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Effect of Magnetic Field on Seeds of Parsley (*Petroselinum crispum*): Modeling and Optimization by Response Surface Methodology

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Abstract

In the current study, the modeling and optimization of various seedling growth and germination indices for parsley seeds were investigated. A lab-scale quadrupole magnetic field was developed, and experiments were conducted using a completely randomized factorial design with three replications. The factors considered were magnetic field intensity (150, 300, and 450 mT), exposure time (30, 60, and 90 minutes), and culture time (0, 7, and 14 days after applying the magnetic field). The results revealed that the magnetic field significantly affected shoot length, fresh root weight, and fresh shoot weight, while exposure time significantly impacted root length. Sowing day also significantly influenced root length and fresh root weight, along with other factors. Immediate sowings after magnetic field application enhanced root length, while sowing 14 days following the exposure increased shoot length, fresh root weight, and fresh shoot weight. A 30-minute exposure to magnetic field intensities of 150 to 300 mT did not significantly affect seedling growth parameters. However, higher field strengths of 450 mT for 60 to 90 minutes proved beneficial, leading to enhanced shoot length, fresh root weight, fresh shoot weight, germination rate, germination percentage, and reduced mean germination time. The analysis and optimization using Response Surface Methodology revealed that the optimal magnetization condition, with a desirability of 0.682, was achieved at a magnetic field of 450 mT, an exposure time of 60 minutes, and sown 14 days post-exposure. Higher magnetic fields appeared to enhance field durability and significantly impact seedling growth indices.

Keywords: Germination, Magnetic field, Modeling, Parsley, Stability

Introduction

Parsley seeds (*Petroselinum crispum*), a globally cultivated herb, present a challenge for growers among the myriad of vegetable crop seedlings in commercial nurseries. Growers in the southeastern United States have encountered obstacles in cultivating parsley under both greenhouse and field conditions, citing issues with poor germination and inconsistent seedling emergence (da Silva, de Barros, Foshee, Candian, & Diaz-Perez, 2022).

Magnetic treatments enhance seed vigor by influencing biochemical processes, thereby stimulating protein and enzyme activity. Additionally, some studies have reported that magnetic fields positively affect the number of flowers and yield, nutrient and water uptake, and increase seed germination and plant growth, demonstrating the benefits of stronger

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magnetic fields (Alarcon, Cuesta, Molejon, Paragsa, & Ypon, 2024).

Numerous experiments have demonstrated that magnetic fields can efficiently enhance the germination characteristics of different plant species. A study on the magnetoreception of *Arabidopsis thaliana* analyzed several developmental responses to weak static magnetic fields ranging from nearly zero up to 122 µT. A 50 µT field accelerated seed germination by approximately 20 hours compared to samples kept in a nearly null field (Dhiman, Wu, & Galland, 2023). Afzal *et al.* (2021) revealed how seed magnetization could enhance sunflower seed growth, germination, and yield. The seeds underwent direct exposure to MF intensities of 50, 100, and 150 mT for durations of 5, 10, and 15 minutes, followed by standard germination tests. The findings indicated that subjecting seeds to MF at 100 milliTesla for 10 minutes, along with seed priming using a 3% solution of moringa leaf extract in water subjected to magnetic treatment, markedly enhanced emergence, rate of crop growth, and yield of sunflowers (Afzal *et al.*, 2021). Sarı, Demir, Yıldırım, and Memiş (2023) documented that magneto-priming augments both seedling growth and germination characteristics of lettuce and onion seeds. They found pre-soaked seeds treated with MF showed a significant increase in germination, and seedling emergence percentages in each species. Their findings indicated that magneto-priming could serve as an effective pre-germination treatment before sowing (Sarı, Demir, Yıldırım, & Memiş, 2023). In another study, the impact of magnetization before planting (45 mT for 15 and 30 seconds) on common bean seeds has been reported to influence plant growth and development elements. The fresh weight of the initial and fifth leaves was favorably impacted by pre-sowing magnetic field stimulation of common bean seeds, but their dry weight was not affected. The bio-stimulation of the seeds with magnetic fields also enhanced the energy, germination capacity, and strength of the common bean seeds (Pszczółkowski *et al.*, 2023). Another experiment was conducted by Alarcon *et al.* (2024) on the effects of magnetic treatment on string bean (*Phaseolus vulgaris*) plants. They concluded that the plants subjected to magnetic treatment are more significant in size, height, and overall health (Alarcon *et al.*, 2024). Nagalakshmi and Dayal (2023) used pre-sowing magnetic field (MF) and electric current (AC) treatments on germination, seedling parameters, and yield attributes in buckwheat (*Fagopyrum esculentum* L.). Results showed that the seeds treated with the magnetic field demonstrated remarkable effects on growth and yield parameters of buckwheat. Germination percent (99%), seedling fresh and dry weight 0.177 g and 0.035 g, respectively, and chlorophyll (a & b) content was maximum in magnetic field 125 mT for 5 minutes, which performed better among the other treatments (Nagalakshmi & Dayal, 2023). The effects of different magnetic field strengths and durations on seed germination (tomato and wheat) and bacteria growth (*Bacillus* and *Staphylococcus*) were investigated in another study. The samples were exposed to a magnetic field of 0.2 and 1 Tesla for 4 days, with the effects of each day evaluated independently. Tomato seeds demonstrated the greatest susceptibility to the application of high magnetic fields, whereas wheat seeds exhibited the lowest level of impact (Atlı & Erez, 2023). The effect of magnetic fields on parameters of seedling growth and germination of parsley seeds has not yet been studied or researched. Therefore, the aim of this investigation was to study the possible effects of different intensities and durations of magnetic fields on some seedling growth indices of parsley seeds such as root length, shoot length, fresh root weight, fresh shoot weight, germination percentage (GP), germination rate (GR), mean germination time (MGT), and to model and optimize the characteristics using response surface method.

