

## THE IMPACT OF VARIED EXPOSURE DURATION TO ELF (EXTREMELY LOW FREQUENCY) MAGNETIC FIELD ON OLD RICE (*Oryza sativa* L.) SEED VIABILITY



Fahmi Azrial<sup>1\*</sup>, Dwijowati Asih Saputri<sup>1)</sup>, Ika Listiana<sup>1)</sup>

<sup>1)</sup>Universitas Islam Negeri Raden Intan Lampung

\*Corresponding author: [fahmiazrial77@gmail.com](mailto:fahmiazrial77@gmail.com)

### To cite this article:

Azrial, F., Saputri, D. A., & Listiana, I. (2025). The Impact of Varied Exposure Duration to ELF (Extremely Low Frequency) Magnetic Field on Old Rice (*Oryza sativa* L.) Seed Viability. *Jurnal Ilmiah Membangun Desa Dan Pertanian*, 10(1), 83–97. <https://doi.org/10.37149/jimdp.v10i1.1661>

**Received:** November 23, 2024; **Accepted:** March 22, 2025; **Published:** March 23, 2025

### ABSTRACT

The deterioration in the viability of rice seeds (*Oryza sativa* L.) during storage, frequently attributed to damage to the cell membrane and accumulation of reactive oxygen species (ROS), presents significant challenges for rice cultivation. ELF magnetic fields offer an eco-friendly solution by enhancing cellular responses and repairing membranes. This study investigated the impact of exposure to a 0.2 mT ELF magnetic field on the viability of 8-month-old aged rice seeds (Inpari 32 HDB variety) using a Completely Randomized Design (CRD) with four exposure durations: control (M0), 3 minutes 54 seconds (M1), 7 minutes 48 seconds (M2), and 11 minutes 42 seconds (M3), replicated four times. Results indicated significant improvements in viability, with M2 and M3 yielding optimal germination rates (98.00%, 97.50%), reduced mean germination time (2.47 days), and enhanced germination index (268.75). Radicle and plumule lengths also increased (6.95 cm and 4.82 cm, respectively). Although germination speed coefficient, germination time, and uniformity values (51.50–60.50%) showed only minor improvements, the results underscore the potential of ELF magnetic fields as a sustainable method to enhance aged rice seed viability, contributing to improved agricultural practices.

**Keywords:** cell membrane; germination; vigor.

### INTRODUCTION

Seeds are one of the essential components in rice (*Oryza sativa* L.) cultivation. The success of rice production heavily depends on the quality of seeds used, particularly their viability. Viability indicates the seed's ability to germinate and produce normal seedlings (Sutradhar et al., 2021). However, seed viability can decline due to storage age (Muis & Firmansyah, 2021). Bista et al. (2022) reported that rice seeds with 8 months of storage showed decreased germination rates compared to seeds stored for 7 months. This indicates that seed quality will continue to decline with longer storage duration (Delouche, 2021).

The deterioration in seed viability during storage is caused by several factors, including reduced food reserves, cell membrane damage, decreased enzyme activity, and accumulation of toxic compounds (Chhabra & Singh, 2019). Kurek et al. (2019) further explained that the decline in seed viability is also influenced by oxidative damage to cell membranes. This phenomenon arises due to the increased creation of reactive oxygen species (ROS) throughout the seed aging process. Additionally, aging cells in seeds can experience metabolite leakage that affects their viability (Avivi, 2021).

Various efforts have been developed to address the problem of viability decline in aged seeds, such as soaking (Afdharani et al., 2019), priming (Megasari, 2022), hormone treatment (Liana et al., 2022), and magnetic field exposure (Radhakrishnan, 2019). Among these methods, using magnetic fields is interesting for further research due to its safe and affordable nature in promoting plant growth (Nyakane, 2019).



A magnetic field (MF) consists of poles that repel and attract each other (Ida, 2021). MF induction can enhance seed germination and stimulate vegetative growth by modifying electron activity at the cellular level, accelerating metabolic activities (Saletnik et al., 2022).

The mechanism of MF in improving seed viability involves several cellular processes. MF can activate cellular voltage responses, synthesize DNA and RNA, protect gene stress expression, and promote cellular proliferation (Djoyowasito et al., 2019). Song et al. (2024) elucidated that applying ELF MF to seeds has the potential to optimize seed viability and vigor. This phenomenon is attributed to mechanisms involving the restoration of cellular membrane integrity and the augmentation of antioxidant enzyme activity. Moreover, the application of MF can potentially modify both the physicochemical characteristics of water when utilized as a germination medium, thereby facilitating an accelerated progression in the developmental pace of seed growth (Kusumawardani et al., 2021).

ELF MF is a specific category of electromagnetic wave characterized by a modest magnetic field intensity ranging from 0.1 to 1.0 millitesla (mT), capable of eliciting non-thermal biological or physiological responses (Putri et al., 2022). ELF MF is environmentally friendly as it does not produce waste and harmful radiation (Tekam et al., 2024), making it suitable for supporting sustainable modern agriculture.

Although research related to MF induction has been conducted on several plant species such as tomatoes (Hasanah et al., 2019), corn (Alattar et al., 2021), red chili (Laksmiari, 2021), turmeric (Kamble et al., 2022), and soybeans (Tirono, 2022), research on aged rice seeds is still rarely conducted. Therefore, this research aims to analyze the impact of extremely low-frequency (ELF) magnetic field (MF) exposure at a strength of 0.2 millitesla (mT) on the viability of aged rice (*Oryza sativa* L.) seeds.

## **MATERIALS AND METHODS**

This research was executed in June 2024 at the Botany Laboratory within the Faculty of Mathematics and Natural Sciences at the University of Lampung. The research method used a Completely Randomized Design (CRD) with four treatments and four replications performed in duplicate. The treatments consisted of four exposure time variations: 0 minutes as control (M0), 3 minutes 54 seconds (M1), 7 minutes 48 seconds (M2), and 11 minutes 42 seconds (M3). The research sample used 8-month-old Inpari 32 HDB rice variety seeds, with 800 seeds distributed in 16 experimental units. Each experimental unit consisted of 50 seeds. Data analysis used One-Way ANOVA and DMRT (Duncan Multiple Range Test) as a post-hoc test with a significance level of  $\alpha=5\%$ .

### **Seed Sorting**

The seeds used in this research were Inpari 32 HDB variety with 8 months storage age. Seeds that were undamaged and had a hard texture were selected for use. The seeds were subsequently soaked in filtered water for five minutes to evaluate their viability, where floating seeds were discarded as they indicated low seed quality. Then, seed sterilization was performed using 1% NaClO solution for 10 minutes (Shofiyani et al., 2020). After this procedure, the seeds were meticulously rinsed with purified water to expunge any lingering traces of the solution.

### **Magnetic Field Induction**

The seeds were drenched in water for 24 hours. After soaking, the seeds were placed in containers lined with straw paper. The seeds were subsequently subjected to a MF induction of 0.2 millitesla (mT) with differing exposure durations of 0 minutes/control (M0), 3 minutes 54 seconds (M1), 7 minutes 48 seconds (M2), and 11 minutes 42 seconds (M3). Each treatment was replicated 4 times (Jannah & Hariyono, 2022).

### **Germination**

Following the MF induction treatment, the seeds were germinated under controlled conditions. The germination process was continued until the emergence of radicles measuring 2 mm in length was observed. The seedlings were placed in a shaded location, avoiding direct sunlight, for 7 days.

