to promoting the use of MF therapy in commercial settings due to the varying optimal dose needs for distinct species. Conducting an extensive amount of screening studies and more detailed investigation on the impact of MF upon crops is crucial for the successful deployment of MF therapies.

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Introduction

The outcomes of current scientific and technological study demonstrate that electromagnetic phenomena are present in the natural environment in conjunction with a variety of life activities. Currently, bio-magnetic technology is being utilized extensively in the domains of bio-engineering, ecological preservation, horticulture, healthcare, and agriculture, and it is garnering scientific interest and attention for research.[1] Magnetism has been extensively used in healthcare, rising to the level of specialized applications and becoming a crucial diagnostic technique. Considerable research has been done on the effect of magnetic field on crops in horticultural

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and agricultural domains. Chemical interventions applied to seeds and crops, such as fungicides, insecticides, fertilizers, biological stimulants, and more, are commonly employed in horticultural and agricultural output. They successfully guarantee crop yield, yield rate, and consistency of emergence as well as growth of plants in succeeding developmental phases. On the other hand, chemical treatment has generated debate regarding food hygiene and safeguarding the environment. The use of chemicals is being discouraged or outlawed in increasing numbers. Physical remedies like magnetic fields, microwave radiation, and laser beams have gained popularity as chemical treatment substitutes in the broader trend of environmentally conscious horticultural and agricultural production.[2-3] Even though crop commercial trait development is the primary focus of magnetic field deployment to crops, a growing number of researchers have currently focused on the use of MF therapy in the context of crop stress tolerance enhancement. The adaptation and vitality of farmed flora to a range of external stressors can be improved by magnetopriming and magnetized water (MW) treatment.[4-7] It increases the capacity of plants to aid in the restoration of soil by guaranteeing not only their capacity to endure harsh circumstances of stress but also their capacity to accumulate heavy metals when cultivated in heavy metal contaminated soil.[8-9] A study on MF remediation in this area offers a lot of promise for using plants to reduce the effect of soil polluted by heavy metal. There is a lot of research on the impact of MF on crops right now. In addition to discussing the benefits of treatment, the investigation offers some insight into the mechanics underlying it. There have been reports of instances, though, where applying MF to seeds did not work. Certain crops only show beneficial impacts within a specific range of MF strength and duration of exposure,[10-13] with weaker or even adverse consequences observed in the other spans.[14-21] The mechanism is currently being explored and requires more investigation due to the intricate relationship between the utilized MF and plants.[22] Consequently, there remains much to learn about the underlying process and macroscopic uniformity of the MF treatment's management of crop physiological functions. In the meantime, advancements in research on MF remediation will contribute to a decrease in the application of conventional chemicals in horticultural and agricultural activities. Hence, the approach holds great potential for fostering environmentally conscious agriculture and horticulture while guaranteeing food safety. First and foremost, the primary goal of this review is to bring out the findings from studies that were pertinent to plants or seeds developing pursuant to the action of MF and MW as well as the effects on enzyme function, resistance to stress, genome security, plant development, production, and quality in horticultural and agricultural crops. Furthermore, considering the prior published results, an attempt was made to clarify the molecular process pertaining to the MF contact, to evolve the physiological and biochemical consequences, to find practical applications and benefits, to address the difficulties and limitations, and to highlight upcoming research directions.

Methodology of the Review

The majority of the literature used in the article was found via Google Scholar. "Impact of MW and MF on crops," "Application of MF in agriculture and horticulture," and "Effect of magnetic field on seeds" were the search terms. This study is divided into five chapters that address issues that scholars in allied subjects should be aware of. These are: "Materials and methods," "Plant parameter improvement by magnetic field," "Molecular mechanisms underlying the reaction to magnetic field interventions," "Complexity of application," and "Conclusions and recommendations." Relevant outcomes of experiments from the gathered articles were explained thoroughly in each chapter and subchapter. Additionally, photographs and tables are used to help readers grasp and relate to the pertinent descriptions more clearly.

The articles chosen for review conformed to distinct Inclusion Criteria they encompassed studies that examined the impact of MF on various crops, explored the biological and physiological responses of plants to magnetic exposure, or evaluated the outcomes related to yield and stress resistance. Studies were excluded when they lacked empirical data and relied on anecdotal evidence. From each study selected, pertinent data were extracted—this included information on crop type, magnetic field factors (like intensity, duration of exposure, and frequency of the magnetic field), experimental design, and the observed effects on growth, yield, and stress tolerance. Furthermore, any reported limitations or challenges were noted. These data were systematically organized under different subsections. The overall findings provided valuable insights into the subject matter.

Materials and Methods

For varying applications, the fundamental parameters of MF treatment are as follows: exposure duration, rate change of MF (alternating MF), number of magnetic lines of force, and MF strength. Currently, farmed crops treated with MF can be broadly classified into three main groups.

Direct Treatment

The first approach involves directly treating seeds or plants with MF; the treatment time varies from 10 minutes to a few days, contingent upon the experimental design.[4,23-29] Both static and variable MF are acceptable forms of MF. Permanent magnets composed of iron (Fe), cobalt (Co), and nickel (Ni) alloys are the primary source of static magnetic fields (MF). Translational, gradient, and rotational MF are other forms of changing MF. According to the MF principle, the changing MF can be produced by passing electricity through a coil to create a changing MF or a current pulse through a coil to create an alternating MF.