Materials and Methods

Sample preparation and experimental procedure

Parsley seeds sourced from the Pakan Bazr Company (Isfahan, Iran) were employed in the study. These seeds were untreated with chemicals, ensuring consistent germination rates throughout the experiment. Selection criteria involved choosing seeds devoid of visible defects, deformities, or signs of insect infestation. Prior to exposure to the magnetic field device, the seeds underwent a three-minute disinfection process using a 1.5% sodium hypochlorite solution, immersed for three minutes and subsequently rinsed with distilled water. A quadrupole magnetic field (Fig. 1) was engineered at the University of Jiroft. The strength of the magnetic field generated within the pole gap was monitored using a digital tesla-meter (LB-828, Taiwan).

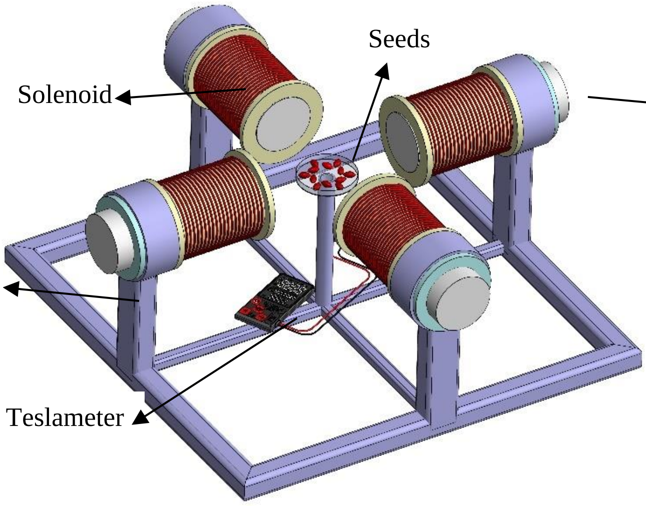

Fig. 1. Quadrupole magnetic field

Output Variables

Firstly, preliminary tests were conducted on parsley to determine appropriate exposure times. Seeds were placed in petri dishes measuring 100 millimeters in diameter, with each dish containing twenty-five seeds allocated for each treatment. The experimental factors comprised magnetic field intensities of 150, 300, and 450 mT, exposure durations of 30, 60, and 90 minutes, and sowing days of 0, 7, and 14 days after magnetic field exposure. After exposing the seeds to the magnetic field, the petri dishes were kept in the growth medium (type IK-RH 200) at 25 ± 1°C. The interval between magnetic field application and seeding aimed to assess the stability of the magnetic field within the seeds. Seeds were checked every day, and seeds with radicle length greater than two millimeters were counted as germinated seeds for calculating germination percentage (GP), germination rate (GR), and the mean germination time (MGT), calculated by the following expressions (Namjoo, Moradi, Dibagar, Taghvaei, & Niakousari, 2022):

$$GP = \sum_{i=1}^{k} n_i / N \quad (1)$$

$$GR = \sum_{i=1}^{k} n_i / \sum_{i=1}^{k} d_i \quad (2)$$

$$MGT = \sum_{i=1}^{k} n_i d_i / \sum_{i=1}^{k} n_i \quad (3)$$

where n_i is the number of seeds germinated at the i-th time, k being the last time of germination, d_i is the number of days from the commencement of the test to the i-th observation, and N is the aggregate seed count (Dehkourdi & Mosavi, 2013; Ranal, Santana, Ferreira, & Mendes-Rodrigues, 2009). The lengths of roots and shoots were assessed by a digital caliper with an accuracy of 0.01 mm, while their fresh weights were determined using an electronic balance (accuracy of 0.001 g). The tests took place at the Mechanical Engineering of Biosystems laboratory at the University of Jiroft, employing a factorial layout based on a completely randomized design with three replications. Statistical analyses were conducted using SAS 9.4 software, with means compared using Duncan's multiple range test at the 5% significance level.

Response surface methodology

The present study employed Response Surface Methodology (RSM) to explore the relationship between independent variables such as magnetic field intensity, durations of field application (exposure time), and sowing day, each at three levels (Table 1), and dependent parameters including root length (RL), stem length (SL), fresh root weight (FRW), fresh shoot weight (FSW), germination percent (GP), germination rate (GR), and mean germination time (MGT). To conduct the statistical analysis and visualize the response surfaces of the experimental outcomes, the software "Design-Expert 13.0.0" was employed. The experimental design layout was established using RSM based on historical data. Moreover, each response variable was characterized by employing a second-degree polynomial equation (Eq. 4) via RSM (Namjoo, Golbakhshi, Kamandar, & Beigi, 2024).

where Y denotes the response function (dependent variable), while X_1, X_2, and X_3 represent the independent variables corresponding to magnetic field intensity, exposure time, and sowing day, respectively. The polynomial coefficients were defined as follows: B_0 represents the constant term of the equation, B_1, B_2, and B_3 signify the linear effects, B_{11}, B_{22}, and B_{33} represent the quadratic effects, and B_{12}, B_{13}, and B_{23} denote the interaction effects (Namjoo, Moradi, Niakousari, & Karparvarfard, 2022).

Table 1- Experimental range and levels of the three variables

Variable	Symbol	Unit	Level		
Magnetic Field	MF	mT	150	300	450
Exposure Time	ET	min	30	60	90
Sowing day	SD	day	0	7	14

Results and Discussion

Table 1 reveals the analysis of variance for some parsley seedling growth indices under different magnetic field intensities, exposure times, and sowing days. The effect of magnetic fields (MF) showed significant impacts on several characteristics, including shoot length, fresh root weight, and fresh shoot weight. Likewise, exposure time (ET) and the interaction ET × SD demonstrated significance only on root length and germination percentage. Sowing day (SD) displayed significance across all indicators, encompassing root and shoot length, fresh root weight, fresh shoot weight, and seed indices such as germination rate, germination percentage, and mean germination time. Furthermore, the interactions of MF × ET and MF × SD exhibited significant effects across a broader range of indices.