### **Parameters**

#### **Percentage of Normal Seedlings (PNS)**

Normal seedlings are seen from seedlings with perfectly grown plumules and radicles. It can be calculated using the following formula (ISTA, 2010):

$$PNS = \frac{nN}{N} \times 100\% \quad (1)$$

Remarks: nN = number of regular germinated seeds, N = total germinated seeds

### **Percentage of Abnormal Seedlings (PAS)**

Abnormal seedlings are characterized by unusual growth characteristics, such as weak primary and secondary roots, rotting in certain parts, coleoptiles without pigments, and the absence of the first leaf (Prabhandaru & Saputro, 2017). It can be calculated using the following formula (ISTA, 2010):

$$PAS = \frac{nA}{N} \times 100\% \quad (2)$$

Remarks: nA = count of seeds exhibiting abnormal germination, N = total count of germinated seeds

### **Mean Germination Time (MGT)**

Mean germination time refers to the average duration needed for seeds in each experimental unit to germinate, which indicates the germination rate in each unit (Fernández-Pascual et al., 2021). The calculation can be enacted by applying the formula provided by Al-Mudaris (1998):

$$MGT = \frac{\sum f \cdot x}{\sum f} \quad (3)$$

Remarks: f = seeds germinated on day x, x = day of observation

### **Germination Speed Coefficient (GSC)**

The germination speed coefficient is measured to determine the germination speed index by applying the specified formula (Al-Mudaris, 1998):

$$GSC = \frac{N_1 + N_2 + \dots + N_x}{100 (N_1 T_1 + N_2 T_2 + \dots + N_x T_x)} \quad (4)$$

Remarks: N = the number of seeds that successfully germinate each day, T = the time, measured in days, necessary for seed germination to occur

### **Germination Rate (GR)**

The germination rate is computed to determine the germination level of seeds tolerant to dry conditions, employing the specified formula (Al-Mudaris, 1998):

$$GR = \frac{G_1}{1} + \frac{G_2}{2} + \dots + \frac{G_x}{x} \quad (5)$$

Remarks: G1 = germination percentage x100 (first day after sowing), G2 = germination percentage x 100 (second day after sowing)

### **Germination Index (GI)**

The germination index is the relationship between the percentage and speed of germination (Afzal et al., 2021). The calculation can be performed by applying the formula as described by Al-Mudaris (1998):

$$GI = (7 \times n_1) + (6 \times n_2) + \dots (1 \times n_7) \quad (6)$$

Remarks: n1, n2,.. n7 = the cumulative count of seeds germinated up to the seventh day, 7, 6, ... 1 = numbers indicating the number of days in the observation

### **Germination Time Span (GTS)**

GTS is the time span between each experimental unit's first and last days of seed germination (Al-Mudaris, 1998).

### Vigor Index (VI)

The vigor index assesses the capacity of seeds to rapidly and consistently germinate and develop across diverse environmental conditions. It can be calculated using the formula (Abdul-Baki & Anderson, 1970):

$$VI = SL \times GP \quad (7)$$

Remarks: SL = seedling length, GP = germination percentage

### Seed Uniformity of Growth (SUG)

The uniformity of seed growth is evaluated by ascertaining the proportion of robust, standard seedlings on the fourth day, quantified through the application of the ensuing equation (Sadjad, 1993):

$$SUG = \frac{NU}{TB} \times 100\% \quad (8)$$

Remarks: NU = number of uniform seedlings, TB = total seeds tested

### Radicle and Plumule Length

The length of the plumule in viable seedlings is ascertained by evaluating the measurement spanning from the basal region of the hypocotyl to the terminal point of the primary leaf situated at the apical extremity of the seedling. Radicle length is measured by calculating the longitudinal distance along the longitudinal axis from the root's base to its apex, specifically on the basal section of a normal seedling. Sampling for measuring plumule and radicle length involved 10 seedlings from each experimental replication, randomly taken from a population of 50 seeds in one lot, with measurements taken on the last day of observation (Rosyad & Qadir, 2022).

## RESULTS AND DISCUSSION

The results of the statistical analysis on all observation parameters, including the percentage of normal and abnormal seedlings, mean germination time, germination speed coefficient, germination rate, germination index, germination time, vigor index, seed uniformity of growth, and radicle and plumule length, are presented in Table 1.

Table 1. Research results on all parameters

Parameters	Average			
	0 minutes (M0)	3 minutes 54 seconds (M1)	7 minutes 48 seconds (M2)	11 minutes 42 seconds (M3)
Percentage of Normal Seedlings (%)	<sup>a</sup> 93.00±2.58	<sup>ab</sup> 94.00±3.65	<sup>b</sup> 98.00±1.63	<sup>b</sup> 97.50±1.91
Percentage of Abnormal Seedlings (%)	<sup>b</sup> 7.00±2.58	<sup>ab</sup> 6.00±3.65	<sup>a</sup> 2.00±1.63	<sup>a</sup> 2.50±1.91
Mean Germination Time (days)	<sup>b</sup> 2.79±0.09	<sup>ab</sup> 2.63±0.07	<sup>a</sup> 2.47±0.21	<sup>a</sup> 2.47±0.07
Germination Speed Coefficient	<sup>a</sup> 27.80±15.94	<sup>a</sup> 38.07±1.02	<sup>a</sup> 40.74±3.25	<sup>a</sup> 40.69±1.61
Germination Rate (%/day)	<sup>a</sup> 17.78±0.53	<sup>ab</sup> 19.31±0.23	<sup>b</sup> 20.98±1.54	<sup>b</sup> 20.56±1.58
Germination Index	<sup>a</sup> 243.25±4.6	<sup>ab</sup> 257.00±3.16	<sup>b</sup> 368.75±9.98	<sup>b</sup> 263.25±14.16
Germination Time Span (days)	<sup>a</sup> 3.75±1.50	<sup>a</sup> 3.25±0.96	<sup>a</sup> 3.00±0.82	<sup>a</sup> 4.00±0.82
Vigor Index	<sup>a</sup> 83.38±12.52	<sup>c</sup> 142.54±11.10	<sup>b</sup> 108.19±9.96	<sup>d</sup> 163.65±17.08
Seed Uniformity of Growth (%)	<sup>a</sup> 51.50±3.41	<sup>a</sup> 54.00±4.32	<sup>a</sup> 56.50±6.19	<sup>a</sup> 60.50±13.00
Radicle Length (cm)	<sup>a</sup> 6.12±0.22	<sup>b</sup> 6.95±0.33	<sup>b</sup> 6.77±0.22	<sup>b</sup> 6.92±0.46
Plumule Length (cm)	<sup>a</sup> 4.07±0.46	<sup>b</sup> 4.67±0.45	<sup>b</sup> 4.80±0.14	<sup>b</sup> 4.82±0.26

Remark: Numbers accompanied by identical letters within the same row denote the absence of a statistically significant difference according to the DMRT test at a significance level of  $\alpha = 5\%$ .

### Percentage of Normal Seedlings

The test results (Table 1) show that the length of exposure to ELF MF significantly influenced the percentage of normal seedlings. Treatments M2 and M3 yielded the highest mean percentages of normal seedlings, achieving 98.00% and 97.50%, respectively, which were significantly elevated compared to those in the control group.

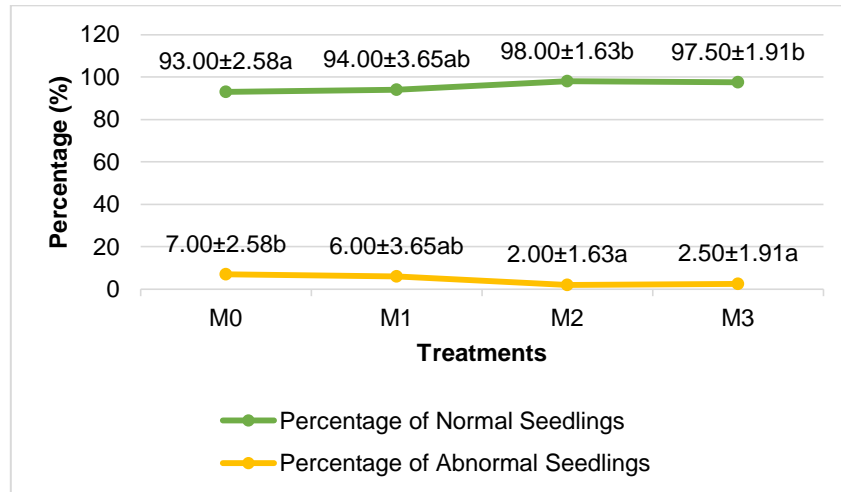


Figure 1. Percentage of normal and abnormal seedlings induced by 0.2 mT MF

In contrast, treatment M1 did not exhibit a statistically significant effect on the control group. Nevertheless, there was an observable rise in the mean percentage of normal seedlings compared to the control (Figure 1). The observed rise in the proportion of normal seedlings aligns with the findings of Lette et al. (2019), who stated that exposure to an MF of 4.33 mT affected the percentage of normal seedlings in rice seeds.