Indirect Treatment

The second approach involves applying MF indirectly to seeds and plants. This method uses a medium that has been magnetized by MF to treat the seeds or plants instead of directly applying MF produced by a magnet. The most popular method for doing this is to apply MW to water. Water is passing through MF at a steady rate, which can cut magnetic force lines and become magnetized water (MW). The treated water is classified as primary MW, secondary MW, and so on based on how many times it passes through the entire static MF. Water can also be statically added directly to MF to obtain MW. The water treatment times vary from 10 minutes to 10 hours. After that, plant watering or seed soaking is done using the MW[5,30-36] as shown in figure 1. The duration of seed soaking in MW varies according to the species; it might take anywhere from a few hours to several days. When MW is applied to plants, the entire growing season is covered by the treatment. Nonetheless, it is important to remember a previously published study in which MW lost its magnetism after exiting the magnetic source.[37]

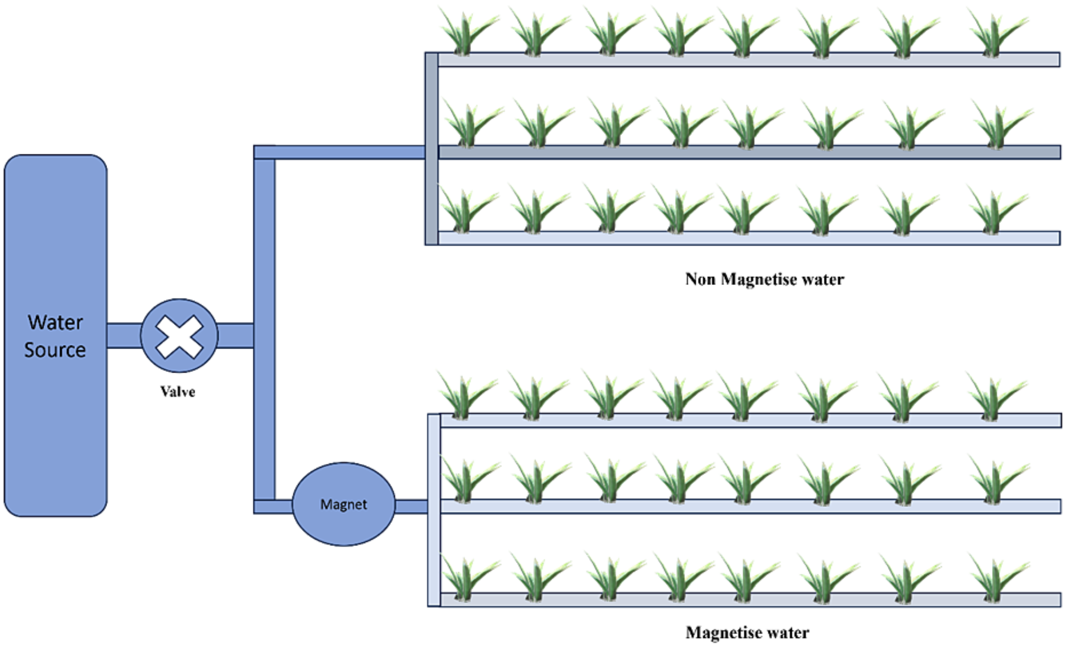

Fig. 1: The effects of Magnetic Water irrigation on plants[43]

Hybrid Treatment

Hybrid processing is used as the 3rd approach. This type of thorough treatment consists of multiple stages of MF or MW processing, hybrid application of both static and dynamic magnetic fields, and composite remedy with MW and MF.

As indicated in Table 1, some seeds, seedlings, and plants of horticultural, agricultural, and other crops are included in the research resources.

Plant Parameters Improvement By Magnetic Field

Current reports state that the following characteristics primarily represent how MF treatment affects plants:

Enhanced Germination and Seedling Growth

The primary focus of MF treatment on seed is on using MF therapy to enhance seed germination. The process by which MF treatment induces seed germination involves boosting enzyme activity, releasing dormancy, quickening water absorption, promoting protein synthesis, and raising respiration rate.[10,13,22] Numerous studies have shown that using MF treatment can significantly enhance the germination characteristics of a range of plant species. Several investigations have reported the beneficial impacts of MF on both horticultural and agricultural crops, including wheat (T. aestivum)[18, 38] rice (O. sativa),[16, 29] maize (Z. mays),[4,29] barley (H. vulgare)[24,39] common bean (P. vulgaris),[13] soybean (G. max)[1,40-41] mung bean (V. radiata),[13] head cabbage (B. oleracea var. capitata), passion fruit (P. edulis),[26] radish (R. sativus),[27] sunflower (H. annuus),[28] and cotton (Gossypium spp.).[42]

The 50 mT MF for 45 minutes produced the best results in the research study on the impact of MF on sunflower (Helianthus annuus) seeds. The treated seeds outperformed the control ones in terms of antioxidant activity and average germination rate (100 ± 0.02).[28] The study examining how MF treatment affects the dimension of rice (O. sativa) seedlings revealed that, on the third day following planting, the seedlings that were subjected to 125 mT and 250 mT MF were longer than the control seedlings by 20.67 mm and 30.61 mm, respectively.[16] The results of the study performed on faba bean (V. faba spp. minor) showed that MF treatment had an impact on germination and seedling growth; 85 mT for 15 s MF treatment produced the best results. Because of the poor success rate for germination, wide-reaching farming of medicinal plants is frequently unfeasible. In recent times, many reports suggest that MF therapy can significantly enhance the germination of Bupleurum chinense and Tetrapanax papyriferus seeds. Bupleurum chinense germination rate rose by 10.5% in comparison to control seeds following the ideal treatment of 100 mT for 55 minutes.[43] According to the study, the most effective treatment for Tetrapanax papyriferus was an electric field strength of 70 kV paired with MF strength of 1500 GS for 10 minutes. This resulted in a 52.5% boost in germination rate when compared to the control seeds.