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_{12}X_1X_2 + B_{13}X_1X_3 + B_{23}X_2X_3 + B_{11}{X_1}^2 + +B_{22}{X_2}^2 + B_{33}{X_3}^2 \quad (4)$$

Table 2- Analysis of variance for some parsley seedling growth indices under magnetic field intensities, exposure times, and sowing days

S.O.V	df	RL	SL	FRW	FSW	GR	GP	MGT
MF	2	4.226^{ns}	290.507**	1.4×10^{-5**}	1.8×10^{-4*}	0.032^{ns}	16.382^{ns}	0.042^{ns}
ET	2	14.272**	64.424^{ns}	1.8×10^{-6ns}	3.3×10^{-5ns}	0.280^{ns}	491.716*	0.817^{ns}
SD	2	165.548**	119.333*	1.0×10^{-5*}	8.4×10^{-4**}	0.522*	978.901**	11.751**
MF×ET	4	11.924**	141.347**	1.6×10^{-5**}	3.7×10^{-4**}	0.441**	777.845**	2.658^{ns}
MF×SD	4	35.510**	79.556^{ns}	8.9×10^{-6*}	2.3×10^{-4ns}	0.696**	458.475**	7.270**
ET×SD	4	14.725**	9.667^{ns}	6.8×10^{-6ns}	1.1×10^{-5ns}	0.067^{ns}	302.364*	0.760^{ns}
MF×ET×SD	8	23.057**	46.364^{ns}	1.9×10^{-5**}	1.7×10^{-4**}	0.134^{ns}	344.799**	0.626^{ns}
Erorr	54	1.448	31.842	2.9×10^{-6}	6.2×10^{-5}	0.126	117.555	1.125
C.V (%)	-	21.032	15.032	20.484	15.441	27.655	19.150	8.646

ns: not significant, *: significant at/above the 5% level, **: significant at/above the 1% level, S.O.V: Source of variation, df: Degrees of Freedom, MF: Magnetic field, ET: Exposure Time, SD: Sowing day, and CV: Coefficient of variation.

Magnetic treatments at 800 mT for durations of 1, 2, 5, and 10 minutes significantly influenced the germination percentage and mean germination time (P<0.01), as well as the seedling emergence percentage (P<0.05) and seedling emergence time (P<0.01) of onion seeds. Furthermore, a statistically significant difference was noted between the impacts of hydro-priming and magneto-priming on germination percentage, mean germination time, seedling emergence percentage, and seedling emergence time (P<0.01) in lettuce seeds (Sarı *et al.*, 2023).

Root length

Using the findings from the depicted testing conditions with different magnetic fields and sowing days at a fixed exposure time level (Fig. 2), the highest root length was established for both factors at their minimum values, e.g., magnetic field 150 mT, sowing on day zero, and exposure time 60 min. The minimum root length was recorded for a magnetic field of 300 mT, planting after 7 days, and an exposure time of 90 minutes. The increase in days following the application of a 150 mT magnetic field intensity resulted in a more significant reduction in root length compared to the other sowing days. Conversely, excessively rapid water uptake can cause physical damage to seed tissues, potentially leading to lower viability in seeds exposed to higher magnetic fields (300 and 450 mT) for 30 and 60 minutes. Root length can be used as the most important parameter in the vegetative growth process. Because researchers believe that root length per unit volume of soil is the best feature for evaluating soil water and nutrient uptake by plants (Eshghizadeh, Kafi, Nezami, & Khoshgoftarmanesh, 2012).

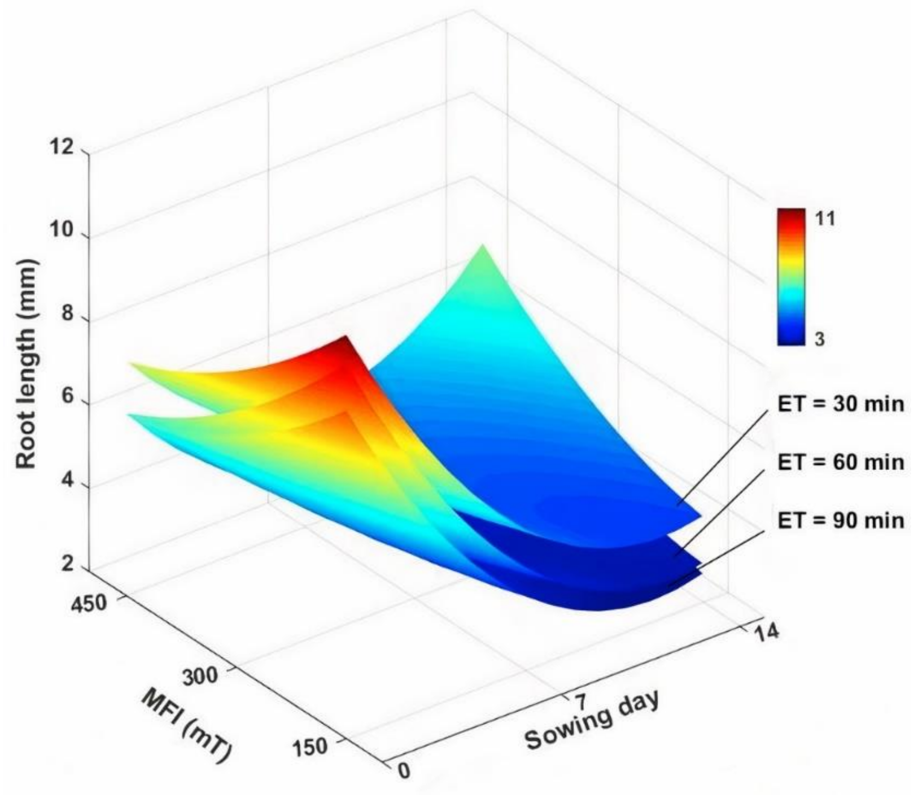

Fig. 2. 3D contour plots for root length against magnetic field, sowing day, and exposure time