The rise in the proportion of normal seedlings indicates that the MF can repair damaged tissue structures in aged seeds that have experienced a lack of starch and protein (Ćalić et al., 2023). Furthermore, subjecting seeds to an MF has been shown to enhance the accumulation of food reserves to produce energy (Kamila & Sudarti, 2022). This increase in food reserves occurs due to enhanced activity of enzymes associated with the germination process, such as  $\alpha$ -amylase and protease, which provide substrates for the cell respiration process to take place (Asra et al., 2020).

### Percentage of Abnormal Seedlings

The study's findings indicate that exposure to ELF MF significantly influenced the proportion of seedlings exhibiting abnormalities (Table 1). Treatments M2 and M3 resulted in the lowest percentage of abnormal seedlings, 2.00%, and 2.50%, respectively. Meanwhile, treatment M1 did not show a significant effect on the control but showed a lower average compared to the control (Figure 1).

This research aligns with the research conducted by Hayati and Setiono (2021), who stated that the aging process or physiological decline of vigor is marked by a reduction in germination potential, a rise in the occurrence of abnormal seedlings, and a decline in seedling emergence in the field, which can ultimately reduce plant production.

The reduced percentage of abnormal seedlings indicates that MF treatment can repair damaged tissues in aged seeds, which is the impact of a lack of starch and protein in plants. In addition, the MF treatment has been proven to elevate the accumulation of food reserves in plants. This increase is attributed to the elevated activity of key roles in the germination process, especially  $\alpha$ -amylase and protease, which provide cellular respiration substrates (Habibah, 2022).

According to Gea et al. (2022), abnormal seedlings are defined as seedlings that cannot develop into normal seedlings. There are four types of abnormal seedlings: seedlings with organ damage, seedlings with disproportionate or weak growth, seedlings affected by severe disease, and seedlings with delayed growth that do not reach standard size at the end of the testing period.

Ashar et al. (2024) also classify seeds that cannot germinate until the end of the testing period into four categories: hard seeds, healthy seeds with standard growth potential that fail to germinate, dead seeds in a non-hard and non-fresh condition, and empty seeds with little tissue inside.

### Mean Germination Time

The findings from the DMRT analysis, as displayed in Table 1, demonstrate that the exposure period to ELF MF had a notable impact on the time required for germination. Exposures for 7 min 48 sec and 11 min 42 sec resulted in the fastest mean germination time of 2.47 days. Meanwhile,

exposure for 3 minutes and 54 seconds did not show a significant effect, with a mean germination time of 2.63 days.

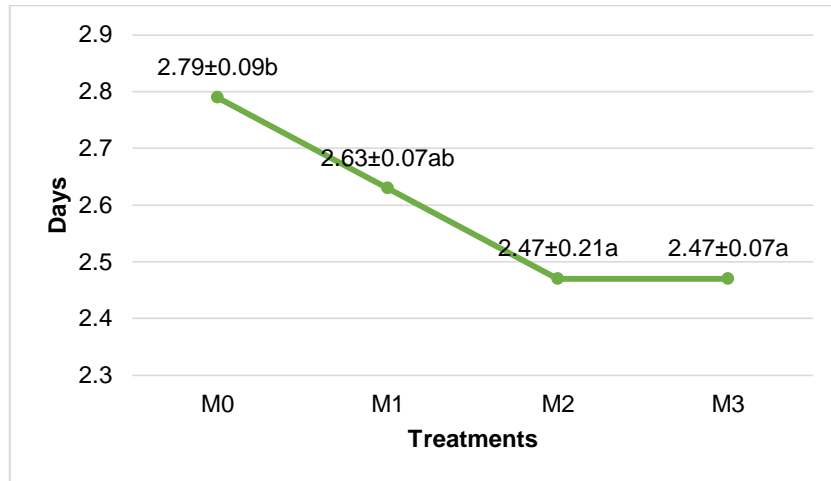


Figure 2. Mean germination time at various exposure times of 0.2 mT MF

This outcome is in agreement with the work of Li et al. (2022), who revealed that subjecting seeds to an electric field can shorten their dormancy phase. This effect is attributed to the electric field's capacity to alter interactions within plant cell membranes.

The increase in germination speed induced by the ELF MF can be explained by changing the permeability of ion channels within cell membranes. This change affects the transport of ions into the cell, which in turn causes biological changes in the organism. Ullrich and Apell (2021) support this argument by stating that exposure to an MF can alter the functionality of ion pumps in cells, primarily related to the transport of calcium ions ( $Ca^{2+}$ ) when the cell membrane is exposed to an MF, energy transfers from the field to the ions. This results in an increase in the speed and rate of ion flow across the cell membrane. The heightened level of cellular activity suggests that the cell transitions into the initial stages of the mitotic cycle, a pivotal period essential for plant germination and early developmental phases.

### Germination Speed Coefficient

The findings in Table 1 demonstrate that the duration of exposure to the ELF MF has no substantial impact on the parameter of the germination speed coefficient. However, the M2 treatment yielded the highest coefficient value, 40.74. Previous findings on local Bangka rice seeds, specifically the Mayang accession, indicated that seeds aged 7 months exhibited the highest germination speed. (Kartika & Sari, 2015). This suggests that exposure to an MF can potentially enhance the efficiency of metabolic processes in seeds.

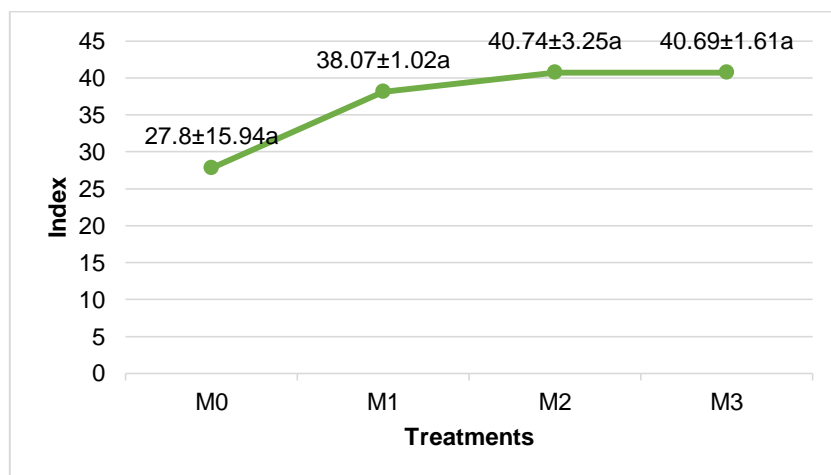


Figure 3. Coefficient of germination velocity at various exposure times of 0.2 mT MF

The increase in metabolic performance induced by the MF relates to the activity of growth regulators (plant hormones). Putri et al. (2022) explain that growth regulators only require a specific concentration to function effectively. Exposing seeds to an appropriate intensity of MF can enhance their metabolic activities, leading to optimized physiological processes. Aisyah et al. (2020) explored that the metabolic boost observed in germinating seeds due to MF exposure contributes to the sufficiency of the energy required to produce normal seedlings.

Growth rate is an important indicator of seed vigor and growth strength. Nugraheni et al. (2019) emphasized that seeds with high growth rates can withstand sub-optimal field conditions better. Drawing from the outcomes of this investigation, it can be inferred that seeds treated with ELF MF have strong growth rates, indicating an increase in seed vigor.

### Germination Rate

The DMRT test analysis showed a statistically significant impact of ELF MF exposure on the germination rate parameter. Treatment M2 showed the highest effectiveness, with an index value reaching 20.98%/day.

