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Electric and magnetic field effects in spruce seed germination and seedling growth

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Abstract
In recent decades, research on the effects of physical fields– particularly electric and magnetic– on biological processes in plants has developed significantly. These fields can influence seed germination, cellular activity, and the subsequent development of seedlings, offering innovative perspectives in agriculture and forestry. The present study evaluated the impact of electric and magnetic fields on spruce seeds, with the aim of improving germination rates and seedling growth. For the electric field, three voltages (10V, 30V, 50V) and two exposure times (15 and 35 minutes) were tested. The most effective combination was 10V for 35 minutes, while the 50V- 15 minutes' variant had negative effects. The highest seedling height was obtained at 10V 15minutes. In the case of the magnetic field, the seeds were exposed to three different times intervals- 10, 20, and 30 minutes- at an intensity of 0.22×10^{-3} T. A 20-minutes exposure resulted in the highest germination rate and produced seedlings with significantly greater heights compared to the control and other variants. The results demonstrate the positive effect of using physical fields as an ecological and efficient method for stimulating germination and plant development, offering valuable applications in forest regeneration and the production of high-quality seedlings

Keywords: physical treatment, exposure, stimulation, seed activation, *Picea abies*

Introduction

Forests, recognized as one of the planet's most valuable resources, are under continuous pressure from abiotic, biotic, and anthropogenic factors. Among these, drought stands out for its direct effects on forest dynamics, limiting tree growth and accelerating physiological decline processes [1]. In this context, the conservation and regeneration of forest species of ecological and economic importance, such as spruce (*Picea abies* (L.) Karst.), become essential for maintaining the stability of forest ecosystems. Forests and trees contribute significantly to ecological balance and food security, representing an important source of raw materials as well as products of nutritional value for human populations. Spruce is one of the most important forest species in Europe, due to its economic, ecological, and landscape roles [2,3]. In the context of increasing climatic stress and habitat degradation, enhancing seed germination capacity and seedling development through unconventional methods has become a priority research direction.

Seed germination is a complex process influenced by genetic and environmental factors, as well as by the pre-sowing preparation of seed material [4]. Pre-sowing seed preparation often involves the use of chemical substances (seed treatment, growth regulators), scarification, stratification, or the application of physical factors such as magnetic and electric fields, microwave, ionizing, or laser radiation. These methods have proven effective in stimulating physiological processes, resulting in higher germination rates, more

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vigorous growth, and increased productivity [5,6,4]. Pre-sowing treatments, whether chemical or physical, aim to break seed dormancy, protect seeds against pests and diseases, and ensure uniform emergence [7]. Through processes such as osmo-priming, hydro-priming, halo-priming, or solid matrix priming, seeds are hydrated in a controlled manner, which improves germination and early development, although it may reduce the optimal storage period [8,9].

In recent decades, the application of electric fields has been extensively studied in agriculture and forestry, being reported as an effective method for stimulating seed germination and plant growth. Electroculture, a technique in which plants are cultivated under the influence of electric current, has proven effective in accelerating physiological processes and increasing productivity [10]. Numerous studies [11], have shown that positive and negative ions in the air can influence plant respiration [12], while negative ions can stimulate growth in species such as lettuce and kale [13,14]. The induced electric field acts from the earliest stages of germination, influencing seedling development and biomass formation [10].

In parallel, magnetic field (MF) treatments have emerged as a promising ecological alternative to chemical procedures, contributing to the reduction of toxic substance accumulation in plants and to the improvement of food and environmental safety [15]. Pre-sowing seed treatments using magnetic fields, known as "magnetopriming," represent a dry and non-destructive method that has been shown to enhance germination rate and seedling vigor in numerous crops [16,17,18,19]. An additional advantage of magnetic field application is the increased permeability of the cell membrane, which facilitates water absorption by seeds and results in faster and more uniform germination [20]. The magnetic field is a natural environmental factor, omnipresent on Earth, influencing the physiological processes of plants. The controlled use of electric and magnetic fields in forestry opens new perspectives for stimulating seed germination and seedling growth, contributing to the production of forest reproductive material with enhanced resilience to abiotic stress.

