Agricultural & Forestry Economics and Management (2025)
Clausius Scientific Press, Canada
DOI: 10.23977/agrfem.2025.080119
ISSN 2616-2202 Vol. 8 Num. 1

Promotion Effects of Electromagnetic Field Treatment on Horticultural Seed Germination

Jinzhe Zhang

Jinling High School Hexi Campus, Nanjing, Jiangsu, 210019, China

Keywords: Electromagnetic Field; Seed Germination; Horticultural Plants; Membrane Permeability

Abstract: Electromagnetic field treatment technology, which might be characterized as a largely non-chemical and non-contact physical stimulation method, appears to tend to suggest potential application value in regulating horticultural plant seed germination. Within this broader analytical framework, what this study seeks to explore are the seemingly multidimensional physiological mechanisms of such electromagnetic field effects. What also appears significant in this context is a substantial analysis of the apparent germination-promoting effects under different electromagnetic field parameters. What seems to emerge from this evidence is the aim of providing theoretical support and data reference for the optimization of what could be more efficient horticultural seed treatment technologies.

1. Introduction

Seed germination, as what might be characterized as a critical starting point in the plant life cycle, appears to substantially influence the quality and yield potential of subsequent plant development. In horticultural crops, considering the nuanced nature of these findings, slow or uneven germination often seems to stem from issues such as the hardening of the seed coat, dormancy, or what appears to represent insufficient environmental conditions during production stages[1]. What appears to emerge from this evidence is an effect on field uniformity and growth consistency after sowing.

Within this broader analytical framework, electromagnetic field parameters ostensibly include field strength, frequency, waveform, and exposure duration. Under various combined conditions, seeds appear to exhibit substantially varying responses to stimuli. What seems to emerge as theoretically important is that different species and varieties of horticultural plants tend to show what appear to be variations in seed structure, metabolic activity, and induction thresholds. This seemingly further complicates the effects of electromagnetic field-induced germination—a point that appears to warrant further interpretive consideration—and apparently increases research challenges. What this pattern seems to suggest, therefore, is that it is apparently essential to systematically analyze experimental data and conduct theoretical studies to help reveal the potential impact patterns and what may be the underlying mechanisms of electromagnetic field-induced germination.

2. Theoretical Basis

2.1 Physiological and Biochemical Processes of Seed Germination

Seed germination is a dynamic process of multiple physiological and biochemical events intertwined, starting from the stage of seed water absorption to the end of the embryonic axis breaking through the seed coat. In the early stage of water absorption, seeds rapidly absorb water under osmotic action, causing cytoplasmic colloid expansion, resetting the cell membrane system, and restoring selective permeability[2]. During this process, the activation level of membrane related enzymes is significantly increased, accompanied by the extensive synthesis of hydrolytic enzymes (such as alpha amylase, protease, lipase, etc.), which gradually decompose storage substances into soluble small molecule substrates, providing substrate sources and energy guarantees for subsequent metabolism. The ion balance state in the cytoplasm has also changed, and the dynamic distribution of calcium and potassium ions has been re regulated, thereby maintaining the internal homeostasis conditions required for cell function recovery and division initiation.

At the beginning of subsequent growth, the metabolic activity rate significantly increases, and respiration rapidly transitions from initial anaerobic respiration to mitochondrial centered aerobic respiration, resulting in a significant increase in ATP production rate[3]. At this time, the activity of nucleic acid metabolism increases, the rate of DNA unwinding and RNA transcription accelerates, and the synthesized peptide chains and functional proteins are beneficial for cell structure recombination and embryonic tissue differentiation. Hormonal regulation is the core of this stage, where an increase in gibberellin concentration promotes the expression of hydrolytic enzyme genes, while a decrease in abscisic acid concentration relieves the inhibitory effect during germination. The precise control response of this series achieves the coordination of time and space, ensuring the elongation of embryonic roots, breaking the seed coat, and establishing the early stage autotrophic ability of seedlings.

2.2 Physical Characteristics and Classification of Electromagnetic Fields

Electromagnetic field is a physical field composed of electric and magnetic fields that are perpendicular to each other and constantly change over time. Its basic properties are described by Maxwell's equations[4]. The intensity and spatial distribution of electromagnetic fields are determined by the characteristics of the source charge or current, and their spectral range covers electromagnetic waves from extremely low frequency (ELF) to high frequency and even higher frequency bands. The penetration depth, energy density, and interaction mechanism of electromagnetic fields in different frequency ranges when propagating in a medium vary greatly. Ultra low frequency electromagnetic fields have strong penetration ability but low energy density, while high-frequency electromagnetic fields have a significant energy deposition effect on shallow tissues. The effect of electromagnetic field can affect the arrangement of charged particles and polar molecules in charged particles through the coupling effect between electric and magnetic components, thereby causing changes in the physical and chemical behavior of charged particles.