Shoot length

Figure 3 depicts contour plots illustrating the relationship between shoot length and three variables: magnetic field, sowing day, and exposure time. The maximum shoot length was achieved with sowing after 14 days with an exposure time of 60 minutes. Conversely, the lowest shoot length was observed with sowing after 7 days, a magnetic field of 150 mT, and an exposure duration of 90 minutes. An increase in shoot length was observed following seed treatment with a magnetic field of 450 mT, potentially as a result of earlier initiation of emergence and a hastened rate of cell division in the root tips (Nagalakshmi & Dayal, 2023). Variations in magnetic field dosage impact root biomass, stem diameter, and leaf dimensions. Additionally, root expansion exhibits greater sensitivity to magnetic fields compared to shoot development. Magnetic fields govern the inherent behavior of iron (Fe) and cobalt (Co) atoms, harnessing their energies to facilitate the transportation of essential microelements within root meristems. Consequently, this process influences root growth by regulating nutrient intake and movement (Sarraf *et al.*, 2020). The plants exhibited enhancements in various morpho-physiological aspects derived from magneto-primed seeds, such as seedling biomass, seedling vigor, plant height, root development, leaf pigments and area, and plant dry weight (Bera, Dutta, & Sadhukhan, 2022).

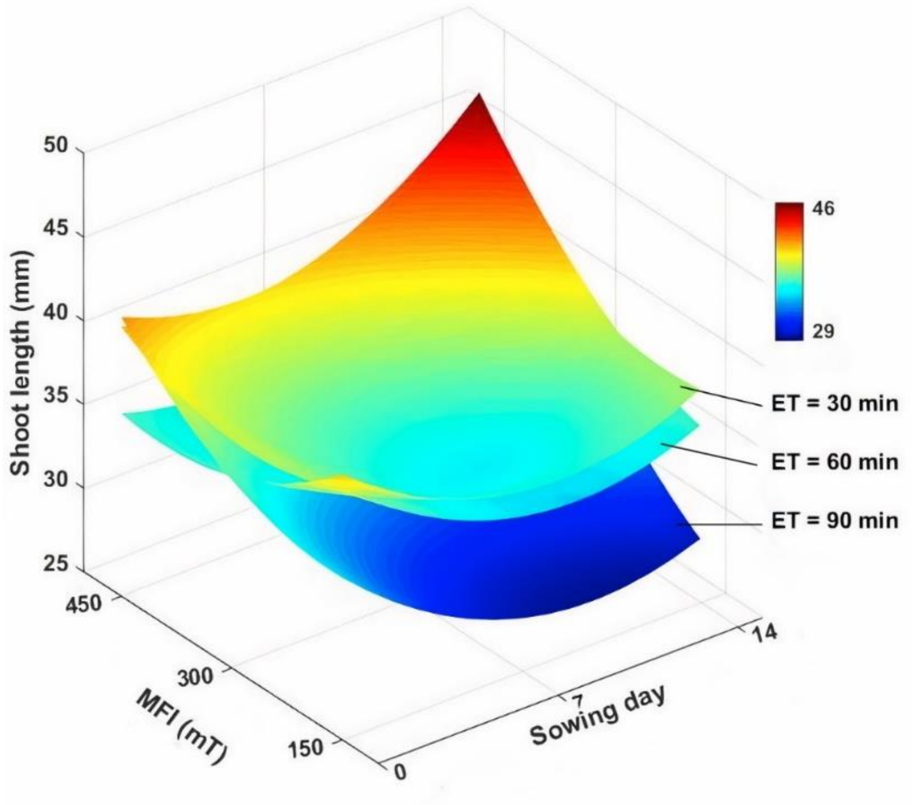

Fig. 3. 3D contour plots for shoot length against magnetic field, sowing day, and exposure time

Fresh root weight

Figure 4 illustrates the fluctuations in fresh root weight against the magnetic field, sowing day, and exposure time. While the impact of the magnetic field on fresh root weight is significant, it does not exhibit a consistent pattern. Consequently, interpreting and isolating potential factors stemming from variations in seed characteristics, such as shape and size, presents challenges. The peak value was observed at high magnetic fields of 300 and 450 mT, occurring on various sowing days. In a study examining the effect of magnetic fields (MF) on *Salvia officinalis* seeds, it was documented that the treated seeds (exposed to 15 mT for 5 min) produced radicles that were heavier and longer in fresh weight compared to the control group. Specifically, the treated seeds achieved lengths of 50.46 mm and weights of 0.11 g (Abdani Nasiri, Mortazaeinezhad, & Taheri, 2018).