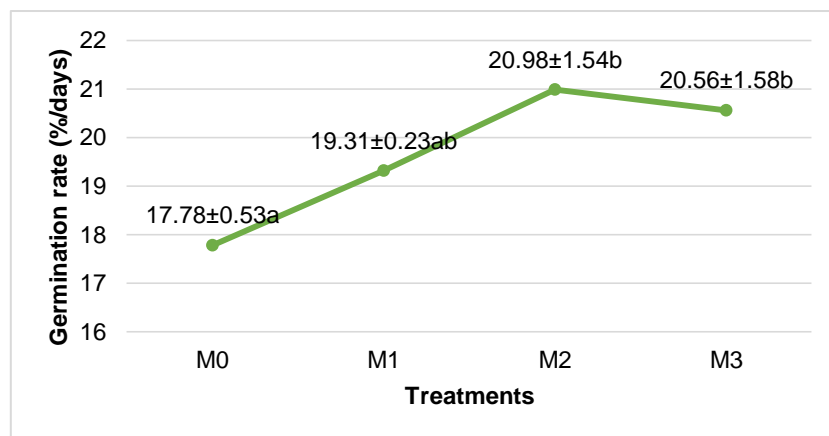


Figure 4. Germination rate at various exposure times of 0.2 mT MF

The outcomes of this research align with the conclusions drawn by Yulianto et al. (2022), who posited that exposure to an MF can enhance the germination rate. Priatama et al. (2022) explained that this increase in germination rate is related to the influence of physical factors, including electromagnetic radiation, ionization, and nitric oxide, which can induce a triggering effect on plant seeds, thereby increasing not only the germination rate but also growth and fruit production.

The increase in germination rate occurs due to changes in cell membrane permeability induced by the MF treatment. Rostami et al. (2014) argued that the energy in seeds responds positively to MF treatment, where seeds subjected to an MF experience changes in potential energy, resulting in the acceleration of electron movement in the cell. Wang et al. (2019) added that MF treatment also increases the absorption of  $Ca^{2+}$  ions into the cell, which contributes to the increase in osmotic pressure in the seeds.

This increase in osmotic pressure has a cascading effect on the physiological processes of the seed, namely an increase in water absorption by the seed (Mustika et al., 2022). This process causes the hydrogen bonds in water molecules to break, facilitating more efficient distribution by the seed cells. As a result, an increase in water potential induces seed hydration. This series of physiological changes collectively contributes to the increase in seed germination rate (Sativa et al., 2022).

### Germination Index

Based on the analysis results presented in Table 1, MF exposure significantly influenced the germination index of aged rice seeds, namely in treatments M2 and M3, with average values of 268.75 and 263.25, respectively. These outcomes corroborate the findings of Nurbaity et al. (2019), who stated that MF exposure significantly influences the germination index in sorghum seeds.

The phenomenon of metabolic growth recovery in aged seeds exposed to an MF occurs due to two main mechanisms: enhanced activity of enzymes associated with the germination process and the plant's improved capacity to absorb nutrients (Agustrina et al., 2022). Perveen et al. (2021) explained that the germination process is accelerated by increased activity of enzymes related to

germination. These enzymes help break down the nutrient reserves in the seeds into simpler forms. The decomposed nutrients can then be efficiently utilized in glycolysis and various metabolic reactions to generate the energy required during germination.

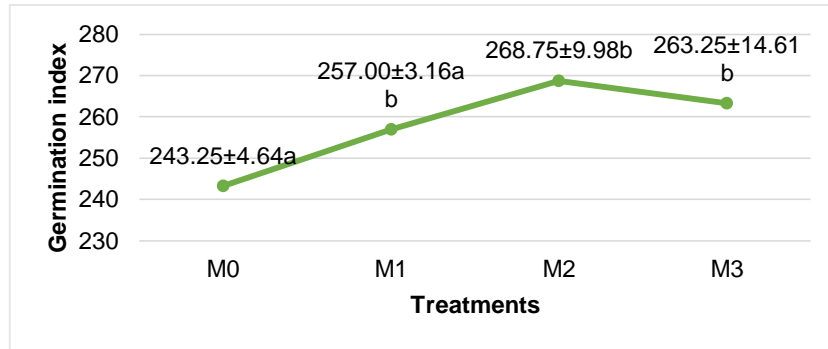


Figure 5. Germination index at various exposure times of 0.2 mT MF

### Germination Time Span

The application of ELF MF to aged rice seeds did not result in statistically significant variations in the duration of the germination period (Table 1). Nonetheless, a trend toward reducing the average germination period was observed in the M1 and M2 treatments, with values of 3.25 days and 3.00 days, respectively (Figure 6).

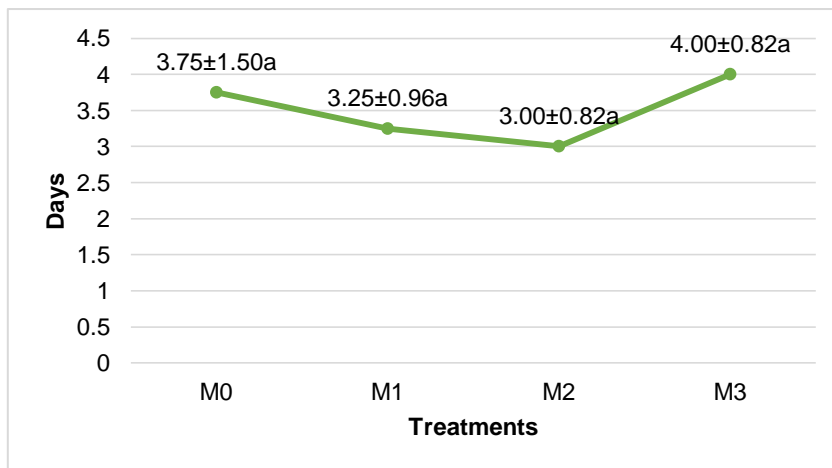


Figure 6. Germination time at various exposure times of 0.2 mT MF

ELF MF exposure induces changes in the position of positive and negative ions in the seed membrane due to electron transport (Lette et al., 2019). Tnunay (2021) further explained that electron transport is the process of transporting electrons through membranes in the plasma membrane and membrane-bound organelles such as chloroplasts and mitochondria. This process involves specific carrier proteins, including ubiquinone, essential for forming cell energy.

Agustina et al. (2021) revealed that modifications in cell membrane permeability due to electron transport can stimulate plant growth processes through cell division or acceleration. In the context of aged rice seeds, this effect has the potential to stimulate the initiation of germination. Mar'atushaliha (2023) added that electric fields can also affect ion transport during germination, especially in the water absorption phase. These changes in membrane permeability subsequently impact the metabolism and movement patterns of ions in plant cells.

### Vigor Index

Data analysis in Table 1 shows that the duration of ELF MF exposure significantly influenced the vigor index in all treatments, with the highest average value of 163.65 in treatment M3. This evidence parallels the research of Melta et al. (2022), who highlighted a significant impact of 0.2 mT MF exposure on the vigor index in chili plants.

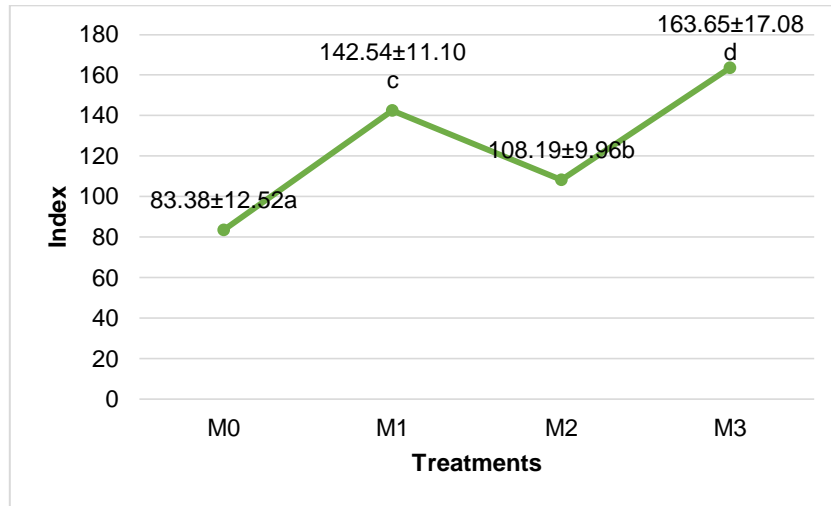


Figure 7. Vigor index at various exposure times of 0.2 mT MF

The vigor index is an important indicator that represents seed quality. A high vigor index indicates superior germination speed and better resistance to suboptimal environmental conditions. Conversely, a low vigor index indicates seed deterioration may adversely affect the potential for plant growth and overall productivity (Winda et al., 2023).

Tefa (2018) identified several characteristics that characterize high seed vigor, including (1) resistance to long-term storage, (2) resistance to pests and diseases, (3) rapid and uniform growth, and (4) the ability to produce regular and productive adult plants under suboptimal environmental conditions. Powell (2022) explained that there is a positive relationship between vigor and various aspects of seed growth. These aspects include high germination capacity, a robust root and shoot system (even in less-than-ideal environmental conditions), and resistance to disease-causing microorganisms.