These findings established the investigation framework for wide-scale production of medicinal plants. It was observed that in research experimenting the effects of magnetic fields on Salvia officinalis, the treated seeds (15 mT, 5 min) produced more substantial and longer radicles than the control seeds.[14]

Enhancement in Crop Yield and Quality

There are two major approaches that have been documented to be employed to boost crop production and quality with MF therapy: direct magnetic field treatment on plants or through magnetized water. These two approaches have been shown to be effective in boosting crop germination rates,[4,38] root formation,[39,44] producing robust seedlings,[4] increasing the size of leaves,[4,6,29,39] and improving stress tolerance.[13,22,45] These are significant justifications for using MF treatment to raise production and quality. Furthermore, irrigation with MW-treated water can enhance the quality of the soil,[32] alter the composition of the organisms' communities,[33-46] and hasten the substance swap and intake of nutrients between the root surface and the soil. The pertinent reports mostly focus on the following: chickpea (C. arietinum),[46] soybean (G. max),[44] mung bean (V. radiata),[13,15] barley (H. vulgare),[6] wheat (T. aestivum),[38] chickpea (H. arietinum),[4,29] sunflower (H. annuus),[21] lettuce (L. sativa), tomato (S. lycopersicum),[42] and eggplant (S. melongena).[32,36] The investigation on mung bean (V. radiata) nutrients impacted by low-frequency alternating MF employed multi-frequency (10 Hz, 50 Hz, 100 Hz) at the field intensity of about 1500 nT for 15 days. Consequently, when compared to control groups, every group receiving treatment displayed increased P and Ca levels in seed but, sprouts show enhanced Ca levels. Additionally, out of the five lines of mung bean that were chosen, sprouts obtained from the seeds that were MF treated of two of the lines exhibited the best improvements in overall protein content: 8.3% (10 Hz) and 7.2% (50 Hz), respectively.[15] In the study on the impact of magnetic field on sunflower (H. annuus), the sprouting, growth rate, and production of the sunflower were enhanced by two techniques: treating the seeds using 100 mT magnetic field for 10 minutes, then priming them using a solution of 3% moringa leaf extract made in MW.[21] Applying MF with an intensity of 200 mT for one hour produced the best possible yield for soybeans subjected to seed magnetopriming.[44]

Enhancement of Enzyme Activity

When MF is administered, carbohydrates, lipids, intracellular proteins, and other metal ions and polar molecules can all align directionally. It triggered the elemental ions of Mg, Mn, Zn, and Fe to alter the arrangement of the enzymes, changing their activity.[47] The research on enzyme activities sweep of plant by MF treatment was primarily concentrated on peroxidase (POD),[48-50] catalase (CAT)[48-49,51] and superoxide dismutase (SOD).[48-51] Part of the research was also focused on polyphenol oxidase (PPO),[48] nitrate reductase (NR),[17, 22] malate dehydrogenase (MDH),[20] ascorbic acid peroxidase (APX),[45, 48,51] glutathione reductase (GR)10 and other enzymes, which have exhibited positive feedback. Many physiological markers of plants are directly impacted by enzyme activity of plants.[13,22,45,52] Research on how MF affects enzyme activity is therefore typically included in these kinds of studies. Changes in enzyme activity induced by MF treatment constitute a potential route to obtain improved characteristics in seeds or plants. In the following chapter, they are introduced.

Improvement in Susceptibility to Environmental Stress

Plants under stress from the environment produce higher levels of reactive oxygen species (ROS), that cause peroxidative harm to the plants. Furthermore, the primary cause of the plant's premature aging is oxidative damage brought on by ROS.[53] The primary enzymes involved in removing reactive oxygen species from plants are POD, SOD, and CAT. These enzymes help plants avoid peroxidative damage by balancing their ROS levels and removing excess ROS brought on by stress.[48-51] By boosting the activity of the aforementioned enzymes, MF treatment improves the plants' capacity to remove ROS, improving their resistance to stress and anti-aging properties.[13,22,45,47] The rehabilitation of polluted soil can benefit from the impact that magnetic fields (MF) have on plants' ability to withstand heavy metal stress.[9] Cadmium (Cd) is mobilized in the rhizosphere of Sedum alfredii by dissolved organic matter (DOM) through the formation of DOM–Cd complexes. In comparison to control plants, experiments revealed that S. alfredii plants cultivated from MF-treated seeds had a greater ability to remove Cd from the soil, leading to higher Cd concentrations in plant tissues. The best course of action was a weekly 20-minute daily exposure to 150 mT magnetic fields. The amount of hydrophilic DOM, which is better at mobilizing Cd, rose from 42.7% in case of the control group to 47.2% with 150 mT of magnetic field in the rhizosphere of these treated plants.[8] According to studies on salinity stress, under different salt stress levels like 0 mM, 25 mM, 50 mM, 75 mM, and 100 mM NaCl, maize (Zea mays) cultivated from seeds exposed to a 200 mT static MF for 60 minutes showed less hydrogen peroxide levels, better photosynthetic activity, and higher yields.[4] Likewise, studies conducted on salinity-stressed soybean seeds revealed that MF treatment assisted in preserving the proper amounts of auxin (IAA), gibberellin (GA), and abscisic acid (ABA) via the signalling molecule nitric oxide. By lowering the ratio of Na+ and K+, this equilibrium lessened the detrimental impacts of salinity. By upregulating genes linked to enzymes similar to nitrate reductase and nitric-oxide synthase, and improving their activity, magnetopriming of seeds of soybean boosted the generation of nitric-oxide. When compared to control seeds, this procedure increased the tolerance index of salt in soybean seeds by 44%.[52] Furthermore, it has been observed that MF treatment improves the anti-aging potential of seeds by synchronizing the actions of peroxidase (POD), catalase (CAT), and superoxide dismutase (SOD), thereby reducing the number of free radicals. The activity of these enzymes normally falls with seed age; however, MF treatment markedly delayed this reduction. MF treatment enhanced the anti-aging properties of pepper (Capsicum Annuum) and Chinese cabbage seeds in studies. After eight days of age treatment, pepper seedlings treated with magnetic field (five times at 100 mT for two minutes each time) exhibited a 17% improvement in germination capacity compared to control seeds.[47] More so than the germination capacity, the MF treatment improved the germination rate in Chinese cabbage.