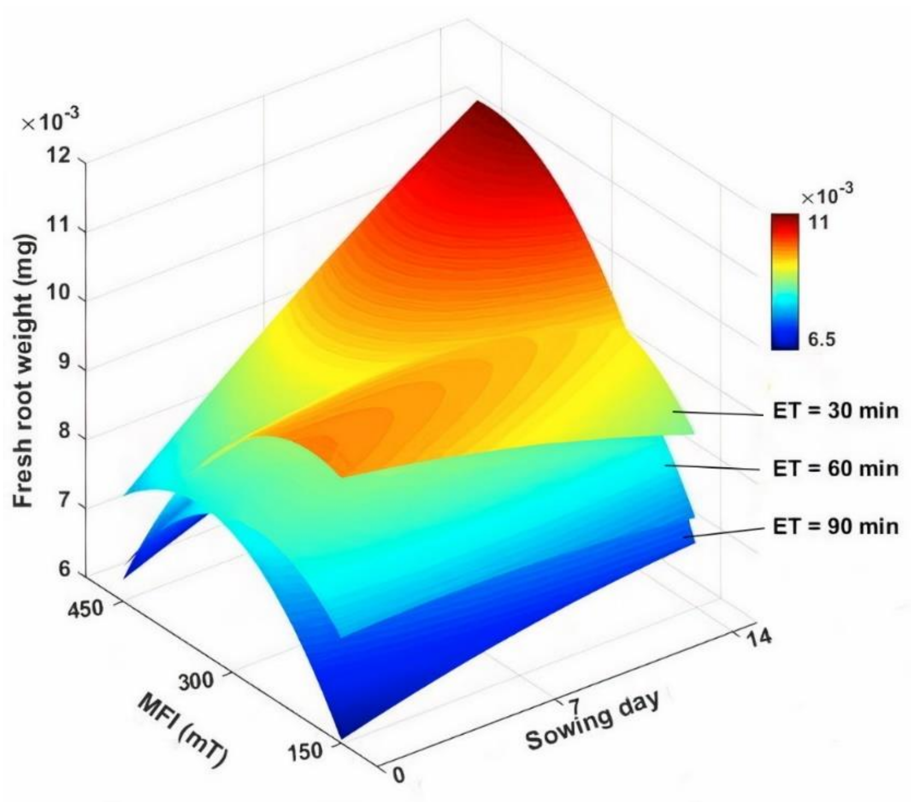

Fig. 4. 3D contour plots for fresh root weight against magnetic field, sowing day, and exposure time

Fresh shoot weight

Based on Fig. 5, the maximum fresh shoot weight correlates with a higher magnetic field, while the minimum fresh shoot weight corresponds to a lower magnetic field. It appears that the influence of the magnetic field on this parameter surpasses that on fresh root weight and exhibits consistent variability. Given that parsley's aerial components are typically in high demand, higher magnetic magnitudes seem to offer more advantageous effects. A comparison of Figs. 5 and 3 concluded that the fresh weight in the shoots increased gradually as the plant shoot duration extended. The precise mechanisms by which magnetic fields influence seeds and the stability of this effect remain unclear. The paramagnetic characteristics of atoms found in plant cells could potentially serve as one of the explanations for the beneficial effects of the magnetic field. Applying an external magnetic field has the ability to align atoms according to the direction of the magnetic field. The magnetic properties of molecules enable them to absorb energy, subsequently transferring this energy to other forms as well as other structures within plant cells, thereby activating them (Zeidali *et al.*, 2017).

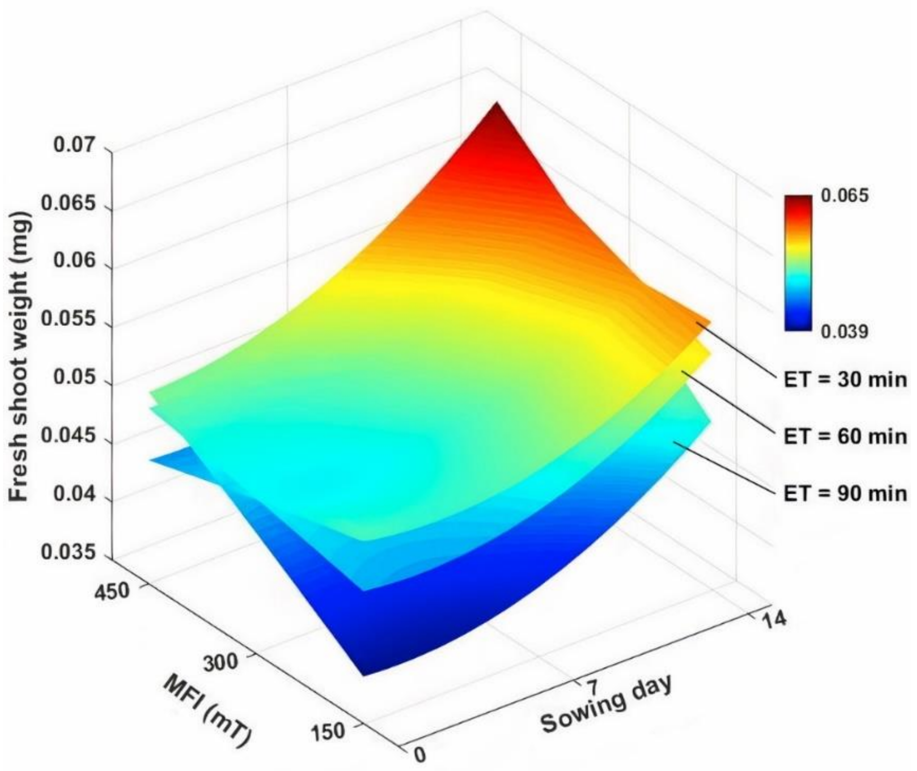

Fig. 5. 3D contour plots for fresh shoot weight against magnetic field, sowing day, and exposure time

Germination percentage

Based on Figure 6, the highest germination percentage was observed at 450 mT and sowing after 14 days, while the lowest was noted at 150 mT. Across all exposure times, a nearly parabolic trend indicated that the lowest germination percentage occurred with sowing after 7 days. Consequently, seeds treated on alternate sowing days (0 and 14 days post-magnetic field application) exhibited a significant increase in germination rate. The higher germination percentage in exposed seedlings may be attributed to their early sprouting, which results in prolonged exposure of growing meristems to electromagnetic fields. This increase could be due to the positive impact of magnetic field intensities on water uptake and the utilization of food reserves by the growing plantlets.

