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The impact of pre-sowing magnetic field stimulation on the germination energy and capacity of parsley seeds

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ABSTRACT

This article explores issues related to the pre-sowing stimulation of plant organisms using a magnetic field. A literature review revealed that similar studies typically have focused on only one type of stimulation or one variety. In the present study, a multifactorial experiment was analyzed. The present study analyzes a multifactorial experimental design, taking into account several levels of magnetic field induction as well as three varieties of root parsley (*Petroselinum crispum*). The influence of magnetic stimulation on selected germination parameters – germination energy and germination capacity – was investigated. Due to the specificity and volume of the samples, custom experimental stands were developed to enable accurate and consistent testing.

Keywords: parsley, static magnetic field, stimulation, germination energy, germination ability.

INTRODUCTION

Nowadays, increasing attention being paid to the quality of the food we consume. We strive for food that is as free from chemical contamination as possible. Social media and public concern have increased fears over genetically modified products. The influence of magnetic stimulation on selected germination parameters – germination energy and germination capacity – was investigated. Due to the specificity and volume of the samples, custom experimental stands were developed to enable accurate and consistent testing. There is a growing preference for products labeled as preservative-free and those not exposed to chemical processing. To ensure such claims are true, appropriate methods must be applied to monitor, among other things, the amount of harmful substances in food (Angowski and Zienkiewicz, 2023; Umapathi et al., 2022; Wahab et al., 2022; Yilmaz, 2023).

In the case of seeds used for sowing in production crops, it is essential to investigate their quality thoroughly and prepare them adequately. Chemicals such as herbicides and fertilizers were initially used to improve soil fertility, protect plants, and increase yield quality. However, uncontrolled use by many farmers has led to the accumulation of toxic substances in food, resulting in altered compositions and decreased final food product quality – which, in turn, may affect human health and longevity (Aktar et al., 2009; Cottenet et al., 2020; Lazarević-Pašti et al., 2025; Popovic et al., 2022).

Despite these concerns, it is not feasible to entirely abandon factors that enhance seed germination energy and capacity, especially as soil conditions are increasingly poor or contaminated. To improve the quality of seed material, modern agriculture applies chemical, physiological, and physical methods. The germination ability of seeds can be improved if they are properly prepared before sowing. Proper seed preparation and successful early growth stages often translate into proper plant development and higher yields (Asadi-Samani et al., 2013.; Kornarzyński et al., 2020; Pietruszewski Stanisław, 2002; Pszczółkowski et al., 2023; Wang et al., 2019).

For seeds to have good sowing value – which leads to better yields – they must be thoroughly sorted, cleaned, dried, and refined.

Today's food market is dominated by low-quality products, while food prices continue to rise. This increase is partly caused by the use of chemical agents in production, which not only harm the environment but also penetrate the food and alter its chemical composition. As a result, there is growing interest in using physical methods such as magnetic field stimulation to improve germination capacity and seed vigor. According to the literature, physical stimulation is considered environmentally safe (Beretta et al., 2019).

Seeds exposed to magnetic stimulation have shown accelerated germination, faster growth, and more vigorous development. The sooner seeds germinate, the more positive the effect. The period between sowing and emergence is crucial for seedling vigor, especially as seeds must withstand adverse environmental conditions – which later impacts plant growth and yield levels (Braga Júnior et al., 2020; Dziergowska et al., 2021; Dziwulska-Hunek et al., 2023; Hozayn et al., 2019; Rajabbeigi, 2022).

Using magnetic fields for seed stimulation has become popular in recent years. However, results vary depending on several parameters including the type and intensity of the magnetic field, duration of exposure, and the species or variety of seeds used (Table 1).

A positive effect of a constant magnetic field on the increase in the percentage of germinated seeds and the germination rate has been observed in the literature (Lazim and Nasur, 2017).