3. Analysis of Electromagnetic Field Treatment on Promoting the Germination of Horticultural Plant Seeds

3.1 The Impact of Different Electromagnetic Field Intensities on Germination Rate

The strength of the electromagnetic field is considered a key factor in determining the range of biological reactions during seed germination experiments. In environments with lower field strengths (usually less than 1 mT), the range of variation in germination rate of horticultural plant seeds is relatively small, but in some species, we can still observe a statistically significant increase in germination rate. This effect is generally related to the fine-tuning of surface charge distribution on the cell membrane and the increase in ion transmembrane transport efficiency, which in turn improves the water potential and osmotic balance inside the cell, and promotes efficiency increase in the early stage of water absorption[5]. In contrast, under moderate intensity (about 1-10 mT) conditions, the trend of increased germination rate is more pronounced, especially in seeds with hard seed coat or dormancy characteristics. The reasons include increased stability of membrane protein conformation, reduced activation energy requirements, and earlier initiation time of key metabolic pathways such as glucose metabolism.

3.2 Changes in Germination Speed under Different Frequency Conditions

The frequency change of electromagnetic field will have a significant impact on the germination speed of seeds, that is, the time interval from the start of water absorption to the breakthrough of seed coat by the embryonic root. Under the action of low-frequency electromagnetic fields (<50 Hz), the germination rate of some horticultural plant seeds shows an accelerating trend, which is related to the slow regulation of cell membrane potential and the promotion of membrane protein activation process by low-frequency signals. In this case, the probability of opening ion channels, especially calcium ion channels, increases, which is beneficial for the rapid initiation of signal transduction chains and the enhancement of related gene expression. Due to its low energy density, low-frequency fields have limited interference with cell structures, making them suitable for seed types that require relatively mild stimulation.

The performance of high-frequency electromagnetic fields (several hundred Hz to several MHz) in accelerating germination speed is more complex. Intermediate frequency pulse waves or amplitude modulated waves utilize resonance effects to affect the dynamic characteristics of specific molecules or subcellular structures in cells, shorten the induction period of enzymatic reactions, and accelerate the rate of decomposition of stored substances. High frequency electromagnetic fields can enhance the fluidity and diffusion speed of cell membranes to some extent, and the deposition of their energy can trigger local thermal effects, leading to imbalances in certain metabolic activities.

3.3 The Extent of Improvement in Seed Vigor Index through Electromagnetic Field Treatment

The seed vitality index comprehensively reflects the germination rate, germination speed, and growth status of seedlings, which helps to gain a deeper understanding of the actual effects of electromagnetic field treatment. Under the action of low to medium intensity electromagnetic fields, the overall vitality index of horticultural plant seeds shows an increasing trend of different amplitudes, which is due to the dual enhancement of germination rate and early growth potential of seedlings. The electromagnetic field can enhance the stability of mitochondrial membrane potential and increase the synthesis rate of ATP, thereby providing sufficient energy for cell division and elongation. Electromagnetic field treatment can also promote the activation of antioxidant enzyme systems (such as superoxide dismutase, catalase, etc.), thereby reducing oxidative damage during germination and indirectly enhancing seedling vitality.

Excessive electromagnetic field intensity or improper frequency combination can adversely affect the vitality index, and even reduce the growth potential of seedlings when the germination rate is maintained at high water levels. This phenomenon is often related to excessive interference with the cell membrane, imbalance of cytoplasmic ions, and disorder of metabolic redistribution. Experiments have shown that high-intensity treatment of seed roots results in lower root length, stem thickness, and leaf unfolding speed compared to the control group, indicating that electromagnetic field stimulation exceeding physiological tolerance limits can lead to a decrease in long-term growth performance. Under the strategy of increasing vitality index, the electromagnetic field parameters need to be finely set to ensure the stability and competitiveness of seedlings at various growth stages, while improving germination efficiency.

4. Analysis of the Possible Mechanism by which Electromagnetic Fields Promote Seed Germination

4.1 Changes in membrane permeability

Electromagnetic field treatment can alter the physical state of cell membranes at the molecular and subcellular levels, thereby affecting permeability characteristics. The microscopic reconstruction of membrane phospholipid molecules in an electromagnetic field results in measurable changes in lipid bilayer fluidity and membrane thickness. This physical structural adjustment changes the distribution of hydrophobic and hydrophilic regions in the membrane, thereby affecting the conformational stability and functional state of transmembrane proteins. Specific intensity and frequency electromagnetic fields can increase the opening probability of ion channels and transporters, improve the transmembrane flow efficiency of K+, Ca2+, Na+ions, and accelerate the process of osmotic regulation. The enhancement of transmembrane ion flow is crucial for the early water absorption of seeds and the recovery of cell turgor pressure.