Germination rate

Based on Figure 7, it is generally observed that exposing seeds to low milliTesla magnetic fields tends to decrease the germination rate. However, longer sowing days and higher magnetic fields tend to increase the germination rate. This could be attributed to tiny microscopic perforations on the seed coat, which facilitate faster water uptake and consequently increase the germination rate. Moreover, the distinction between short and long sowing days turned out to be irrelevant. The process by which MF treatment promotes seed germination is linked to enhanced enzyme activity within seeds, accelerating seed water absorption, breaking seed dormancy, stimulating protein synthesis in seeds, and augmenting their respiration rate (Xia *et al*., 2024).

Mean germination time

In Figure 8, contour plots depict the relation between mean germination time and magnetic field, sowing day, and exposure time. Similar to the previous figure, the highest and lowest values of this parameter correspond to the highest and lowest magnetic fields, respectively. The stimulation of seeds by the magnetic field, along with varying sowing days and exposure times, resulted in a notable rise in this characteristic. In the study investigating the effects of magnetic fields (MF) on sunflower seeds, the most favorable outcome was observed with the application of 50 mT for 45 min. Compared to the control group, the treated seeds demonstrated significantly greater mean germination rates and antioxidant activity (Bukhari, Tanveer, Mustafa, & Zia-Ud-Den, 2021).

RSM optimization of the studied parameters

Design-expert software was used for fitting the response surfaces and optimizing the germination indices through solving a multiple regression equation (Eq. 4), using historical data, and RSM to evaluate the impact of the magnetization conditions on parsley seeds. The responses analyzed were root length (RL), stem length (SL), fresh root weight (FRW), fresh shoot weight (FSW), germination rate (GR), germination percent (GP), and mean germination time (MGT). The relationship between the input variables and the response surfaces was then determined through appropriate regression analysis. Table 3 shows the final second-order polynomial equations for each response variable in coded values, with neglected non-significant coefficients. The fitted equations correlated each response variable with the significant linear, interaction, and quadratic terms. Including the infinitesimal coefficients in the equations for fresh root weight (FRW), and fresh shoot weight (FSW) indicated minimal variations of these parameters and low affectability under the treatments. Each of the three treatments must be considered when measuring the studied parameters, as they contribute to the complex equations. However, the germination rate equation requires only the treatment of the sowing day.

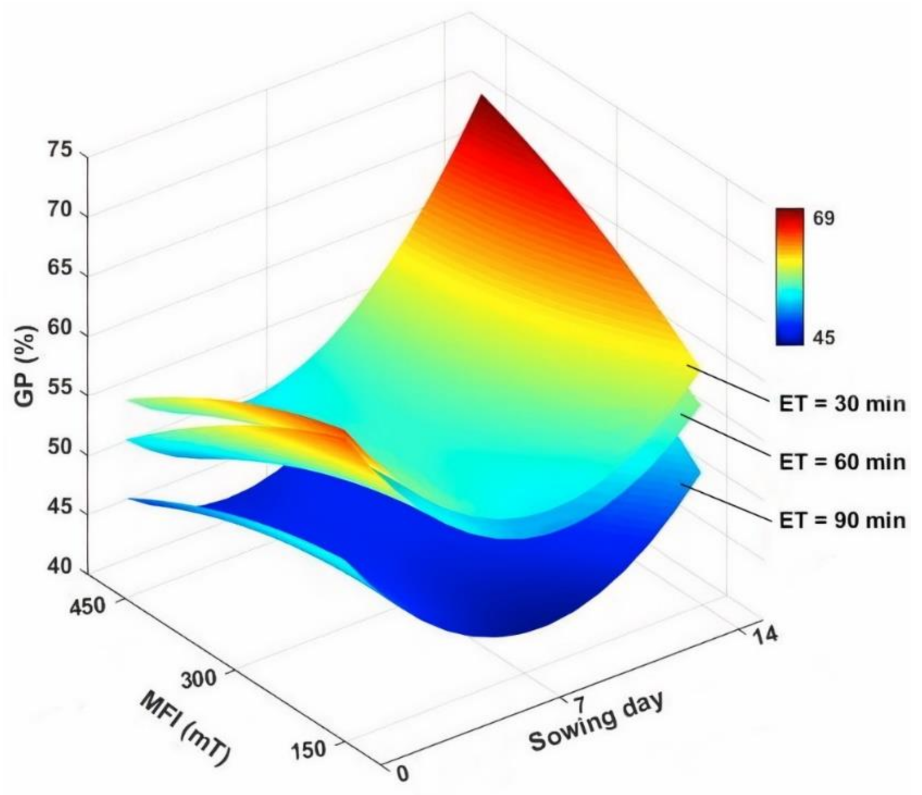

Fig. 6. 3D contour plots for germination percentage against magnetic field, sowing day, and exposure time