An increase in germination speed has been recorded in certain plant species, including sorghum, coffee, and tomato (Braga Júnior et al., 2020; Lazim and Nasur, 2017; Nurbaity et al., 2022). Magnetic field exposure also stimulated selected plant quality parameters such as: dry mass increase (Pentoś et al., 2022), seed length (Lazim and Nasur, 2017), seed vigor (Nurbaity et al., 2022; Zaredost et al., 2017), root length stimulation may also affect plant size and increase the number of leaves (Lazim and Nasur, 2017; Nurbaity et al., 2022; Pordel et al., 2024).

MATERIALS AND METHODS

The research was conducted in laboratory conditions using root parsley (*Petroselinum crispum*) seeds, stored under optimal conditions. Three varieties were analyzed: Konika, Osborne and Hanácká (Table 2).

Prior to the start of the experiments, seeds were stored in a dark, ventilated room at 18±1 °C and 40–45% relative humidity. These conditions ensured optimal storage and stability of the seed material until testing.

Root parsley is a widely consumed vegetable in Poland, valued for its distinctive flavor and high nutritional content. It is a rich source of: vitamin C, folate (vitamin B9), vitamin B6 that enhance resistance to stress as well as to certain diseases, such as those affecting the digestive and urinary systems, and the skin.

An additional advantage is its availability, as it is a plant adapted to temperate climates and does not have high thermal requirements. The germination process begins at a temperature of 3–4 °C. Young seedlings can withstand frosts as low as – 9 °C. Late varieties with fully developed roots can overwinter in the field under snow.

Table 1. The effect of magnetic fields on selected plant species

Plant species	Field induction	Duration	Author	Observed effects
Sorghum	125 mT	6 days	Lazim and Nasur, 2017	Increased germination %, seedling length, root length, number of leaves
Coffee	10–28 mT	6 days	(Braga Júnior et al., 2020)	Increased germination speed
Cucumber	200 mT–9 T	15–60 min	(Pentoś et al., 2022)	Increased dry mass
Common bean	1–5 T	15–60 min	(Pszczółkowski et al., 2023)	Faster germination, improved taproot growth
Tomato	0.2 mT	15 min	(Nurbaity et al., 2022)	Increased germination, seed vigor, seed size, plant height, chlorophyll
Cumin	40–120 mT	30 min	(Feizi and Salari, 2022)	Improved seedling/root length and vigor; increased seedling mass by up to 52.5%
Madagascar periwinkle	100 mT	20–30 min	(Zaredost et al., 2017)	Increased germination %, vigor, and germination speed

Table 2. Comparison of the used parsley seed varieties

Variety	Sowing	Harvest	Spacing
Konika	March – April	October – November (bunch collection) March – April (collection of roots for storage)	30-45 × 4–6 cm
Osborne	March – April	August–October	30-40 × 4–6 cm
Hanácká	March – April	July–October	30 × 4 cm

The most suitable soils for parsley cultivation are humus-rich, moderately light soils. The soil pH should be close to neutral 6.5–7.0. It is recommended to grow parsley after crops such as onions, cabbage plants, or cereals.

Konika is a variety of root parsley, classified as medium-early. It is usually grown on heavy soils, and also adapted to wintering in the field. It has a conical, thick root, without a tendency to fork, but it clearly narrows towards the tip. It reaches a length of 12 to 15 cm. The root surface is smooth and is characterized by a creamy-white color. The vegetation period is from 160 to 170 days. However, its most favorable yield can be obtained when sown on fertile soils rich in nutrients. Its greatest advantage is the possibility of long storage in appropriate parameters.

The Osborne variety is a medium-late variety. It is best grown in fertile, humus soils that are adequately sunny. It can also be sown on light soils or in ridges. This variety is characterized by a fairly long root with a simple and cylindrical structure, which is of good quality. The root reaches a length of 22 to 25 cm. The upper part of the root is greenish-white, and the flesh is creamy-white. The vegetation period is from 185 to 200 days. Resistant to low temperatures (it can germinate at a temperature of 2–4 °C), as well as to short periods of drought (however, it likes frequent irrigation). Like the previous variety, it is also suitable for storage.