### Seed Uniformity of Growth

According to the findings illustrated in Figure 8, the seed uniformity of growth tested ranged from 51.50 to 60.50%. These results indicate that the seeds had a high level of growth uniformity.

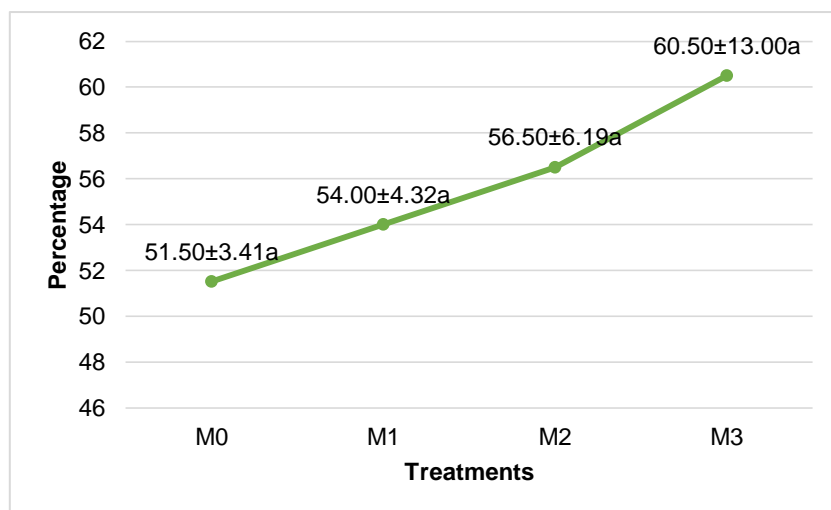


Figure 8. Seed growth simultaneity at various exposure times of 0.2 mT magnetic field

According to the criteria set by Sadjad (1993), the seed uniformity of growth can be categorized into several groups. Seeds with a uniformity level of 40-70% are categorized as standard, while those exceeding 70% indicate excellent vigor. On the other hand, seeds with a uniformity of growth of less than 40% are considered to have poor vigor. Sambayu and Muharam (2021) emphasized that the level of uniformity of growth is closely related to the overall vigor index of the

plant, as seeds that grow simultaneously and strongly usually show superior growth strength, reflecting a high absolute vigor.

### Radicle Length

The statistical analysis in Table 1 and Figure 9 shows that the length of exposure to ELF MF significantly influenced the radicle length of aged rice seeds.

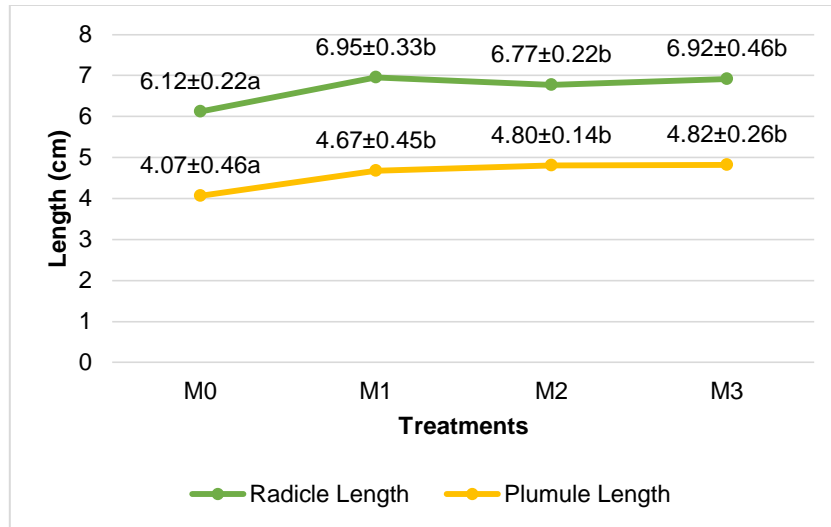


Figure 9. Radicle and plumule length at various exposure times of 0.2 mT MF

Treatment M1 showed the most significant result, with an average radicle length of 6.95 cm. This is in line with previous research on mung bean plants, where the application of an MF at an intensity of 0.1 mT resulted in an increase in the radicle length of seedlings through the modulation of  $\alpha$ -amylase enzyme activity (Afzal et al., 2021).

Exposure to an MF can enhance the efficiency of ion pumps in transporting intracellular  $\text{Ca}^{2+}$ , which supports root elongation and facilitates enzyme binding to the root membrane. Furthermore, MF exposure also intensifies the motion of the amylase enzyme, which is implicated in the cell division process in active mitotic zones, including the root tip, hypocotyl, plumule, and epicotyl (Kandar & Pal, 2024).

Luo et al. (2022) found that subjecting mustard plants to an MF can escalate the motion of the  $\alpha$ -amylase enzyme, thereby promoting root development. Biochemically, the  $\alpha$ -amylase enzyme functions to hydrolyze starch by cleaving glycosidic bonds, resulting in dextrans and oligosaccharides as products (Farooq et al., 2021). The unique characteristic of this enzyme is its capacity to cleave the  $\alpha$ -1.4 glycosidic linkages present in the amylose or amylopectin chains, resulting in the fabrication of products with an  $\alpha$ -configuration (Martinez et al., 2015).  $\alpha$ -amylase is an enzyme found in various organisms, from plants, animals, fungi, and bacteria (Okunwaye et al., 2021).

### Plumule Length

Applying statistical methods, specifically the ANOVA test supplemented by the DMRT test, demonstrated that exposure to ELF MF statistically impacted the plumule length of aged rice seeds. The observations showed that the M3 treatment produced the longest average plumule length of 4.82 cm (Figure 9). This result aligns with previous research demonstrating the beneficial influence of MF on shoot growth in various plants, as documented by El-Gizawy et al. (2016) on potatoes and Pramana et al. (2015) on chrysanthemum plants.

Exposure to ELF MF can increase plumule length by affecting dipole-dipole interactions in the soil, enhancing microbial activity, and accelerating ion exchange in the growth medium (Ramadhani et al., 2022). Exposure to ELF MF has been demonstrated to enhance key enzymes in the germination process, especially cellulase and  $\alpha$ -amylase (Prihatin et al., 2020).

The increase in plumule length indicates an enhancement in  $\alpha$ -amylase enzyme activity in the cotyledons of rice seeds in response to MF exposure. This is substantiated by Poghosyan et al. (2023) investigation, which demonstrated that MF treatment has a beneficial impact on enhancing  $\alpha$ -amylase enzyme activity and promoting the elongation of cotyledons in red bean sprouts. Good plumule growth is characterized by the stimulation of growth hormones by the magnetic field,

especially gibberellin. This hormone plays a role in stimulating cell division and expansion, stem elongation, increasing leaf surface area, regulating fruit and seed development, and influencing stem growth (Murrinie et al., 2021).

## CONCLUSIONS

The findings demonstrate that prolonged exposure to ELF MF substantially influences the germination potential and overall viability of aged rice seeds. The MF has been proven to repair damaged tissue structures in old seeds and increase food reserves through increased activity of  $\alpha$ -amylase and protease enzymes. The M2 and M3 treatments showed optimal results on several tested parameters, including the percentage of normal seedlings (98.00% and 97.50%), the percentage of abnormal seedlings (2.00% and 2.50%), and the average germination time (2.47 days). Exposure to ELF MF significantly influenced radicle length, with the most optimal outcome observed in the M1 treatment, reaching a measurement of 6.95 cm. While for the plumule length parameter, the best results were in the M3 treatment, which was 4.82 cm. ELF MF significantly increased the germination index and germination rate, with the best results in the M2 treatment, which were 268.75 and 20.98%/day, respectively. Meanwhile, ELF MF significantly affected the vigor index, with the highest value in the M3 treatment, which was 163.65. The exposure to an ELF magnetic field did not show any statistically significant impact on the germination speed coefficient parameters, the germination time range, or the uniformity of seedling growth in the seeds. However, the uniformity of seedling growth showed an increase with a range of 51.50 - 60.50%.