The present research analyzes the effects of electric and magnetic fields on the germination process and seedling development of Norway spruce (*Picea abies*), aiming to identify physiological and morphological responses under different field intensities and exposure durations. The results obtained may contribute to optimizing technologies for the production of forest reproductive material and supporting natural regeneration under abiotic stress conditions such as drought.

Material and Method

For this experiment, the seed material of Norway spruce (*Picea abies* (L.) Karst.) was collected from the Măria Mică Seed Reserve, located in Bistrița-Năsăud County. The seeds were carefully cleaned and sorted to obtain homogenous lots in terms of size and viability. For each treatment variant, 50 seeds were used, with three replications, in order to ensure statistical accuracy of the experimental results.

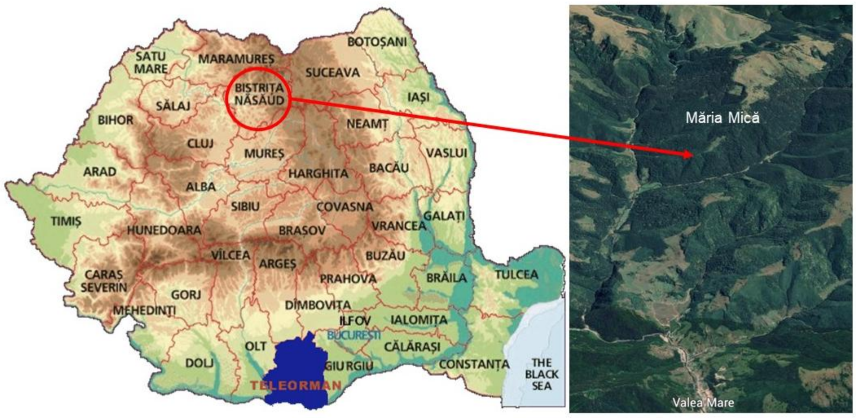

Figure 1. Location of Măria Mică Seed Reserve, Bistrița-Năsăud County

The experimental treatments consisted of exposing the seeds to electric and magnetic fields under controlled laboratory conditions. In the case of the electric field, three voltages levels (10V, 30V and 50V) and two exposure times (15 and 35 minutes) were applied. For the magnetic field treatment, the seeds were exposed to an intensity of 0.22×10^{-3} T for 10, 20 and 30 minutes, respectively.

Figure 2. Stages of the experiment on the germination and seedling development of Norway spruce (*Picea abies*)

After the treatments, the seeds were placed to germinate in Linhardt pots, together with the control group represented by untreated seeds. At the end of the germination period, the resulting seedlings were transplanted into seedling trays, using a substrate composed of a peat and perlite mixture, which provides a good balance between aeration and moisture retention. To evaluate seedling development, their height was measured precisely using an electronic calliper. This parameter was considered the most representative indicator for assessing vigour and early growth potential in spruce seedlings.

Results and Discussion

The influence of the electric field on seed germination

The application of an electric field to seeds modifies the biophysical and biochemical processes that precede germination, leading to faster activation of metabolism and increased permeability of the cell membrane. The results obtained in this study revealed a direct relationship between the voltage of the electric field and the germination rate. The highest value (93.3%) was recorded for the treatment of 10 V applied for 35 minutes, while the lowest germination rate was observed for the 50 V – 15-minute variant.

This pattern confirms the existence of an optimal stimulation range, beyond which the effect becomes neutral or even inhibitory. Similar studies have reported consistent results, [21] indicated that electrical stimulation at a voltage of 22 V for short periods (5–15 minutes) increased the germination rate and seedling vigour of maize (*Zea mays*), with the strongest effects obtained at moderate voltages. The authors showed that electrical stimulation activates oxidative metabolism and enhances the expression of genes involved in embryo development.