Root parsley of the Hanácká variety is a late variety. The root is shapely (cone with a blunt end) and even. It reaches a length of up to 14–17 cm. The flesh is creamy-white and is characterized by high aromaticity. The vegetation period lasts from 128 to 200 days. It grows well in places with fertile, humus soil, which are sunny. It is ideal for transport.

The study focused on parsley seeds because they have low germination capacity. This means that they are considered difficult to grow because of problems with their emergence and growth. Therefore, it was concluded that stimulation may enhance these parameters.

Constant magnetic field stimulation

The use of a constant magnetic field for stimulation was aimed at determining its effect on improving the germination parameters of seeds that have a low germination capacity. Before the stimulation began, all seeds were counted carefully. Each sample contained 100 seeds. All studies were conducted in four replicates. The variety is suitable for transport and storage, and it is resistant to root rust. Stimulations were performed in appropriate containers (Figure 1).

Figure 1. Seeds in containers for stimulation

Parsley seeds were stimulated with a constant magnetic field of three different magnetic inductions using two Halbach arrays (Figure 2). This array is a system of permanent magnets, which are characterized by different magnetization directions, i.e. they are arranged in an appropriate configuration. The seed magnetization process was carried out at a temperature of 20 °C. Three magnetic field inductions and three different exposure times were used for stimulation. In our research we used a static magnetic field with induction of 250 mT, 500 mT and 1 T.

We appreciate the opportunity to clarify the methodology regarding the application of the constant magnetic field and sample preparation. The constant magnetic fields were generated using two distinct Halbach arrays, details of which are provided below.

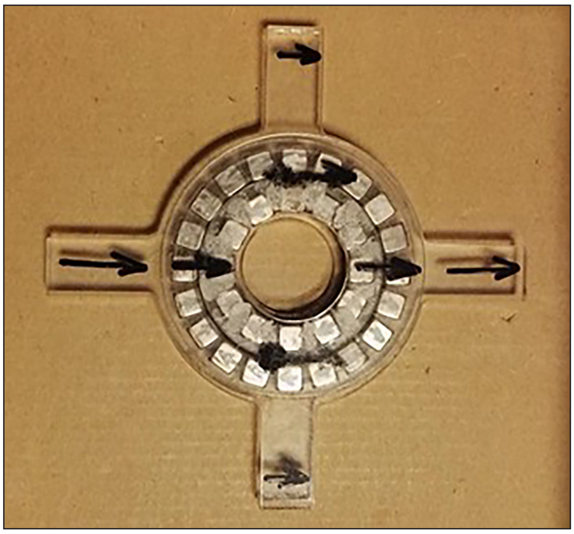
We used two different Halbach array designs to achieve the required magnetic flux densities:

- Halbach Array 1: This array possessed an outer diameter of 125 mm, an inner diameter of 28 mm, and a thickness of 25 mm. This single array was utilized to apply two specific magnetic flux densities: 1 T and 500 mT.
- Halbach Array 2: For the third condition of 250 mT, a second, larger Halbach array was necessary. Its dimensions were: outer diameter 150 mm, inner diameter 35 mm, and thickness 15 mm.

The spatial distribution of the magnetic field within the first Halbach array was characterized using a magnetovision camera. As demonstrated in Figure 3, the magnetic field lines exhibited a clear parallel distribution within the operational volume. Furthermore, the highest measured magnetic flux density of 1 T was concentrated adjacent to the inner wall of the array.