## REFERENCES

- Abdul-Baki, A. A., & Anderson, J. D. (1970). Viability and Leaching of Sugars from Germinating Barley<sup>1</sup>. *Crop Science*, 10(1), 31–34. <https://doi.org/10.2135/cropsci1970.0011183X001000010012x>
- Afdharani, R., Hasanuddin, H., & Bakhtiar, B. (2019). Pengaruh Bahan Invigorasi dan Lama Perendaman pada Benih Padi Kadaluarsa (*Oryza sativa* L.) terhadap Viabilitas dan Vigor Benih. *Jurnal Ilmiah Mahasiswa Pertanian*, 4(1), 169–183. <https://doi.org/10.17969/jimfp.v4i1.10361>
- Afzal, I., Saleem, S., Skalicky, M., Javed, T., Bakhtavar, M. A., Ul Haq, Z., Kamran, M., Shahid, M., Sohail Saddiq, M., & Afzal, A. (2021). Magnetic Field Treatments Improve Sunflower Yield by Inducing Physiological and Biochemical Modulations in Seeds. *Molecules*, 26(7), 2022. <https://doi.org/10.3390/molecules26072022>
- Agustina, D. K., Zen, S., Dede Cahyati Sahrir, S. P. I., Fadhila, F., AK, A., Vertygo, S., Mago, O. Y. T., Ruhardi, A., KL, M., & Arianto, S. (2021). *Teori Biologi Sel*. Yayasan Penerbit Muhammad Zaini.
- Agustrina, R., Nukmal, N., & Wahyuningsih, S. (2022). Induksi pertumbuhan Vegetatif Tomat (*Lycopersicon esculentum* Mill.) pada Benih Lama yang dengan Medan Magnet 0, 2 mT. *Prosiding Seminar Nasional Sains, Matematika, Informatika Dan Aplikasinya*, 5(2).
- Aisyah, N., Jumar, J., & Heiriyani, T. (2020). Respon Viabilitas Benih Padi (*Oryza sativa* L.) Pada Perendaman Air Kelapa Muda. *Agroekotek View*, 3(2), 8–14. <https://doi.org/10.20527/agtview.v3i2.2149>
- Alattar, E., Elwasife, K., & Radwan, E. (2021). Effects of Magnetic Field Treated Water On Some Growth Parameters of Corn (*Zea mays*) Plants. *AIMS Biophysics*, 8(3). <https://doi.org/10.3934/biophy.2021021>
- Al-Mudaris, M. A. (1998). Notes on Various Parameters Recording the Speed of Seed Germination. *Der Tropenlandwirt-Journal of Agriculture in the Tropics and Subtropics*, 99(2), 147–154.
- Ashar, J. R., Farhanah, A., Haris, A., Tuhuteru, S., Pangestuti, R., Utami, E. P., & Dewi, S. M. (2024). *Ilmu dan Teknologi Benih*. TOHAR MEDIA.
- Asra, R., Samarlina, R. A., & Silalahi, M. (2020). *Hormon Tumbuhan*. Uki Press. <http://repository.uki.ac.id/1579/>
- Avivi, S. (2021). *Buku Teks Fisiologi & Metabolisme Benih*. UPT Penerbitan & Percetakan Universitas Jember.
- Bista, M., Ghimire, P., Khanal, D., Khatri, N., & Marasini, S. (2022). Effect of Storage Materials and Duration on Quality of Rice Seed. *Agronomy Journal of Nepal*, 36–44. <https://doi.org/10.3126/aj.n.v6i1.47926>
- Čalić, D., Ristić-Djurović, J. L., Ćirković, S., Milojević, J., Belić, M., Stanišić, M., & Zdravković-Korać, S. (2023). Overcoming Low Germination and Low Quality of Flax Seeds (*Linum usitatissimum*

- L.) in Unfavorable Storage Using Static Magnetic Fields. *Agriculture*, 13(11), 2120. <https://doi.org/10.3390/agriculture13112120>
- Chhabra, R., & Singh, T. (2019). Seed Aging, Storage and Deterioration: An Irresistible Physiological Phenomenon. *Agricultural Reviews*, 40(3), 234–238. <http://dx.doi.org/10.18805/ag.R-1914>
- Delouche, J. C. (2021). *Physiological Changes During Storage That Affect Soybean Seed Quality*.
- Djoyowasito, G., Ahmad, A. M., Lutfi, M., & Maulidiyah, A. (2019). Pengaruh Induksi Medan Magnet Extremely Low Frequency (ELF) Terhadap Pertumbuhan Tanaman Sawi (*Brassica juncea* L.). *Jurnal Keteknik Pertanian Tropis Dan Biosistem*, 7(1), 8–19. <https://doi.org/10.21776/ub.jkptb.2019.007.01.2>
- El-Gizawy, A. M., Ragab, M. E., Helal, N. A., El-Satar, A., & Osman, I. H. (2016). Effect of Magnetic Field Treatments on Germination of True Potato Seeds, Seedlings Growth and Potato Tubers Characteristics. *Middle East J Agric Res*, 5(1), 74–81.
- Farooq, M. A., Ali, S., Hassan, A., Tahir, H. M., Mumtaz, S., & Mumtaz, S. (2021). Biosynthesis and Industrial Applications of  $\alpha$ -Amylase: A Review. *Archives of Microbiology*, 203(4), 1281–1292. <https://doi.org/10.1007/s00203-020-02128-y>
- Fernández-Pascual, E., Carta, A., Mondoni, A., Cavieres, L. A., Rosbakh, S., Venn, S., Satyanti, A., Guja, L., Briceño, V. F., Vandellook, F., Mattana, E., Saatkamp, A., Bu, H., Sommerville, K., Poschlod, P., Liu, K., Nicotra, A., & Jiménez-Alfaro, B. (2021). The Seed Germination Spectrum of Alpine Plants: A Global Meta-Analysis. *New Phytologist*, 229(6), 3573–3586. <https://doi.org/10.1111/nph.17086>
- Gea, D., Sinaga, R., TP, S., & Nainggolan, I. L. (2022). Uji Daya Kecambah Benih Bayam Merah (*Amarantus tricolor* L.) Pada Media Semai Kompos dan Tanah Hitam. *Prosiding Seminar Nasional PSSH (Pendidikan, Sainstek, Sosial dan Hukum)*, 1, 91–1. <http://jurnal.semnapssh.com/index.php/pssh/article/download/176/121>
- Habibah, M. (2022). *Pengaruh Konsentrasi Giberelin Dana Lama Perendaman Dalam Meningkatkan Perkecambahan Benih Cabai (*Capsicum frutescens* L.) Varietas ORI 212 Terdeteriorasi* [PhD Thesis, Universitas Islam Negeri Maulana Malik Ibrahim]. <http://etheses.uin-malang.ac.id/id/eprint/37700>
- Hasanah, F., Rochmah Agustina, R., Eti Ernawati, E., & Sri Wahyuningsih, W. (2019). *Pengaruh Kuat Medan Magnet Terhadap Pertumbuhan Generatif Tanaman Tomat (*Lycopersicon esculentum* Mill.) Dari Benih Lama*. <http://repository.lppm.unila.ac.id/id/eprint/15003>
- Hayati, N., & Setiono, S. (2021). Pengaruh Lama Penyimpanan Terhadap Viabilitas Benih Kedelai (*Glycine max* (L) Merrill) Varietas Anjasmoro. *Jurnal Sains Agro*, 6(2), 66–76. <https://doi.org/10.36355/jsa.v6i2.655>
- Ida, N. (2021). The Static Magnetic Field. In N. Ida, *Engineering Electromagnetics* (pp. 377–418). Springer International Publishing. [https://doi.org/10.1007/978-3-030-15557-5\\_8](https://doi.org/10.1007/978-3-030-15557-5_8)
- International Seed Testing Association (ISTA). (2010). *Seed Science and Technology. International Rules for Seed Testing*.
- Jannah, A., & Hariyono, K. (2022). Pengaruh Paparan Medan Elektromagnetik pada Biji terhadap Pertumbuhan dan Hasil Selada (*Lactuca sativa* L.). *Berkala Ilmiah Pertanian*, 5(4), Article 4. <https://doi.org/10.19184/bip.v5i4.35299>
- Kamble, S. N., Satdive, R. K., Manwatkar, S. N., Salunkhe, C., Itteera, J., Singh, K., Suprasanna, P., & Singh, S. (2022). Influence of Magnetic Field on the Growth, Development, and Rhizome Yield of Turmeric (*Curcuma longa* L.). *Plant Cell, Tissue and Organ Culture (PCTOC)*, 150(3), 555–561. <https://doi.org/10.1007/s11240-022-02304-6>
- Kamila, B. S., & Sudarti, S. (2022). Potensi Pemanfaatan Radiasi Medan Elektromagnetik Extremely Low Frequency (ELF) Pada Proses Germinasi. *Jurnal Sains Agro*, 7(2), 136–143. <https://doi.org/10.36355/jsa.v7i2.804>
- Kandar, C. C., & Pal, D. (2024). Relation Between Seed Life Cycle and Cell Proliferation. Metabolic Changes in Seed Germination. In D. Pal (Ed.), *Seeds: Anti-proliferative Storehouse for Bioactive Secondary Metabolites* (pp. 49–79). Springer Nature Singapore. [https://doi.org/10.1007/978-981-97-3014-8\\_2](https://doi.org/10.1007/978-981-97-3014-8_2)
- Kartika, K., & Sari, D. K. (2015). Pengaruh Lama Penyimpanan dan Invigorasi Terhadap Viabilitas dan Vigor Benih Padi Lokal Bangka Aksesori Mayang. *Enviagro: Jurnal Pertanian Dan Lingkungan*, 8(1), 10–18.
- Kurek, K., Plitta-Michalak, B., & Ratajczak, E. (2019). Reactive Oxygen Species as Potential Drivers of the Seed Aging Process. *Plants*, 8(6), 174. <https://doi.org/10.3390/plants8060174>
- Kusumawardani, M., Kusumaningtyas, Z. A., & Arinie, F. (2021). Telemonitoring Perkecambahan Benih Jati Emas Dengan Induksi Medan Magnet Statis. *Journal of Applied Smart Electrical Network and Systems*, 2(01), 8–14. <https://doi.org/10.52158/jasens.v2i01.180>