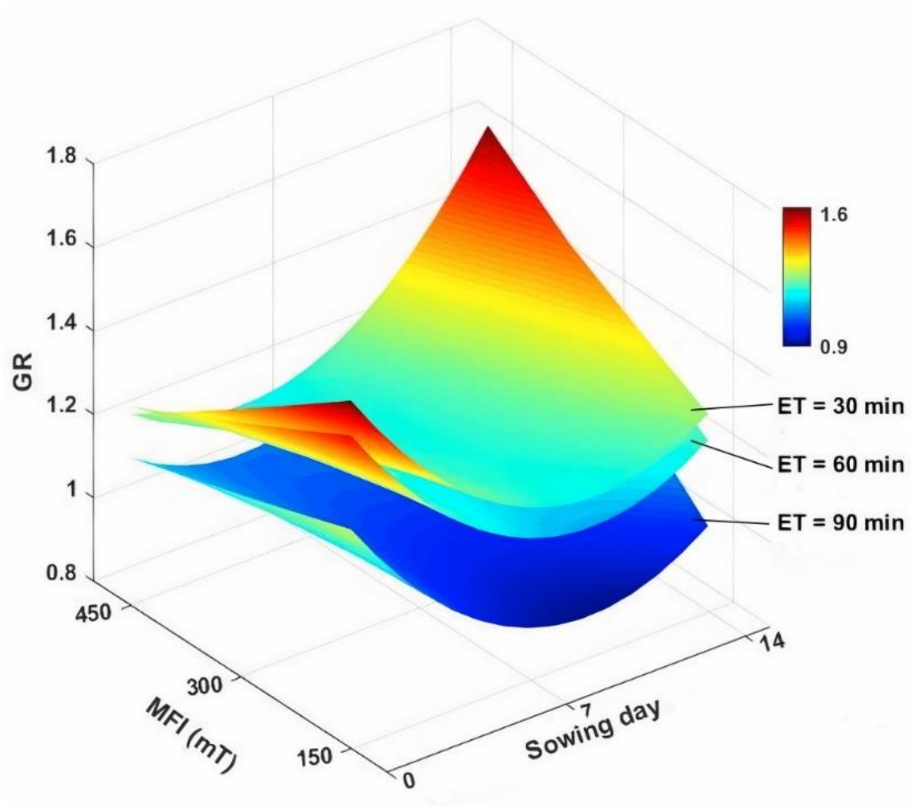

Fig. 7. 3D contour plots for germination rate against magnetic field, sowing day, and exposure time

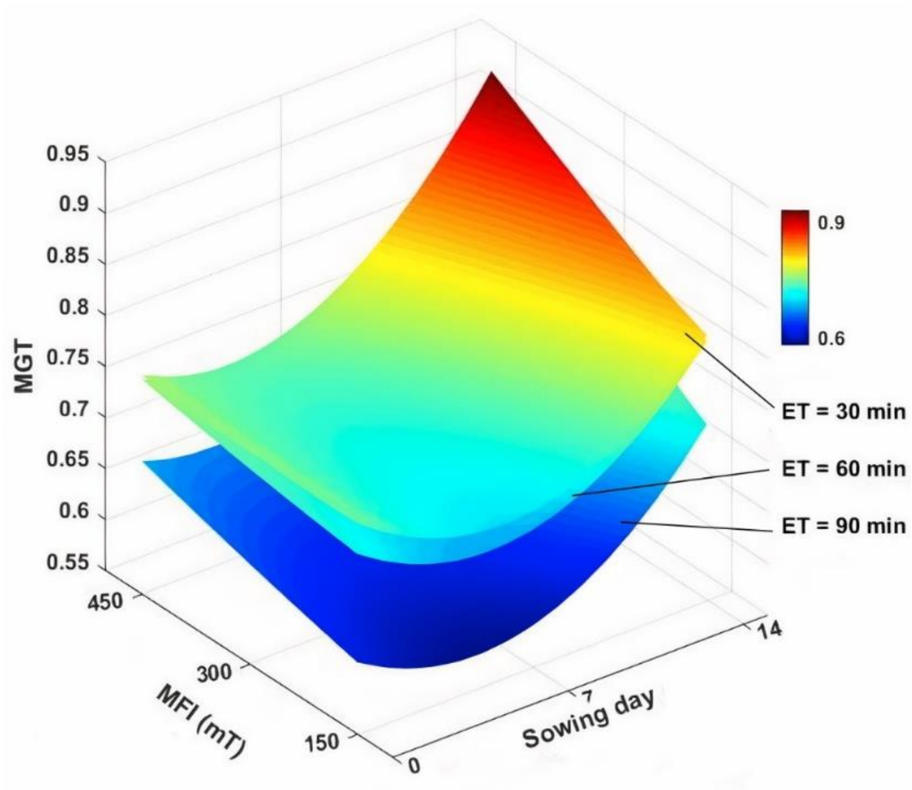

Fig. 8. 3D contour plots for mean germination time against magnetic field, sowing day, and exposure time

Table 3- Final second-order polynomial equations for each response variable in coded values, with neglected non-significant coefficients

Process variable	Second-order polynomial equations with neglected insignificant coefficients
RL	$RL=12.04-0.03\times MF+0.14\times ET-1.57\times SD+0.05\times SD^2$
SL	$SL=48.286-0.09\times MF+0.1\times ET-1.52\times SD+0.07\times SD^2$
FRW	$FRW=0.012+(2.78\times MF\times ET+6.88\times MF\times SD+26.4\times ET\times SD-0.55\times MF^2+4.69\times ET^2-27.2\times SD^2)\ e^{-7}$
FSW	$FSW=0.06+(-4.2\times MF+0.1\times MF\times ET+0.07\times MF\times SD+0.36\times ET\times SD-0.2\times ET^2+6.84\times SD^2)\ e^{-5}$
GR	$GR=1.83-0.12\times SD+0.005\times SD^2$
GP	$GP=57.27-0.02\times MF+0.56\times ET-4.34\times SD+0.2\times SD^2$
MGT	$MGT=0.73-0.024\times SD+(2.89\times MF\times ET+0.2\times MF\times SD+0.6\times ET\times SD+0.01\times MF^2-0.4\times ET^2)\ e^{-6}+0.002\times SD^2$

The primary challenge in the optimization process of the conducted research is selecting the appropriate magnetic parameters to achieve the desired response surfaces. In this study, the optimization process was conducted using an RSM-based approach, with the magnetic field, exposure time, and sowing day chosen as the key parameters. These input factors, along with their respective levels, were the critical variables in determining the criteria such as maximum root length (RL), stem length (SL), fresh root weight (FRW), fresh shoot weight (FSW), germination rate (GR), germination percent (GP), and mean germination time (MGT) (Table 4). Based on the optimization results, the first optimal working condition for seed magnetization of parsley was found to be a magnetic field of 450 mT, an exposure time of 66 min, and sowing after 14 days, with a desirability of 0.682. The responses for the total studied parameters under these conditions are detailed in Table 5.