From a physiological functional perspective, changes in membrane permeability further affect extracellular signal perception and intracellular signal transmission. The binding affinity between membrane receptors and ligands is regulated by the influence of membrane potential, and the activation rate of signal transduction pathways also changes accordingly. Experimental data shows that electromagnetic field treatment significantly enhances the activity of H+- ATPase on the plasma membrane, which not only accelerates the process of proton efflux, but also indirectly drives the coordinated transport of multiple ions. The increased efficiency of substance exchange between the plasma membrane and organelle membrane leads to a more balanced distribution of metabolic substrates and signaling molecules, providing the necessary physical and chemical conditions for the continued germination process.

4.2 Accelerated energy metabolism

Electromagnetic field treatment directly promotes energy metabolism during seed germination. When mitochondria are excited by electromagnetic fields, the activity of the inner membrane electron transport chain increases, the oxidative phosphorylation process accelerates, and the ATP generation rate increases. The respiratory rate detection results showed that after appropriate electromagnetic field treatment, the initial oxygen consumption rate of seed germination was significantly higher than that of the control group, which can provide sufficient energy reserve for cell division and elongation. The increase in glycolysis pathway and tricarboxylic acid cycle metabolic flux indicates that substance decomposition and energy conversion simultaneously promote several metabolic levels.

This metabolic acceleration effect is not limited to energy production, but involves the optimization of energy allocation strategies. Electromagnetic field treatment causes a change in the proportion of ATP distribution between mitochondria, cytoplasm, and organelles, making energy supply more inclined to support processes closely related to germination such as nucleic acid synthesis, protein synthesis, and cytoskeleton remodeling. Simultaneously accelerating energy metabolism helps maintain the reduced state within cells, reduce the accumulation rate of reactive oxygen species, and thus alleviate the damage of oxidative stress to germinating cells.

4.3 Regulation of Signal Molecules and Hormone Levels

Electromagnetic field stimulation can trigger a significant regulation of the distribution of signal molecules inside seeds with the level of plant hormones, which plays a core role in initiating germination. Electromagnetic field treatment can promote an increase in the relative content of gibberellin (GA3), while reducing the concentration of abscisic acid (ABA), thereby weakening the inhibitory signal and enhancing the sprouting signal. The immediate changes in intracellular signaling molecules such as Ca2+, nitric oxide (NO), and reactive oxygen species (ROS) can trigger a series of downstream signaling pathways, regulate the expression patterns of related genes, and accelerate the synthesis and metabolic reactions required for germination.

At the level of hormone interaction, electromagnetic field treatment alters the dynamic balance between gibberellin, cytokinin, ethylene, jasmonic acid, and other hormones, leading to synergistic or antagonistic effects on cell division, elongation, and metabolic rate. This regulation not only plays a role in the elongation of embryonic roots, but also participates in the early development stages of embryonic axes and cotyledons.

5. Conclusion

Electromagnetic field treatment has a significant promoting effect on the germination process of horticultural plant seeds, manifested in multi-level physical and biochemical pathways, involving membrane permeability regulation, accelerated energy metabolism, and optimized regulation of signal molecules and hormone levels. When the intensity and frequency are appropriate, electromagnetic fields can promote germination rate, shorten germination time, and improve seed vitality index, laying the foundation for early and stable growth of seedlings. Seeds of different types, varieties, and physiological states have varying degrees of sensitivity to electromagnetic fields. Parameters that are too high or too low can induce physiological imbalances and even inhibitory effects.

References

[1] Tang Ping and Long Yuyi. Effect of magnetic field on germination and growth of black bean seeds [J]. Cultivation and Planting, 2021,41(05):43-46.

[2] Li Yingjie, Duan Guangde, Hu Xiaolong et al. Effect of high-voltage corona electric field on germination characteristics of golden lotus seeds [J]. Inner Mongolia Forestry Science and Technology, 2020,46(04):16-19.

[3] Zhao Haiyang, Xu Yinsheng, Wang Yuxiang et al. Effects of electric field on seed germination and physiological indexes of young plants under drought stress in Ephedra japonica [J]. Agricultural Science and Technology Communications, 2017, (11):141-145.

[4] Liu Yuan, Wang Yuguo, Wen Yinyuan, et al. Magnetic field effects on biological effects of mung bean seeds under drought stress [J]. Shanxi Agricultural Science, 2017,45(05):718-721.

[5] Cui Lulu, Yu Haixia, Li Jingfu et al. Effects and mechanism of magnetic field on germination of cabbage seeds[J]. Chinese Journal of Vegetables, 2014, (06):34-39.