- Laksmiari, K. (2021). Analysis Of Extremely Low Frequency (ELF) Magnetic Field Exposure Impact on The Mass of Great Red Chili Plant (*Capsicum annum* L.). *Jurnal Pembelajaran Fisika*, 10(1), 15–21.
- Lette, S. Y., Refli, R., Tanesib, J. L., & Amalo, D. (2019). Stimulasi Perkecambahan Padi (*Oriza sativa* L.) dengan Penggunaan Medan Magnet. *SAINSTEK*, 4(1), 512–520.
- Li, X., Luo, J., Han, K., Shi, X., Ren, Z., Xi, Y., Ying, Y., Ping, J., & Wang, Z. L. (2022). Stimulation of Ambient Energy Generated Electric Field on Crop Plant Growth. *Nature Food*, 3(2), 133–142. <https://doi.org/10.1038/s43016-021-00449-9>
- Liana, N. F. M., Anwar, S., & Kusmiyati, F. (2022). Pengaruh Hormon Alami dan Lama Perendaman Benih Cabai Merah (*Capsicum annum* L.) Kedaluwarsa Terhadap Perkecambahan, Pertumbuhan, dan Produksinya. *Jurnal Ilmiah Pertanian*, 19(3), 155–164. <https://doi.org/10.31849/jip.v19i3.10569>
- Luo, X., Li, D., Tao, Y., Wang, P., Yang, R., & Han, Y. (2022). Effect of Static Magnetic Field Treatment on the Germination of Brown Rice: Changes in A-Amylase Activity and Structural and Functional Properties in Starch. *Food Chemistry*, 383, 132392. <https://doi.org/10.1016/j.foodchem.2022.132392>
- Mar'atushaliha, S. (2023). *Fisiologi Tumbuhan*. Penerbit NEM.
- Martinez, M. M., Pico, J., & Gómez, M. (2015). Physicochemical Modification of Native and Extruded Wheat Flours By Enzymatic Amylolysis. *Food Chemistry*, 167, 447–453. <https://doi.org/10.1016/j.foodchem.2014.07.031>
- Megasari, A. (2022). Bio-Invigorasi Benih Padi (*Oryza sativa* L.) Varietas Inpari 32. *SCIENTIA: Journal of Multi-Disciplinary Science*, 1(1), 35–48. <https://doi.org/10.62394/scientia.v1i1.5>
- Melta, A. A., Yulianty, Y., Agustina, R., Setiawan, W. A., Suratman, S., & Chrisnawati, L. (2022). Pertumbuhan Benih Cabai (*Capsicum annum* L.) dengan Induksi Medan Magnet 0, 2 mT dan Infeksi *Fusarium oxysporum*. *Biota: Jurnal Ilmiah Ilmu-Ilmu Hayati*, 151–159. <https://doi.org/10.24002/biota.v7i2.4731>
- Muis, A., & Firmansyah, F. (2021). Uji Mutu Benih Beberapa Varietas Padi (*Oryza sativa*) pada Berbagai Periode Umur Simpan. *Gunung Djati Conference Series*, 6, 248–256. <http://conferences.uinsgd.ac.id/index.php/gdcs/article/view/520>
- Murrinie, E. D., Sudjiyanto, U., & Ma'rufa, K. M. (2021). Pengaruh giberelin terhadap perkecambahan benih dan pertumbuhan semai kawista (*Feronia limonia* (L.) Swingle). *Agritech: Jurnal Fakultas Pertanian Universitas Muhammadiyah Purwokerto*, 23(2), 183–191. <https://dx.doi.org/10.30595/agritech.v23i2.12614>
- Mustika, E. F., Nafisah, N., Laksono, R. A., & Samaulah, M. Y. (2022). Toleransi Galur-Galur Elit Tanaman Padi (*Oryza sativa* L.) terhadap Cekaman Salin Pada Fase Perkecambahan dan Fase Bibit. *Jurnal AGROHITA: Jurnal Agroteknologi Fakultas Pertanian Universitas Muhammadiyah Tapanuli Selatan*, 7(1), 105–115. <http://dx.doi.org/10.31604/jap.v7i1.6828>
- Nugraheni, F. T., Haryanti, S., & Prihastanti, E. (2019). Pengaruh Perbedaan Kedalaman Tanam dan Volume Air Terhadap Perkecambahan dan Pertumbuhan Benih Sorgum (*Sorghum bicolor* (L.) Moench). *Buletin Anatomi Dan Fisiologi*, 3(2), 223–232. <https://doi.org/10.14710/baf.3.2.2018.223-232>
- Nurbaity, A., Nuraini, A., Agustine, E., Solihin, M. A., Setiawan, A., & Mbusango, A. (2019). Enhanced Seedling Germination and Growth of Sorghum Through Pre-Sowing Seed Magnetic Field Treatment. *IOP Conference Series: Earth and Environmental Science*, 393(1), 012101. <https://doi.org/10.1088/1755-1315/393/1/012101>
- Nyakane, N. (2019). *Use of Magnetic Field Nutrient Solution Amended With Mycorrhizal and Ratio of Calcium to Magnesium on Yield and Oil Quality of Rose Geranium (Pelargonium Graveolens L.)*. <http://ir.cut.ac.za/handle/11462/2258>
- Okunwaye, T., Uadia, P. O., Okogbenin, B. O., Okogbenin, E. A., Onyia, D. C., & Obibuzor, J. U. (2021). Amylase-Producing Fungi and Bacteria Associated With Some Food Processing Wastes. *Nigerian Journal of Biotechnology*, 38(1), 74–82. <https://doi.org/10.4314/njb.v38i1.9>
- Perveen, R., Wang, X., Jamil, Y., Ali, Q., Ali, S., Zakaria, M. Q., Afzaal, M., Kasana, R. A., Saleem, M. H., & Fiaz, S. (2021). Quantitative Determination of the Effects of He–Ne Laser Irradiation on Seed Thermodynamics, Germination Attributes and Metabolites of Safflower (*Carthamus tinctorius* L.) in Relation With The Activities of Germination Enzymes. *Agronomy*, 11(7), 1411. <https://doi.org/10.3390/agronomy11071411>
- Poghosyan, G. H., Mikaelyan, M. S., & Vardevanyan, P. H. (2023). Effect of Extremely High-Frequency Electromagnetic Irradiation Treatment on Wheat Seeds' Germination, Growth and Amylase Activity. *Proceedings of the YSU B: Chemical and Biological Sciences*, 57(1 (260)), 19–31. <https://doi.org/10.46991/PYSU:B/2023.57.1.019>