Impact on Genome Stability

Hozayn[54] examined the impact of magnetic field treatments on genome integrity in onion seedlings subjected to MF in a static magnetic device. Under all investigated settings, the meristematic cells' mitotic index rose. But concurrently, there was also a noticeable rise in the frequency of chromosomal abnormalities, albeit not fatal ones.[54] Aksoy[55] reported similar outcomes in wheat. Furthermore, according to the scientists, certain aberrations caused in seeds by MF exposure may be passed on to subsequent generations, resulting in either beneficial or faulty phenotypes.[56] The genotoxic impact of a low-frequency EM field was evaluated for both fresh and dried bean seeds in a follow-up investigation and it was seen that genome stability may have been impacted in the random amplified polymorphic DNA (RAPD) profiles.[57]

Molecular Mechanisms underlying the Response to MF Interventions

To give better rationale underpinnings for the development of individualized seed invigoration therapies, an in-depth knowledge of the molecular and cellular networks activated following exposure to MF, which are liable for the reported biological effects, is necessary. The majority of investigations on both human and animal systems have shown certain routes and targets that are highlighted by the state of the art at this time.[25] One fascinating component of MF perceptions has been proposed to arise based on the concept of the "radical pair mechanism".[58] MF sensitivity in plants has been linked to cryptochromes as a function of photoreceptors during growth. Cryptochrome regulates ROS levels and, in turn, cellular redox processes when MF is present. This mechanism influences the expression of genes and is shared by plants and animals.[59] "Molecular gyroscope mechanism" is devised to describe how MF affects biological activities. The outcome of the reaction, the quantity of gyroscopes entering the reaction, or the quantity of gyroscopes in an equilibrium condition are all linked to the biological impact. The ferritin oscillation caused by MF is the basis of the theoretical model.[18] These models all operate under the supposition that MF radiation is taken up by the cells, impacting ion mobility and uptake that play crucial roles in maintaining cellular homeostasis. There is still a dearth of knowledge regarding the MF process in plants, and the majority of published reports centre on the plant response as opposed to seed germination. The model organism Arabidopsis thaliana is used in the few papers that have so far helped to advance understanding in the field of plants. The effect of static magnetic with magnitude- and direction-dependent profiles.[25] According to transcriptomics, MF led to both PIN3 gene downregulation, which codes for an auxin efflux transporter, and overexpression of the AUX1 gene, which codes for the transporter of an auxin influx. Genes involved in nitrate transport, cell wall organization, and the flavonoid biosynthesis pathway were found to be up-regulated in the MF-tailored Arabidopsis transcriptome. The metabolomics and transcriptomics of ROS generation in the shoots and roots of Arabidopsis thaliana herbs subjected to magnetic field were investigated.[59] ROS metabolomics and transcriptomics generation in the shoots and roots of Arabidopsis thaliana plants subjected to MF were investigated.[59] In the examined tissues, there was an increase in the expression of multiple genes that code for oxygenases. These genes included AERO2, which participates in the formation of oxidative proteins in the endoplasmic reticulum, and GulLO1, which is engaged in the synthesis of the redox molecule and antioxidant l-ascorbic acid. The overexpression of encoding of genes for enzymes that produce ROS, such as respiratory burst oxidase homologs (RBOGs), was linked to progressive alterations in ROS formation in MF-treated plants.[59] The pattern of buildup of antioxidant molecules, like polyphenols, has been explained by metabolomics. Moreover, plants exposed to MF produced more H2O2, and this was linked to gradually lower amounts of polyphenols.[59] In a study with magnetoprimed seeds of soybean, it is shown that increased nitric oxide production decreased the ratio of Na+ and K+ and raised the salt resistance capacity in soybean seeds.[52] After magnetopriming soybean seeds, the genes encoding the nitric oxide-related enzymes NOS-like and NR were upregulated, and these genes' increased activity resulted in increased production of NO. The GmNOS-like 2 and GmNR1 genes are good choices for characterization regarding their role in soybean NO generation. To now, just a portion of the intricate molecular networks that underlie plant cells' reaction to MF have been made public. It is still necessary to determine the molecular factors involved in plant perception and signalling pathways, in addition to the downstream agents that support biological reactions, including expansion and defence against antioxidants. Increased endeavours are needed to learn more about the molecular responses of the seed pregerminative metabolism to MF treatments. This will enable the development of more controlled and logical magnetic field-based agri-food application protocols.

Complexity of Application

It is significant to highlight that numerous study findings indicated that various ideal MF strengths and exposure intervals were discovered for various cultivated crops and target features. Excessive strength and exposure duration of MF will result in diminished beneficial benefits and, in certain cases, even negative impacts in crops. The crops indicated in the Table 1, which include horticultural, agricultural, and herbal plants, have all shown favourable effects within specific ranges of MF level and exposure interval.

Upon reviewing the table, it should be noted that numerous researchers in the past who attempted and were unsuccessful in utilizing MF or MW in plant trials had never disclosed it. Given the advancements in technology, it may be possible to replicate some of these earlier studies. Furthermore, a lot of these publications appeared in languages apart from English, so people who exclusively follow articles published in English would not have seen them. The lack of a single primary method for applying MF in operational horticulture and agriculture, given its impact on a variety of plant organs, is another significant challenge arising from this review. Hence, in certain species, the goal of MF intervention can only be efficiently achieved by conducting a significant amount of screening trials to identify the optimal treatment settings.