The seed arrangement and positioning were standardized across all experimental conditions, as detailed in Figure 4. Ten seeds were placed on the inner top surface of a standard eppendorf tube to ensure their even distribution. Next the prepared eppendorf tube was positioned inside the first Halbach array using a rubber holder designed to maintain a precise, fixed location where the magnetic flux density was measured to be 1 T. The exact same procedure and container were used. However, the eppendorf was relocated to a pre-measured specific point closer to the geometric center of the first Halbach array, corresponding to a stable flux density of 500 mT. A similar protocol for seed arrangement and in-array placement using a holder was followed, but the experiment was conducted within the second, larger Halbach array to achieve the 250 mT flux density.

(a)



(b)

Figure 2. Halbach matrix: a) magnetic field with induction of 150 mT, b) magnetic field with induction of 500 mT and 1 T

The selection of static magnetic fields with inductions of 250 mT and 500 mT for seed stimulation is justified by their proven efficacy in enhancing germination and early growth, their

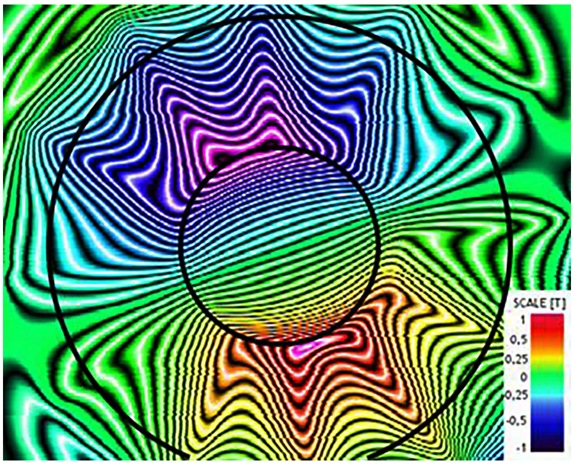


Figure 3. Magnetic field distribution around Halbach Array 1, black circles are the contours

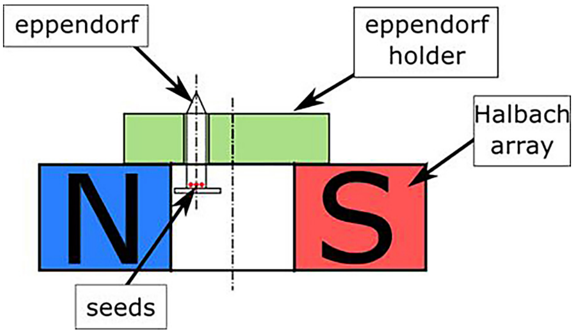


Figure 4. Position of the seeds inside Halbach Array

safety for biological material, and their practical applicability. These field strengths represent an optimal range for achieving significant biostimulatory effects without compromising seed viability (Radhakrishnan, 2019; Vashisth and Nagarajan, 2010).

Stimulation of seeds using a magnetic field with induction of 1 T is a relatively intense form of physical treatment that has been studied for its potential to enhance germination, growth, and improve plant health. Although a 1 T magnetic field is significantly stronger than the Earth's natural magnetic field (about 50 μT), research suggests that short-term exposure can have beneficial effects – depending on the plant species, duration of exposure, and seed development stage (Latef et al., 2020; Youssef and Abou Kamer, 2019). The following experimental groups were used in this study (Table 3).

The selection of three magnetic field induction values covers a range from moderate to strong static fields, which have been shown in the literature to exhibit biological activity without causing structural damage to the seeds. This range was therefore adopted as representative for assessing the threshold and maximal physiological response of parsley seeds.

GERMINATION TEST

All germination tests were performed under identical and strictly controlled environmental conditions. The temperature (22 ± 1 °C), relative humidity (76 ± 2%), and illumination level were kept constant for all varieties throughout the experiment. This ensured that any observed differences in germination parameters were attributable solely to the magnetic field treatment and not to variations in environmental factors.

After the appropriate time, in accordance with The International Seed Testing Association (ISTA) regulations, the effect of pre-sowing stimulation on the energy and germination capacity of the seeds was checked:

- germination energy (GE),
- germination capacity (GC).