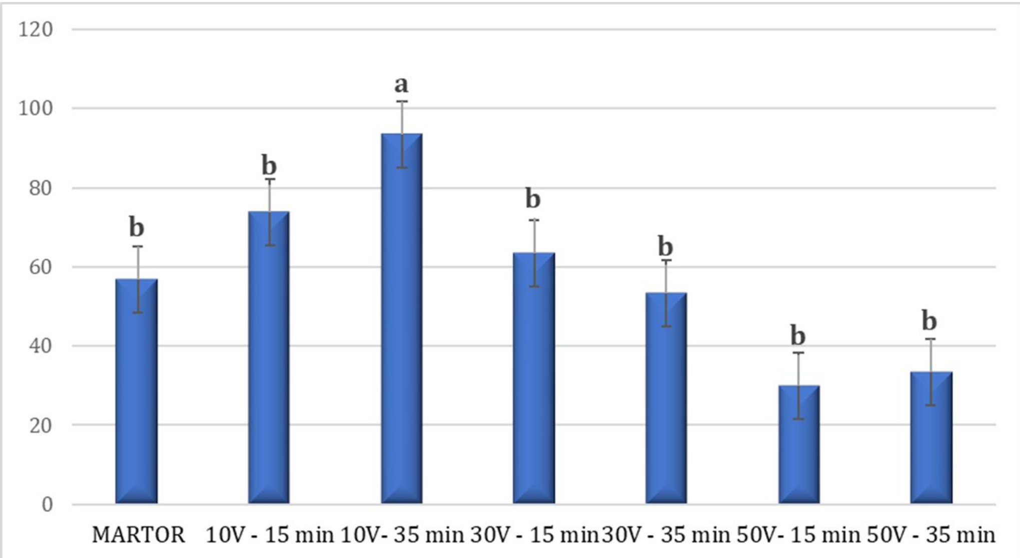

Figure 3. Germination capacity – electric field

Development of spruce seedlings under the influence of the electric field

The effect of the electric field was maintained during the seedling development phase, showing a consistent positive influence compared to the germination stage. The best results were obtained with the 10 V – 35 minute treatment, where spruce seedlings reached an average height of 3.91 cm. This variant was also characterized by uniform growth and a well-developed hypocotyl, suggesting a balanced stimulation of cell division and elongation processes.

Similar results were reported by [22], who found that applying an electrostatic field of 2 kV/mm for 20 seconds led to a significant increase in root and stem length and improved seed vigor in tomato (*Lycopersicon esculentum*).

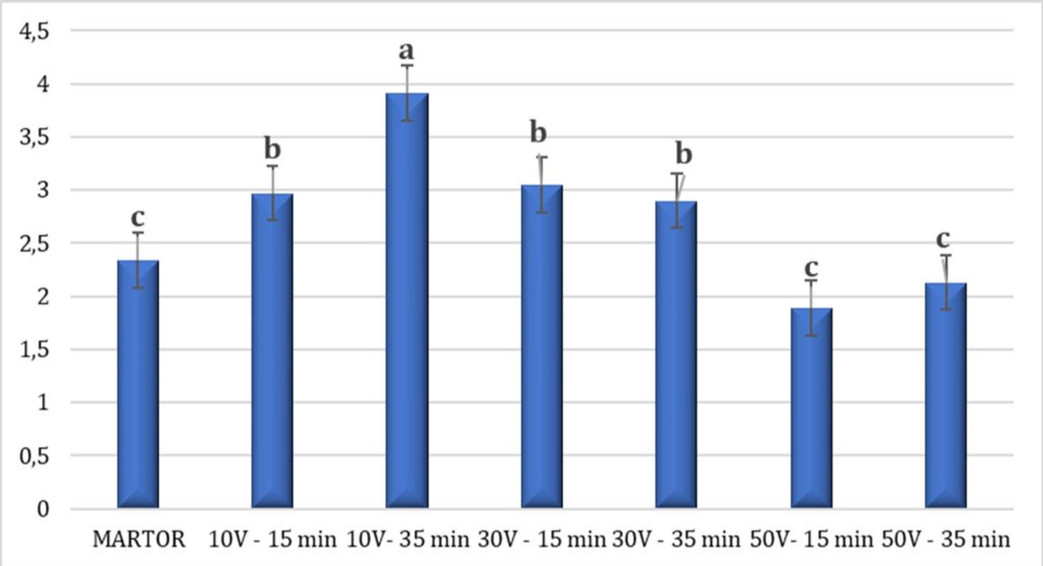

Figure 4. Seedlings development – electric field

In the present study, the treatment with 10 V applied for 35 minutes appears to represent the optimal stimulation range, as higher voltages (30 V and 50 V) resulted in less pronounced growth, indicating the existence of a threshold beyond which the stimulatory effect declines. This pattern confirms the nonlinear response model described by [23] for *Picea abies*, according to which moderate intensities of physical treatments, such as low-voltage electric fields, stimulate early growth, while excessive exposure may interfere with normal metabolic processes.