- Powell, A. A. (2022). Seed Vigour in the 21st Century. *Seed Science and Technology*, 50(2), 45–73. <https://doi.org/10.15258/sst.2022.50.1.s.04>
- Prabhandaru, I., & Saputro, T. B. (2017). Respon Perkecambah Benih Padi (*Oryza sativa* L.) Varietas Lokal Sigadis Hasil Iradiasi Sinar Gamma. *Jurnal Sains Dan Seni ITS*, 6(2), E52–E57. <http://dx.doi.org/10.12962/j23373520.v6i2.25544>
- Pramana, I., Wijaya, I., & Gunadnya, I. P. B. (2015). Peranan Kuat Medan Elektromagnetik dalam Memacu Pertumbuhan Vegetatif Tanaman Krisan (*Crhysantemum*). *Universitas Udayana. Bali*.
- Priatama, R. A., Pervitasari, A. N., Park, S., Park, S. J., & Lee, Y. K. (2022). Current Advancements in The Molecular Mechanism of Plasma Treatment For Seed Germination and Plant Growth. *International Journal of Molecular Sciences*, 23(9), 4609. <https://doi.org/10.3390/ijms23094609>
- Prihatin, W. N., Sudarti, S., & Prihandono, T. (2020). Pengaruh Medan Magnet Extremely Low Frequency Terhadap Biomassa Tanaman Edamame. *JPFT (Jurnal Pendidikan Fisika Tadulako Online)*, 8(3). <https://core.ac.uk/download/pdf/389609840.pdf>
- Putri, N. K. I. S., Darmawati, I. A. P., & Astawa, I. N. G. (2022). *Pengaruh Lama Penyimpanan Benih dan Konsentrasi Rendaman Air Kelapa terhadap Viabilitas Benih Padi (Oryza sativa L.)*. Skripsi.
- Radhakrishnan, R. (2019). Magnetic Field Regulates Plant Functions, Growth and Enhances Tolerance Against Environmental Stresses. *Physiology and Molecular Biology of Plants*, 25(5), 1107–1119. <https://doi.org/10.1007/s12298-019-00699-9>
- Ramadhani, P. I., Sudarti, S., & Prihandono, T. (2022). Pengaruh Medan Magnet Extremely Low Frequency (ELF) pada Pertumbuhan Vegetatif Tanaman. *Jurnal Teknologi Pertanian Gorontalo (JTPG)*, 7(1), 12–16. <https://doi.org/10.30869/jtpg.v7i1.885>
- Rostami, Z. E., Majd, A., & Arbabian, S. (2014). Effects of Electromagnetic Fields on Seed Germination in (*Urtica dioica* L). *International Journal of Scientific and Technology Research*, 3(4), 2277–8616.
- Rosyad, A., & Qadir, A. (2022). Pengembangan Metode Uji Vigor Benih Cabai Merah (*Capsicum annum* L.) Pada Beberapa Potensial Air. *Jurnal Agronida*, 8(2), 50–59. <https://doi.org/10.30997/jag.v8i2.6392>
- Sadjad, S. (1993). Dari Benih Kepada Benih. *Grasindo, Jakarta*, 143.
- Saletnik, B., Saletnik, A., Słysz, E., Zaguła, G., Bajcar, M., Puchalska-Sarna, A., & Puchalski, C. (2022). The Static Magnetic Field Regulates Plants' Structure, Biochemical Activity, and Gene Expression. *Molecules*, 27(18), 5823. <https://doi.org/10.3390/molecules27185823>
- Sambayu, D. S., & Muharam, M. (2021). Invigorasi Benih dengan Berbagai Zat Pengatur Tumbuh (ZPT) Terhadap Cabai Keriting (*Capsicum annum* L). *Jurnal Ilmiah Wahana Pendidikan*, 7(2), 288–295. <https://doi.org/10.5281/zenodo.4695326>
- Sativa, N., Baharzyah, R. M., Nafi'ah, H. H., Fajarfika, R., & Rismayanti, A. Y. (2022). Pengaruh Berbagai Konsentrasi PEG (Polyethylene Glycol) 6000 dan Lama Perendaman terhadap Vigor Benih Jintan Hitam (*Nigella sativa*). *JAGROS: Jurnal Agroteknologi Dan Sains (Journal of Agrotechnology Science)*, 6(2), 125–133. <https://doi.org/10.52434/jagros.v6i2.2040>
- Shofiyani, A., Purnawanto, A. M., & Aziz, R. Z. A. (2020). Pengaruh Berbagai Jenis Sterilan dan Waktu Perendaman terhadap Keberhasilan Sterilisasi Eksplan Daun Kencur (*Kaempferia galanga* L.) pada Teknik Kultur In Vitro. *Agritech: Jurnal Fakultas Pertanian Universitas Muhammadiyah Purwokerto*, 22(1). <https://dx.doi.org/10.30595/agritech.v22i1.7523>
- Song, Y., Zhao, W., Su, Z., Guo, S., Du, Y., Song, X., Shi, X., Li, X., Liu, Y., & Liu, Z. (2024). Effect of Pulsed Electric Field Treatment on Seed Germination and Seedling Growth of *Scutellaria baicalensis*. *Agriculture*, 14(1), 158. <https://doi.org/10.3390/agriculture14010158>
- Sutradhar, M., Samanta, S., Singh, B. K., Ali, M. N., & Mandal, N. (2021). The Effect of Sodium Hypochlorite (NaOCl) and Heat Treatments on Seed Germination of Rice: An Approach to Restore Seed Viability. *Journal of Experimental Agriculture International*, 43(5), 49–53. <https://doi.org/10.9734/JEAI/2021/v43i530689>
- Tefa, A. (2018). Perlakuan Invigorasi Pada Benih Padi di Kelompok Tani Pelita Desa Noepesu. *Bakti Cendana*, 1(1), 1–10.
- Tekam, C. K. S., Majumdar, S., Kumari, P., Prajapati, S. K., Sahi, A. K., Singh, R., Krishnamurthy, S., & Mahto, S. K. (2024). Effects of extremely Low-Frequency (50 Hz) Electromagnetic Fields on Vital Organs of Adult Wistar Rats and Viability of Mouse Fibroblast Cells. *Radiation Protection Dosimetry*, ncae220. <https://doi.org/10.3390/agriculture14071167>
- Tirono, M. (2022). Using a Time-Changing Magnetic Field to Increase Soybean (*Glycine max*) Growth and Productivity. *International Journal of Design & Nature and Ecodynamics*, 17(5), 737–747.

- Tnunay, I. M. Y. (2021). Pengaruh Medan Listrik sebagai Stimulan Pertumbuhan Bawang Putih Lokal Timor. *Jurnal Teori dan Aplikasi Fisika Vol, 9*(02).
- Ullrich, V., & Apell, H.-J. (2021). Electromagnetic Fields And Calcium Signaling By The Voltage Dependent Anion Channel. *Open Journal of Veterinary Medicine, 11*(01), 57. <https://doi.org/10.4236/ojvm.2021.1111004>
- Wang, J., Ma, H., & Wang, S. (2019). Application of Ultrasound, Microwaves, and Magnetic Fields Techniques in The Germination of Cereals. *Food Science and Technology Research, 25*(4), 489–497. <https://doi.org/10.3136/fstr.25.489>
- Winda, W., Saputri, R., & Kurniasari, L. (2023). Pengujian After Ripening Serta Efektivitas Pematangan Dormansi Pada Benih Padi Gogo Lokal Bangka Aksesori Balok. *Fruitset Sains: Jurnal Pertanian Agroteknologi, 11*(2), 116–125. <https://doi.org/10.35335/fruitset.v11i2.3815>
- Yulianto, R. A., Sudarti, S., & Yushardi, Y. (2022). Potensi Medan Magnet Extremely Low Frequency (ELF) Untuk Mempercepat Pertumbuhan Tanaman. *OPTIKA: Jurnal Pendidikan Fisika, 6*(2), 150–157. <https://doi.org/10.37478/optika.v6i2.2191>