According to the principles of ISTA, in laboratory conditions, for root parsley seeds, germination energy is determined after 10 days, while total germination capacity after 21 days. Then, the seeds are assessed for the appearance of normal and abnormal seedlings. In order to assess the significance of the effect of the constant magnetic field on the value of energy and germination capacity, a statistical analysis of the obtained results was carried out.

Germination energy (GE)

During the first part of the study, the influence of stimulating factors on germination energy (GE) Stimulation of seeds using a magnetic field with induction of 1 T is a relatively intense form of physical treatment that has been studied for its potential to improve germination, growth, and overall plant health. It is a percentage value from 0 to 100%. This parameter determines the number of germinated seeds, at which the germination of seeds of this species reaches its maximum. For parsley seeds, germination energy is determined 10 days after sowing (Czuksanow, 2014; Gruszecki, 2005).

Figures 5–7 present the obtained results for individual varieties. Based on the obtained

Table 3. Experimental groups of parsley seeds

Group	Magnetic field	Exposure time
0	Control, without stimulation	
1	150 mT	1 min
2	150 mT	3 min
3	150 mT	9 min
4	500 mT	1 min
5	500 mT	3 min
6	500 mT	9 min
7	1T	1 min
8	1 T	3 min
9	1 T	9 min

results, it can be clearly stated that the seeds of the Osborne variety of root parsley were characterized by the highest germination energy, while the seeds of the Hanácká variety had the lowest.

When analyzing the Osborne variety (Figure 5), it can be seen in most cases magnetic field stimulation did not affect the parameter studied. However, in the case of magnetic field stimulation with an induction of 150 mT and times of 1 and 3 min, as well as 500 mT and 3 min, and 1 T and 9 min, a decrease in germination energy can be observed in relation to the control sample. Therefore, it can be stated that magnetic field exposure in selected cases has a dissimulating effect on germination energy.

In the case of the Hanácká variety seeds (Figure 6), a significant decrease in germination energy was observed in almost all magnetic field combinations compared to the control sample. In the remaining cases, no significant changes were recorded.

Significant changes were observed in Konika variety parsley seeds (Figure 7) subjected only to stimulation with a magnetic field with an induction of 1 T compared to the control sample. After exposure for 1 and 9 min, an increase in germination energy is visible. Interestingly, in the case of stimulation with the same field (1 T) for 3 min, a decrease in the value of the tested parameter is visible.

Germination capacity (GC)

Another parameter that was checked for the effect of the magnetic field on seed germination was germination capacity. This is a parameter describing the germination potential of a batch of seeds. The value of this parameter, similarly to germination energy, is expressed in percentage (%). This parameter can be used to compare different batches of seeds in terms of quality and to estimate the field sowing value. For parsley seeds, germination capacity is defined as 21 days from sowing (Czuksanow, 2014; Gruszecki, 2005).

The results indicate that a positive effect of stimulation on parsley seeds of the Osborne variety can be observed (Figure 8). In all cases, a significant increase in the tested parameter was recorded. The best results were obtained for stimulation with a magnetic field with an induction of 500 mT and 1 T for 3 min.

Root parsley of Hanácká variety (Figure 9) reacted completely differently to exposure to a magnetic field compared to Osborne variety. Only in the case of stimulation with a field of 1 T induction for 9 min can we notice a significant decrease in the value of the tested parameter.

Subjecting parsley seeds of the Konika variety to stimulation (Figure 10) we can observe a different effect depending on the selected parameters. The best results were obtained for the highest value of magnetic field induction (1 T) and