The influence of the magnetic field on the germination of spruce seeds

In the case of the magnetic field treatment, significant differences were observed among the tested variants, with the best germination recorded for the 20-minute exposure, where the germination rate reached 87.5%, a value higher than in the other analyzed treatments (Figure 5). The results confirm the positive effect of magnetic fields applied under controlled conditions on germination processes, a phenomenon also reported by [24], who studied the effects of electromagnetic treatments on sessile oak (*Quercus petraea*) seeds. The authors reported a magnetic field intensity of 0.4 mT (i = 0.680 A) and three exposure durations (10, 20, and 30 minutes), noting that the 20-minute exposure produced the highest germination rate (90%) and the greatest germination index (1.81).

The mechanisms involved in this favorable response can be attributed to the intensification of enzymatic activity, the activation of the antioxidant system, and the increase in membrane permeability. [3] showed that, in *Picea abies*, pre-sowing treatments with electromagnetic fields can activate the antioxidant system of seeds, enhancing their ability to neutralize reactive oxygen species (ROS) and thus increasing germination rate. Similar results were reported by [25] for *Lactuca sativa*, where moderate magnetic fields (125–250 mT for 10–20 minutes) significantly improved both the germination rate and uniformity.

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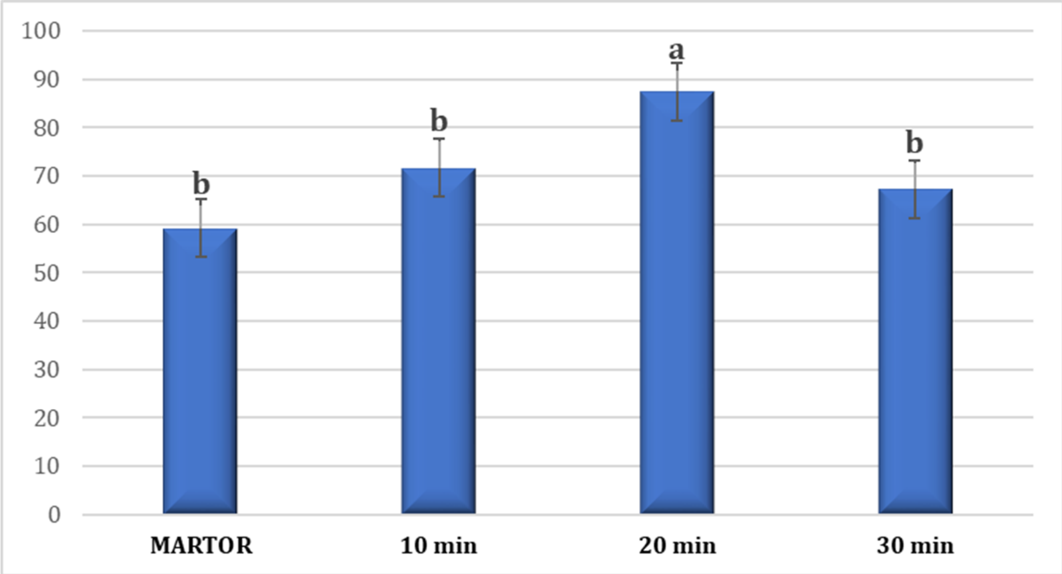

Figure 5. Germination capacity – magnetic field

Development of spruce seedlings under the influence of the magnetic field

Regarding seedling development, the beneficial effect of the magnetic field was maintained during the growth phase, confirming the positive influence observed in the germination stage. The best development was recorded in the 20-minute exposure treatment, where spruce seedlings reached an average height of 3.72 cm, showing balanced morphology and greater uniformity compared to the other experimental variants (Figure 6).