Table 4- Criteria for simultaneous optimization of magnetic field effects on parsley seeds

Output	Criteria	Minimum value	Maximum value	Significance level
RL	Maximal	2	20	2
SL	Maximal	15.2	53.4	4
FRW	Maximal	0.001	0.014	2
FSW	Maximal	0.024	0.072	2
GR	Maximal	0.320	2.421	5
GP	Maximal	20	84	4
MGT	Maximal	0.307	1.117	5

Table 5- Optimal treatment conditions for parsley seeds: predicted responses and desirability

Number of points	MF	ET	SD	RL	SL	FRW	FSW	GR	GP	MGT	Desirability
1	450	66	14	7.219	47.099	0.01	0.063	1.614	70.674	0.926	0.682
2	450	66	14	7.219	47.096	0.01	0.063	1.614	70.688	0.927	0.682
3	450	67	14	7.216	47.113	0.01	0.063	1.612	70.606	0.926	0.682

Conclusion

The application of magnetic fields and planting time are found to affect some physiological and biochemical processes of parsley seeds, including their development. It is suggested that the pretreatment with magnetic fields (MF) has a significant impact on indices such as shoot length, fresh root weight ($p\geq 0.01$), as well as fresh shoot weight ($p\geq 0.05$). Additionally, the time exposure treatment is observed to significantly affect root length ($p\geq 0.01$). The sowing day is noted to have a significant impact on root length, fresh root weight ($p\geq 0.01$), and also a significant effect on other indices ($p\geq 0.05$). The longest shoot length and the highest fresh shoot weight of parsley are observed when exposed to a magnetic field of 450 mT for 60 minutes, sown 14 days after exposure. It is indicated that exposure to stationary magnetic fields of 450 mT for 30 minutes, followed by planting after 7 days, enhances shoot length, fresh root weight, fresh shoot weight, mean germination time (MGT), germination rate (GR), and germination percentage (GP) indices of parsley seeds under laboratory conditions. For instance, the fresh shoot weight is found to be highest with a magnetic field of 450 mT for 90 minutes, sown 14 days post-exposure. Additionally, the combination of a 300 mT magnetic field, a 30-minute exposure time, and planting on the 7th day after exposure significantly increases the fresh root weights. The seed magnetization strategy, followed by selecting the optimal points (magnetic field of 450 mT, exposure time of 66 minutes, sown after 14 days, with a desirability of 0.682), is found to enhance the performance of magnetic treatments, promoting various seedling growth and germination indices for parsley seeds.

Conflict of Interest: The authors declare no competing interests.

Authors Contribution

M. Rafiei: Data acquisition, Statistical analysis.

F. Khoshnam: Supervision, Writing-Original draft and editing.

M. Namjoo: Data pre and post processing, Software, Modeling and Optimization, Validation.

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مدل‌سازی و بهینه‌سازی تاثیر میدان مغناطیسی روی بذر جعفری (*Petroselinum crispum*) به روش پاسخ سطح

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چکیده

در این تحقیق، مدل‌سازی و بهینه‌سازی رشد گیاهچه‌های مختلف بذر جعفری و شاخص‌های جوانه‌زنی آن مورد بررسی قرار گرفت. بدین منظور میدان مغناطیسی چهار قطبی آزمایشگاهی ساخته و آزمایش‌ها به‌صورت فاکتوریل در قالب طرح کاملاً تصادفی با سه تکرار انجام شد. فاکتورهای شدت میدان مغناطیسی (۱۵۰، ۳۰۰ و ۴۵۰ میلی‌تسلا)، مدت زمان اعمال میدان بر روی بذرها (۳۰، ۶۰ و ۹۰ دقیقه)، و زمان کاشت (۰، ۷ و ۱۴ روز پس از اعمال میدان مغناطیسی) در نظر گرفته شد. نتایج نشان داد که میدان مغناطیسی بر طول ساقه‌چه، وزن تر ریشه‌چه و وزن تر ساقه‌چه، و مدت زمان اعمال میدان بر طول ریشه‌چه تاثیر معنی‌داری دارد. زمان کاشت و فاکتورهای دیگر تاثیر معنی‌داری بر طول ریشه‌چه و وزن تر ریشه‌چه داشت. زمان کاشت بلافاصله پس از اعمال میدان مغناطیسی طول ریشه را افزایش، ولی زمان کاشت پس از ۱۴ روز همراه با مدت زمان اعمال میدان باعث افزایش طول ساقه‌چه، وزن تر ریشه‌چه و وزن تر ساقه‌چه شد. مدت زمان اعمال میدان ۳۰ دقیقه و شدت میدان مغناطیسی بین ۱۵۰ و ۳۰۰ میلی‌تسلا تاثیر معنی‌داری بر پارامترهای گیاهچه نداشت. با این حال شدت میدان‌های بالاتر از ۴۵۰ میلی‌تسلا و مدت زمان ۶۰ و ۹۰ دقیقه موثرتر بوده و منجر به افزایش طول ساقه‌چه، وزن تر ریشه‌چه، وزن تر ساقه‌چه، سرعت جوانه‌زنی، درصد جوانه‌زنی و میانگین زمان جوانه‌زنی شد. تحلیل و بهینه‌سازی به کمک روش سطح پاسخ نشان داد که شرایط مغناطیسی بهینه، با مقبولیت ۰/۶۸۲، در میدان مغناطیسی ۴۵۰ میلی‌ثانیه، مدت زمان اعمال ۶۰ دقیقه و پس از ۱۴ روز کاشت به‌دست آمد. به نظر می‌رسد که میدان‌های مغناطیسی بالاتر ماندگاری میدان مغناطیسی را افزایش داده و تاثیر معنی‌داری بر شاخص‌های رشد گیاهچه دارد.

واژه‌های کلیدی: جعفری، جوانه‌زنی، ماندگاری، مدل‌سازی، میدان مغناطیسی

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