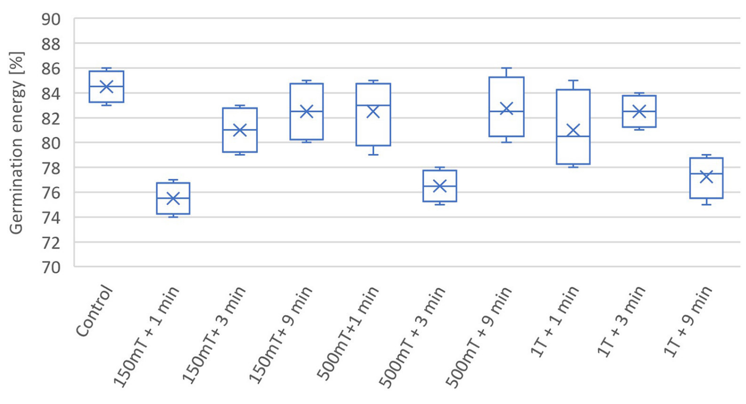


Figure 5. Germination energy of Osborne variety seeds

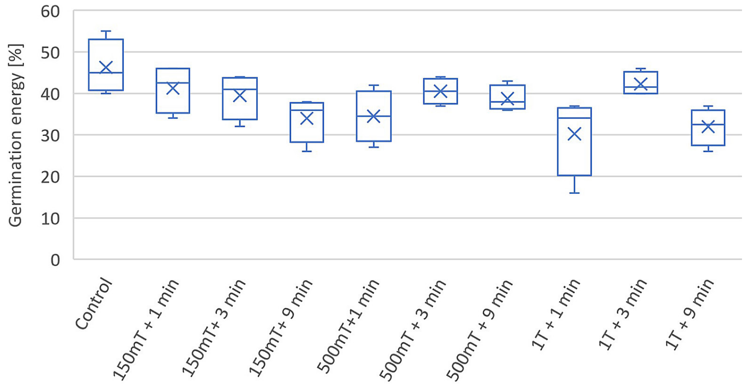


Figure 6. Germination energy of Hanácká variety seeds

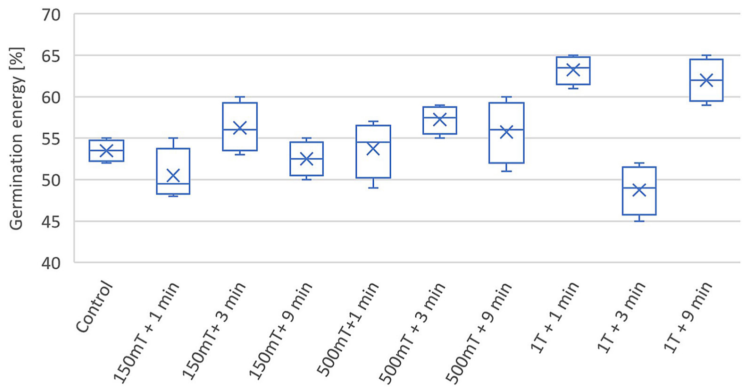


Figure 7. Germination energy of Konika variety seeds

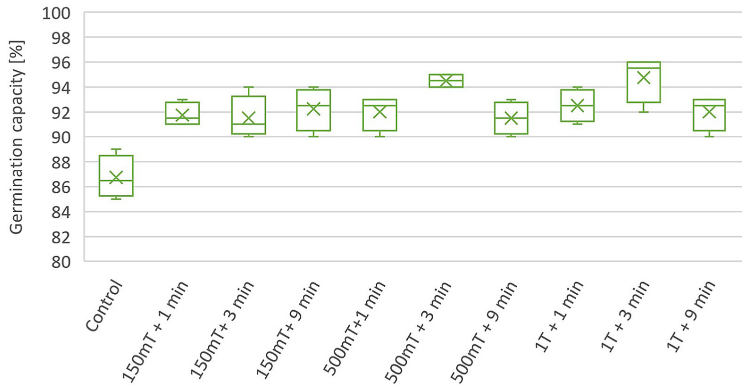


Figure 8. Germination capacity of Osborne variety

short exposure time (1 and 3 min). In the case of extending the time (9 min), the germination capacity decreased in comparison with the control sample. Similarly, to the induction value of 500 mT and time of 1 min. In the remaining cases, no significant differences were recorded.