Table 1: An overview of the beneficial and detrimental effects of MF treatment on a few chosen planted crops

Crop	Method Selected	Parameters	Positive Dose		Negative Dose		Reference
			M.F	Time	M.F	Time	
Lentil (Lens culinaris)	Seed MF treatment	Seedling growth, lipid peroxidation, and antioxidant enzyme activity	20 mT 20 mT	20 minutes. 25 minutes	50 mT	30 minutes	Harb[51]
Sunflower (Helianthus annuus) FH620	Seed MF treatment	Final emergence rate and average germination time	50 mT	45 minutes	80 mT 100 mT	30 minutes 15 minutes	Bukhari[28]
Sunflower (Helianthus annuus) Armoni	Seed MF treatment	1000-achene weight (Plant yield from MF-treated seeds)	100 mT	10 minutes	150 mT	10 minutes	Afzal[21]
Coffee (Coffea arabica) Catuaí Vermelho 144	Seed MF treatment	Enzyme activity - EST	28 mT	6 days	10 mT	6 days	Júnior[20]

Mung bean (Vigna radiata) line NM94	Seed MF treatment	Protein contents in sprouts	100 Hz, 1500 nT ± 250 nT 125 mT	5 hr/day for 15 days 48 hours	50 Hz, 1500 nT ± 250 nT	5 hr/day for 15 days	Nair[15]
Medicinal sage (Salvia officinalis)	Seed MF treatment	Radicle length Radicle dry weight	15 mT 15 mT 30 mT	5 minutes 5 minutes 5 minutes	3 mT 30 mT 3 mT	5 minutes 5 minutes 5 minutes	Nasiri[14]
Alfalfa (Medicago sativa)	Seed MF treatment	Growth parameters, protein contents, and enzymes activity	0.75 mT	30 min/day for 4 days	1.5 mT	30 min/ day for 4 days	Khaledi[17]
Wheat (Triticum aestivum) Alborz	Seed MW treatment (distilled water)	Seed germination Root length, shoot length, and seedling vigour index	400 mT 600 mT 400 mT 500 mT	30 minutes 30 minutes 30 minutes 30 minutes	500 mT 501 mT 600 mT	30 minutes 30 minutes 30 minutes	Massah[18]
Soybean (Glycine max) JS-335	Seed MF treatment	Percentage and speed of germination	200 mT	60 minutes	250 mT 300 mT	90 minutes 90 minutes	Shine[40]
Ryegrass (Lolium perenne) Accent	Seed MF treatment	Seed germination capacity	1000 Gs, 1500 Gs 2000 Gs	30 minutes. 30 minutes 30 minutes	2500 Gs	30 minutes	Tang[8]
Head cabbage (Brassica oleracea var. capitata) Wanfeng	Seed MF treatment	Seed germination	1000–3500 Gs	1–6 minutes	Over 3500 Gs	over 6 minutes	Cui[32]
Cauliflower (Brassica oleracea L. var. botrytis) Xueling 1	Seed MF treatment	Enzyme activity - POD	3000 Gs	8 hours	3500 Gs 3500 Gs	8 hours 12 hours	Cui[32]
Cucumber (Cucumis sativus) Shandong Mici	Seed MF treatment	Seed germination capacity	0.5 T 1.0 T 1.5 T	(5, 10 minutes) (5, 10 minutes) (5, 10 minutes)	2.0 T	(5, 10 minutes)	Feng[47]

Discussion

The use of magnetic field in horticulture and agriculture has received growing interest in recent years, particularly in the area of MF intervention on germination of seed and seedling development. In the application investigation of MF impacts on seeds, we can achieve favourable results and revenue enhancement after conducting numerous screening experiments to find the ideal dosage for specific species and cultivars. This is the primary obstacle that stands in the way of commercialization of MF in agriculture and horticulture. The majority of the work done thus far in the practical study of MF impacts has been on enhancing economic characteristics and raising economic output. Simultaneously, a growing number of studies are emphasizing the application of MF therapy or MW irrigation to enhance plant resilience to stress under heavy metal or salt pressures, with the goal of achieving soil restoration through the accumulation of heavy metals in plants. Numerous findings suggest that MF treatment can effectively boost a plant's resistance to a variety of environmental challenges at the moment. They have all demonstrated the possibility of using MF in this field and offered fresh, eco-friendly suggestions for protecting the environment and restoring soil. Furthermore, findings on the anti-aging properties of seeds due to magnetic fields also suggest that MF treatment could have technological use in seed storage. The current expense of machinery to generate magnetic field, as well as the moderate improvement in plant growth characteristics found in some study of the review paper, limit the wider implementation of this technique for commercial production of plants. Future study may enable the design of more effective MF treatments for all types of plants, along with more cost-effective machinery for generation of MF.

Conclusion

Firstly, a thorough investigation of the processes underlying MF impacts on germination of seeds and the enhancement of crop development is still the focus of future studies. It would assist us in comprehending or perhaps accurately forecasting the potential improvement of the treatment-enhanced crop metrics. Secondly, more investigation and advancement regarding the application of MF to enhance plant resilience to stress are required to realize the large-scale implementation in soil remediation and environmental protection. We can improve the efficacy and targeting of MF therapy in landscape restoration and agricultural and horticultural yield by pursuing these two areas of additional research and development.

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Conflict of Interest

The authors do not have any conflict of interest.

Data Availability Statement

The data for this review are gathered from a variety of sources and are extensively cited in the tables offered in this publication. All referenced tables, containing pertinent data points, are included in the main body of the text. Readers are advised to refer to these tables for more information on the sources and data used in this research. Additional questions about specific data points can be forwarded to the respective author.

Ethics Approval Statement

This review study does not include any experiments on humans or animals. This study does not require official ethics approval.

Author Contributions

The sole author was responsible for the conceptualization, methodology, data collection, analysis, writing, and final approval of the manuscript.