In contrast, the control variant, which was not subjected to any treatment, recorded the lowest values for both germination rate and seedling height. This significant difference highlights the positive impact and efficiency of the 20-minute magnetic field treatment, which not only improved germination but also promoted faster seedling growth compared to the untreated seeds.

The results are supported by the observations of [26], who reported that the application of electromagnetic fields to *Picea abies* led to accelerated biomass accumulation and activation of the antioxidant system, partially explaining the persistence of the beneficial effect during the growth phase.

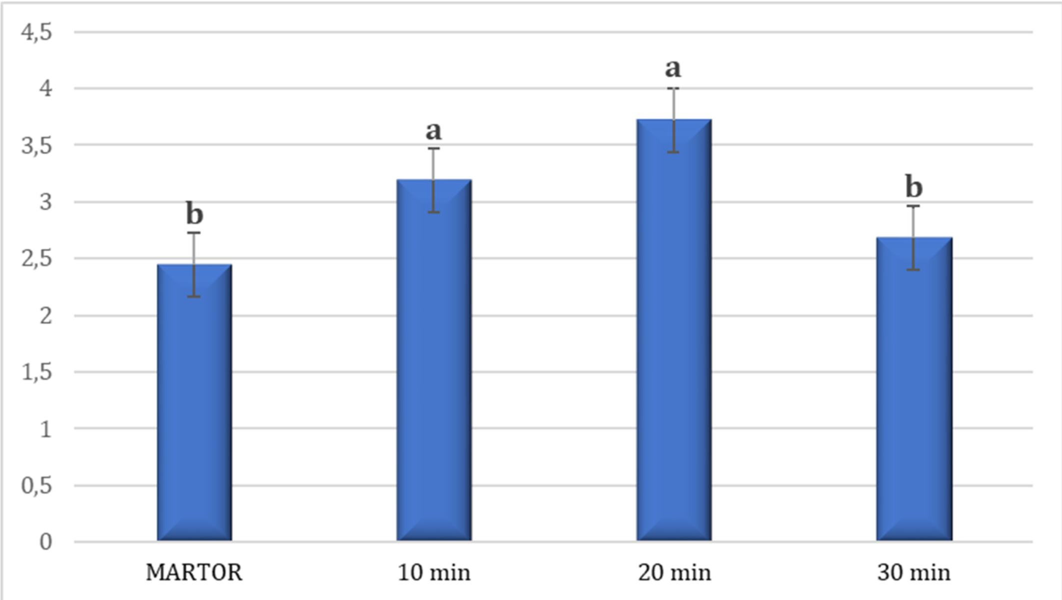

Figure 6. Seedlings development - magnetic field

Conclusions

The conducted research highlighted that biophysical treatments based on electric and magnetic fields can significantly influence the physiological processes involved in the germination and development of Norway spruce (*Picea abies* (L.) Karst.) seedlings. The results demonstrated that, when exposure parameters are carefully controlled, these treatments can stimulate seed metabolism, leading to faster germination, uniform emergence, and more vigorous early seedling development.

In the case of electric field treatments, the best results were obtained at a voltage of 10 V applied for 35 minutes, a variant that recorded the highest germination rate and the greatest average seedling height. This exposure regime favored cell division and elongation processes, contributing to balanced growth of both the root system and the stem. Higher voltages led to a decrease in efficiency, indicating the existence of an optimal physiological threshold for stimulation.

For magnetic field treatments, an exposure duration of 20 minutes proved to be the most effective, resulting in a germination rate of 87.5% and an average seedling height of 3.72 cm. This variant produced more uniform growth and greater vigor compared to the untreated control, which recorded the lowest values for all analyzed indicators.

Both electric and magnetic field treatments showed a common pattern in which moderate exposure levels produced the most beneficial effects on seeds and seedlings. The results confirm that these methods can serve as non-invasive and environmentally friendly alternatives to conventional chemical treatments, reducing ecological impact and contributing to the production of higher-quality forest reproductive material.

The application of these technologies in forest nurseries could support the production of more vigorous seedlings capable of better tolerating abiotic stress conditions such as drought and temperature fluctuations. Future research should aim to optimize the applied voltages and magnetic field intensities, exposure durations, and environmental conditions to define the optimal parameters for stimulating germination and seedling growth.

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