The markedly different responses between the Konika and Hanácká varieties can be explained by varietal differences in seed structure and metabolism. Konika seeds, characterized by a thinner seed coat and higher initial metabolic activity, may have absorbed magnetic energy more efficiently, promoting faster activation of biochemical processes. In contrast, the Hanácká variety, with a thicker and harder seed coat, may have exhibited reduced permeability to water and oxygen. Under high-intensity exposure (1 T, 9 min), this could have led to oxidative stress or enzymatic inhibition, resulting in the observed inhibitory effects.

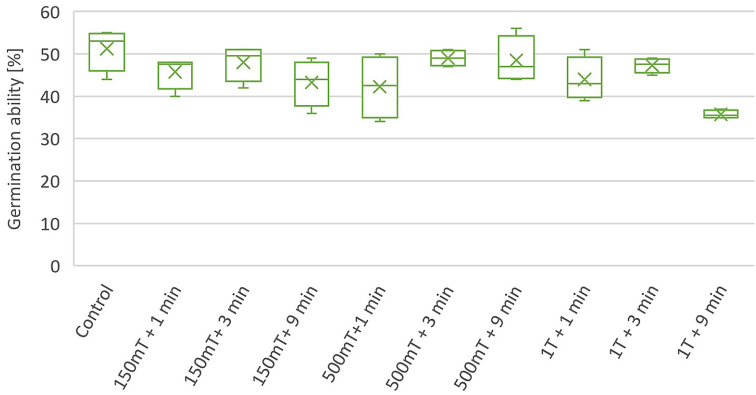


Figure 9. Germination capacity of Hanácká variety

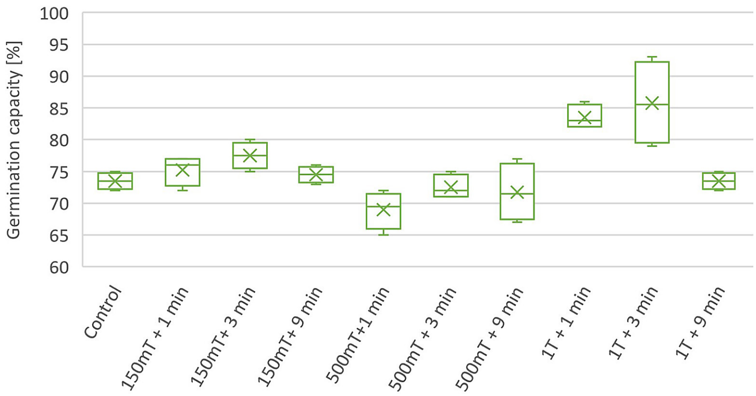


Figure 10. Germination capacity of Konika variety

The observed variation in the effects of magnetic stimulation between the Konika and Hanácká parsley varieties is likely related to genetic and physiological differences influencing seed responsiveness to magnetic fields. These may include variations in seed coat thickness and permeability, moisture content, metabolic activity, or the composition of enzymatic and antioxidant systems involved in germination and early seedling development. Such factors can affect the way magnetic fields interact with cellular processes, leading to genotype-specific physiological responses. Similar variety-dependent effects have been reported in other species, indicating that genetic background and seed structure play an important role in determining the sensitivity of plants to magnetic stimulation.

RESULTS AND DISCUSSION

In this study, root parsley seeds were exposed to a static magnetic field (150 mT, 500 mT and 1 T; for 1, 3 and 9 min) to assess germination capacity. The best results for germination energy and germination capacity were obtained for the Konika variety after stimulation with a constant magnetic field of 1 T for 1 min. Conversely the magnetic field had the most destimulating effect on both parameters of the Hanácká variety seeds after 9 min and 1 T induction. As can be seen, there is no single appropriate dose of constant magnetic field that can be applied to each variety. The verification of the magnetic field's effect should be preceded by laboratory tests to determine the most favorable parameters for the selected variety.