References

1. Radhakrishnan R. Seed pretreatment with magnetic field alters the storage proteins and lipid profiles in harvested soybean seeds. *Physiology and Molecular Biology of Plants.* 2018;24(2):343-347. doi:10.1007/s12298-018-0505-8
2. Kuper R. European Agriculture in the Crucible of the WTO. *Capitalism Nature Socialism.* 2007;18(3):68-80. doi:https://doi.org/10.1080/10455750701526351

3. Chen HH, Chang HC, Chen YK, Hung CL, Lin SY, Chen YS. An improved process for high nutrition of germinated brown rice production: Low-pressure plasma. *Food Chemistry.* 2016;191:120-127. doi:https://doi.org/10.1016/j.foodchem.2015.01.083
4. Baghel L, Kataria S, Jain M. Mitigation of adverse effects of salt stress on germination, growth, photosynthetic efficiency and yield in maize (Zea mays L.) through magnetopriming. *Acta Agrobotanica.* 2019;72(1). doi:https://doi.org/10.5586/aa.1757
5. Hasan M, Alharby HF, Md. Nashir Uddin, et al. Magnetized Water Confers Drought Stress Tolerance in *Moringa* Biotype via Modulation of Growth, Gas Exchange, Lipid Peroxidation and Antioxidant Activity. Pol. J. Environ. Stud. 2020;29(2):1625-1636. doi:https://doi.org/10.15244/pjoes/110347
6. Mahmoud Hozayn, Anis Elaoud, Attia A, Nahla Ben Salah. Effect of magnetic field on growth and yield of barley treated with different salinity levels. *Arabian Journal of Geosciences.* 2021;14(8). doi:https://doi.org/10.1007/s12517-021-07077-4
7. Juhie Joshi-Paneri, Sharma S, Guruprasad KN, Kataria S. Enhancing the Yield Potential of Soybean after Magneto-Priming: Detailed Study on Its Relation to Underlying Physiological Processes. *Seeds.* 2023;2(1):60-84. doi:https://doi.org/10.3390/seeds2010006
8. Tang Y, Ji S, Chen D, Wang J, Cao M, Luo J. Effects of Magnetically Treated Sedum Alfredii Seeds On The Dissolved Organic Matter Characteristics of Cd-Contaminated Soil During Phytoextraction. *Research Square (Research Square).* 2021;2. doi:https://doi.org/10.21203/rs.3.rs-560215/v1
9. Prajapati, K., and Patel, R. (2023). Accumulation of heavy metals in soil-crop systems. *Journal of Stress Physiology & Biochemistry,* 19(2), 11–15.
10. Araújo S de S, Paparella S, Dondi D, Bentivoglio A, Carbonera D, Balestrazzi A. Physical Methods for Seed Invigoration: Advantages and Challenges in Seed Technology. *Frontiers in Plant Science.* 2016;7. doi:https://doi.org/10.3389/fpls.2016.00646
11. Farooq M, Usman M, Nadeem F, et al. Seed priming in field crops: potential benefits, adoption and challenges. *Crop and Pasture Science.* 2019;70(9):731. doi:https://doi.org/10.1071/cp18604
12. Rifna EJ, Ratish Ramanan K, Mahendran R. Emerging technology applications for improving seed germination. *Trends in Food Science & Technology.* 2019;86:95-108. doi:https://doi.org/10.1016/j.tifs.2019.02.029
13. Sarraf M, Kataria S, Taimourya H, et al. Magnetic Field (MF) Applications in Plants: An Overview. *Plants.* 2020;9(9):1139. doi:https://doi.org/10.3390/plants9091139
14. Abdani Nasiri A, Mortazaeinezhad F, Taheri R. Seed germination of medicinal sage is affected by gibberellic acid, magnetic field and laser irradiation. *Electromagnetic Biology and Medicine.* 2018;37(1):50-56. doi:https://doi.org/10.1080/15368378.2017.1336100
15. Nair RM, T. Leelapriya, K.S.Dhilip, V.N. Boddepalli, Ledesma DR. Beneficial effects of Extremely Low Frequency (ELF) Sinusoidal magnetic field (SMF) exposure on mineral and protein content of mungbean seeds and sprout. *Indian journal of agricultural research.* 2018;52(2). doi:https://doi.org/10.18805/ijare.a-4908
16. Florez M, Alvarez J, Martinez E, Carbonell V. Stationary Magnetic Field Stimulates Rice Roots Growth. *Romanian Reports in Physics.* 2019;71:713. https://rrp.nipne.ro/2019/AN71713.pdf
17. Kazemi Khaledi N, Saadatmand S, Khavari-Nejad RA, Nejadsattari T. Responses of alfalfa influenced by magnetic field and rhizobial inoculant. *Iranian Journal of Plant Physiology.* 2019;9(4):2963-2970.
18. Massah J, Dousti A, Khazaei J, Vaezzadeh M. Effects of water magnetic treatment on seed germination and seedling growth of wheat. *Journal of Plant Nutrition.* 2019;42(11-12):1283-1289. doi:https://doi.org/10.1080/01904167.2019.1617309
19. Migahid MM, Elghobashy RM, Bidak LM, Amin AW. Priming of Silybum marianum (L.) Gaertn seeds with H2O2 and magnetic field ameliorates seawater stress. *Heliyon.* 2019;5(6):e01886. doi:https://doi.org/10.1016/j.heliyon.2019.e01886

20. Braga Júnior RA, Azevedo RL de, Guimarães RM, Reis LV. Magnetic field in coffee seed germination. *Ciência e Agrotecnologia.* 2020;44. doi:https://doi.org/10.1590/1413-7054202044003920
21. Afzal I, Saleem S, Skalicky M, et al. Magnetic Field Treatments Improves Sunflower Yield by Inducing Physiological and Biochemical Modulations in Seeds. *Molecules.* 2021;26(7):2022. doi:https://doi.org/10.3390/molecules26072022
22. Radhakrishnan R. Magnetic field regulates plant functions, growth and enhances tolerance against environmental stresses. *Physiology and Molecular Biology of Plants.* 2019;25(5):1107-1119. doi:https://doi.org/10.1007/s12298-019-00699-9
23. HOŁUBOWICZ R, KUBISZ L, GAUZA M, TONG Y, HOJAN-JEZIERSKA D. Effect of Low Frequency Magnetic Field (LFMF) on the Germination of Seeds and Selected Useful Characters of Onion (*Allium cepa* L.). *Notulae Botanicae Horti Agrobotanici Cluj-Napoca.* 2014;42(1). doi:https://doi.org/10.15835/nbha4219131
24. Migahid MM, Elghobashy RM, Bidak LM, Amin AW. Priming of Silybum marianum (L.) Gaertn seeds with H2O2 and magnetic field ameliorates seawater stress. *Heliyon.* 2019;5(6):e01886. doi:https://doi.org/10.1016/j.heliyon.2019.e01886
25. Jin Y, Guo W, Hu X, et al. Static magnetic field regulates Arabidopsis root growth via auxin signaling. *Scientific Reports.* 2019;9(1):14384. doi:https://doi.org/10.1038/s41598-019-50970-y
26. Menegatti RD, Oliveira LO de, Lira da Costa ÁV, Bolacel Braga EJ, Bianchi VJ. Magnetic Field And Gibberelic Acid As Pre-Germination Treatments Of Passion Fruit Seeds. *Revista Ciência Agrícola.* 2019;17(1):15. doi:https://doi.org/10.28998/rca.v17i1.6522
27. XIA XZ, PADULA G, KUBISZ L, HOŁUBOWICZ R. Effect of low frequency magnetic field (LFMF) on seed quality of radish (Raphanus sativus L.) seeds. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca.* 2020;48(3):1458-1464. doi:https://doi.org/10.15835/nbha48311918.
28. Bukhari SA, Tanveer M, Mustafa G, Zia-Ud-Den N. Magnetic Field Stimulation Effect on Germination and Antioxidant Activities of Presown Hybrid Seeds of Sunflower and Its Seedlings. Khan TA, ed. *Journal of Food Quality.* 2021;2021:1-9. doi:https://doi.org/10.1155/2021/5594183
29. Himoud M, Lazim S, Al-Bahadliy A. Effect of Tillage Depths and Static Magnetic Seed Treatment on Growth Parameters and Yield of Maize (L.) Zea mays. *Indian Journal of Ecology.* 2022;49(18):18-23. Accessed June 5, 2024. https://faculty.uobasrah.edu.iq/uploads/publications/1694595978.pdf
30. Chibowski E, Szcześ A. Magnetic water treatment–A review of the latest approaches. *Chemosphere.* 2018;203:54-67. doi:https://doi.org/10.1016/j.chemosphere.2018.03.160
31. Fouad Abobatta W. Overview of Role of Magnetizing Treated Water in Agricultural Sector Development. *Advances in Agricultural Technology & Plant Sciences Review Article.* 2019;2019(1):180023. Accessed June 6, 2024. https://academicstrive.com/AATPS/AATPS180023.pdf
32. Cui H, Liu X, Jing Ruyan, et al. Irrigation with Magnetized Water Affects the Soil Microenvironment and Fruit Quality of Eggplants in a Covered Vegetable Production System in Shouguang City, China. 2020; 20(4):2684-2697. doi:https://doi.org/10.1007/s42729-020-00334-7
33. Elhindi KM, Al-Mana FA, Algahtani AM, Alotaibi MA. Effect of irrigation with saline magnetized water and different soil amendments on growth and flower production of Calendula officinalis L. plants. *Saudi Journal of Biological Sciences.* 2020;27(11):3072-3078. doi:https://doi.org/10.1016/j.sjbs.2020.09.015
34. Samarah NH, Bany Hani MMI, Makhadmeh IM. Effect of Magnetic Treatment of Water or Seeds on Germination and Productivity of Tomato Plants under Salinity Stress. *Horticulturae.* 2021;7(8):220. doi:https://doi.org/10.3390/horticulturae7080220
35. Kishore G, Saxena C, Yogesh Rajwade. Magnetic treatment of irrigation water: Its effect on water properties and characteristics of eggplant (Solanum melongena. *Emirates Journal of Food and Agriculture.* 2022;34(9). doi:https://doi.org/10.9755/ejfa.2022.v34.