Magnetic stimulation had a positive effect on the germination of root parsley seeds, significantly improving both germination energy and germination capacity.

The most beneficial results were obtained with magnetic field induction of 1 T and 1 min, which led to the highest increases in germination parameters across all tested varieties.

Among the tested varieties, Konika showed the highest sensitivity and the most positive response to magnetic field stimulation, while the Hanácká variety showed the weakest response.

Magnetic field stimulation may be a valuable method for improving seed quality and supporting germination processes, especially in varieties that.

In certain parameter combinations, particularly under high magnetic field induction (1 T) and long exposure duration (9 min), an inhibitory effect was observed. This phenomenon may result from overstimulation of seed physiological systems, leading to short-term metabolic imbalance or oxidative stress in the embryonic tissues. Excessive magnetic stimulation can temporarily disturb enzymatic activity and membrane integrity, delaying germination onset. Similar inhibitory effects of strong static magnetic fields have been reported for soybean and alfalfa, where prolonged exposure caused transient reductions in dehydrogenase and amylase activities (Radhakrishnan, 2019; Hozayn et al., 2019).

The differences in response among parsley varieties may also be associated with intrinsic physiological and structural traits of the seeds – such as seed coat thickness and permeability, the content of paramagnetic compounds (e.g., Fe^{2+} and Mn^{2+} ions), storage time, and moisture level. Seeds with thicker or less permeable coats may show weaker responses to magnetic stimulation because the field interacts less efficiently with the embryo and endosperm. Conversely, higher concentrations of paramagnetic ions can enhance magnetic energy absorption, potentially accelerating enzymatic and metabolic processes involved in germination.

In some treatment combinations, a reduction in germination energy was accompanied by unchanged or even increased germination capacity, as observed for the Osborne variety. This pattern likely indicates transient physiological stress that delayed early germination dynamics (lower GE) but did not impair overall seed viability. The seeds may have required a longer time to overcome the temporary metabolic inhibition, ultimately achieving normal or improved total germination after the full incubation period (21 days).

It would be important to conduct research on other varieties of root parsley. This approach would make it possible to check whether a given type (medium early, medium late) reacts in the same way to the used stimulating factors. At the same time, it would be important to conduct research on early varieties, which were not included in this work at all.

Future studies should include species with contrasting seed morphology and physiological characteristics to identify general patterns of magnetic field sensitivity. Particularly relevant comparisons would involve other members of the Apiaceae family, such as carrot (*Daucus carota*) and celery (*Apium graveolens*), which share structural similarities with parsley seeds. Additionally, extending the research to species with different seed coat properties and germination dynamics – for example, legumes (soybean, bean) or cereals (wheat, maize) – would provide a broader understanding of species-specific responses to magnetic stimulation.

For future studies, it would be most relevant to include plant species that are agriculturally important and have seeds with diverse morphological and physiological characteristics. For instance, comparisons could be made with other Apiaceae members such as celery (*Apium graveolens*) or carrot (*Daucus carota*), which share some structural similarities with parsley seeds. Additionally, including species with contrasting seed coat thickness, germination rates, and metabolic activity, such as legumes (e.g., soybean, bean) or cereals (e.g., wheat, maize), could help to better understand species-specific responses to magnetic stimulation and identify general patterns of sensitivity across plant groups.

Further research should also examine the effect of the used stimulating factors on other plant species, which are also characterized by low germination capacity and which are commonly used in human and animal nutrition technologies.

It would also be important to test other methods of physical seed stimulation, e.g. variable magnetic field, application of red light. Algae extracts could also be used to improve the tested parameters.

The results presented above offer only partial insight into the properties of the examined material. There are currently no reports in the available literature on the effect of stimulating factors on the processes (biological, biochemical) occurring in seeds (tubers) under the influence of electromagnetic and magnetic stimulating factors. To fully investigate this, it would be necessary to conduct research at the microstructural and genetic level respond well to such treatments.

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