i9.2945

36. Mohamed TMK, Gao J, Abuarab ME, Kassem M, Wasef E, El-Ssawy W. Applying Different Magnetic Water Densities as Irrigation for Aeroponically and Hydroponically Grown Strawberries. *Agriculture.* 2022; 12(6):819. doi:https://doi.org/10.3390/agriculture 12060819
37. Martín Algarra RV, Lahuerta Zamora L, Antón Fos GM, Alemán López PA. Magnetized Water: Science or Fraud? *Journal of Chemical Education.* 2008;85(10):1416. doi:https://doi.org/10.1021/ed085p1416
38. Selim DAFH, Zayed M, Ali MME, et al. Germination, physio-anatomical behavior, and productivity of wheat plants irrigated with magnetically treated seawater. *Frontiers in Plant Science.* 2022;13. doi:https://doi.org/10.3389/fpls.2022.923872
39. Sayed H. Impact of Magnetic Water Irrigation for Improve the Growth, Chemical Composition and Yield Production of Broad Bean (Vicia faba L.) Plant. *American Journal of Experimental Agriculture.* 2014;4(4):476-496. doi:https://doi.org/10.9734/ajea/2014/7468
40. Shine MB, Guruprasad KN, Anand A. Enhancement of germination, growth, and photosynthesis in soybean by pre-treatment of seeds with magnetic field. *Bioelectromagnetics.* 2011;32(6):474-484. doi:https://doi.org/10.1002/bem.20656
41. Michalak I, Lewandowska S, Niemczyk K, et al. Germination of soybean seeds exposed to the static/alternating magnetic field and algal extract. *Engineering in Life Sciences.* 2019;19(12):986-999. doi:https://doi.org/10.1002/elsc.201900039
42. Teixeira da Silva JA, Dobránszki J. Magnetic fields: how is plant growth and development impacted? *Protoplasma.* 2015;253(2):231-248. doi:https://doi.org/10.1007/s00709-015-0820-7
43. Xia X, Pagano A, Anca Macovei, Padula G, Balestrazzi A, Hołubowicz R. Magnetic field treatment on horticultural and agricultural crops: its benefits and challenges. *Folia Horticulturae.* 2024;34(1). doi:https://doi.org/10.2478/fhort-2024-0004
44. Juhie Joshi-Paneri, Sharma S, Guruprasad KN, Kataria S. Enhancing the Yield Potential of Soybean after Magneto-Priming: Detailed Study on Its Relation to Underlying Physiological Processes. *Seeds.* 2023;2(1):60-84. doi:https://doi.org/10.3390/seeds2010006
45. Nyakane NE, Markus ED, Sedibe MM. The Effects of Magnetic Fields on Plants Growth: A Comprehensive Review. *ETP International Journal of Food Engineering.* 2019;5(1):79-87. doi:https://doi.org/10.18178/ijfe.5.1.79-87
46. Connect Journals. Connectjournals.com. Published 2024. Accessed July 12, 2024. https://connectjournals.com/03899.2022.18.47
47. Feng T, Zhang M, Mujumdar AS, Zhang L. Effect of a magnetic field/electrostatic field on the quality attributes of green bell peppers during cool chain transportation. *Sustainable Food Technology.* 2023;1(4):582-589. doi:https://doi.org/10.1039/d3fb00067b
48. Arafat, Mona, Halimeh Hassanpour, Rezayian M, Younes NA. Impact of the Static Magnetic Field on Growth, Pigments, Osmolytes, Nitric Oxide, Hydrogen Sulfide, Phenylalanine Ammonia-Lyase Activity, Antioxidant Defense System, and Yield in Lettuce. *Biology.* 2020;9(7):172-172. doi:https://doi.org/10.3390/biology9070172
49. Anand A, Kumari A, Thakur M, Koul A. Hydrogen peroxide signaling integrates with phytohormones during the germination of magnetoprimed tomato seeds. *Scientific Reports.* 2019;9(1). doi:https://doi.org/10.1038/s41598-019-45102-5
50. Kataria S, Lokesh Baghel, Jain M, Guruprasad KN. Magnetopriming regulates antioxidant defense system in soybean against salt stress. 2019;18:101090-101090. doi:https://doi.org/10.1016/j.bcab.2019.101090
51. Harb A, Alnawateer M, Abu-Aljarayesh I. Influence of static magnetic field seed treatments on the morphological and the biochemical changes in lentil seedlings (Lens Culinaris Medik.). *Jordan Journal of Biological Sciences.* 2021;14(01):179-186. doi:10.54319/jjbs/140123
52. Kataria S, Anand A, Ritesh Kumar Raipuria, et al. Magnetopriming Actuates Nitric Oxide Synthesis to Regulate Phytohormones for Improving Germination of Soybean Seeds

under Salt Stress. *Cells.* 2022;11(14):2174-2174. doi:https://doi.org/10.3390/cells11142174

53. Trends in oxidative aging theories. *Free Radical Biology and Medicine.* 2007;43(4):477-503. doi:https://doi.org/10.1016/j.freeradbiomed.2007.03.034
54. Hozayn M, Amal AAEM, Abdel Rahman HMH. Effect of magnetic field on germination, seedling growth and cytogenetic of onion (Allium cepa L.). *African Journal of Agricultural Research.* 2015;10(8):849-857. doi:https://doi.org/10.5897/ajar2014.9383
55. Aksoy H, Unal F, Ozcan S. Genotoxic effects of electromagnetic fields from high voltage power lines on some plants. *International Journal of Environmental Research.* 2010;4(4):595-606. doi:https://doi.org/10.22059/ijer.2010.245
56. Attia S, Gad N, Rahman A. Effect of Cobalt on Growth, Yield and Production Quality with Mitotic and Meiotic Divisions in Two Onion Cultivars. *Current Science International.* 2014;3(2):122-131. Accessed June 12, 2024. https://www.curresweb.com/csi/csi/2014/122-131.pdf
57. S Tajik Esmaeili. Assessment Of Dna Damage Using Random Amplified Polymorphic Dna In Vegetative-Stage Bean (Phaseolus Vulgaris L.) Grown Under A Low Frequency Electromagnetic Field. *Applied Ecology and Environmental Research.* 2017;15(4):729-739. doi:https://doi.org/10.15666/aeer/1504_729739
58. Hammad M, M. Albaqami, M. Pooam, et al. Cryptochrome mediated magnetic sensitivity in Arabidopsis occurs independently of light-induced electron transfer to the flavin. *Photochemical & Photobiological Sciences.* 2020;19(3):341-352. doi:https://doi.org/10.1039/c9pp00469f
59. Parmagnani AS, Mannino G, Maffei ME. Transcriptomics and Metabolomics of Reactive Oxygen Species Modulation in Near-Null Magnetic Field-Induced Arabidopsis thaliana. *Biomolecules.* 2022;12(12):1824-1824. doi:https://doi.org/10.3390/biom12121824