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EVALUATION OF THE EFFECTS OF MAGNETIC FIELDS ON THE GROWTH AND DEVELOPMENT OF BITTER GOURD (*Momordica charantia*)

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Abstract. Bitter gourd (*Momordica charantia*), a nutritionally and medicinally important crop, is widely cultivated but faces challenges such as inconsistent yields and environmental stress. Magnetic fields (MFs) have emerged as a promising, non-invasive approach to enhance plant growth and development by influencing key physiological processes. This study evaluated the effects of a 150 mT MF on bitter gourd growth during germination, vegetative emergence, the cotyledon stage, and V1 - V5 vegetative stages by measuring germination rate, germination index, plant height, root length, fresh weight of roots and shoots, chlorophyll content, and leaf area. Results showed that MF-treated seeds achieved a 100% germination rate at 84 hours, compared to 90.25% in the control group, with a consistently higher germination index. During vegetative stages, particularly from V1 to V5, MF-treated plants exhibited slight increases in plant height, root length, and biomass; however, most of these improvements were not statistically significant. These findings suggest that while exposure to a 150 mT MF can significantly improve early-stage germination in bitter gourd, its impact on later vegetative development remains limited and warrants further investigation and optimization. This study builds upon a growing body of research demonstrating the potential of MFs to enhance crop traits, such as germination rate, root elongation, biomass accumulation, and stress tolerance in crops. The results provide a species-specific foundation for advancing the application of MF technology in precision agriculture and crop improvement strategies.

Keywords: magnetic field, bitter gourd, hydroponic, root, plant.

1. Introduction

Bitter gourd (*Momordica charantia*), a climber native to tropical and subtropical regions of Asia and Africa [1], is a crop of significant nutritional and medicinal value [2], [3]. Renowned for its distinctive bitter flavor, the fruit is rich in bioactive compounds, including charantin and polypeptide-P [3], [4], recognized for their potential roles in blood sugar regulation and health promotion [5]. In addition to its medicinal importance, bitter gourd is an essential agricultural product in Vietnam, where it is widely cultivated in various regions to meet domestic and export demands. Its integration into traditional diets and therapeutic practices underscores its cultural and economic significance. However, bitter gourd cultivation faces several challenges, such as susceptibility to environmental stresses, pests, and inconsistent yields, which can hinder productivity [6]. Addressing these challenges requires innovative approaches to enhance its growth and development, ensuring sustainable production and maximizing its agricultural and economic potential. Thus, exploring strategies for improving bitter gourd cultivation to support farmers and meet growing market demands is crucial.

In recent years, the application of magnetic fields (MF) in agricultural practices has gained significant attention due to its potential to enhance plant growth and development [7], [8]. MFs are thought to influence plant cells through various biophysical and biochemical mechanisms, including alterations in ion transport, enzyme activity, and the alignment of water molecules within cells [9]. These changes at the cellular level can lead to improvements in various physiological processes, such as seed germination, root elongation, photosynthesis, and nutrient absorption [7]. For instance, MFs may enhance the mobility of ions across cell membranes, influencing the uptake of essential nutrients and improving cellular metabolism [9], [10]. Additionally, magnetic field exposure has been linked to the modulation of oxidative stress and the activation of specific enzymes, which may further enhance metabolic processes and stress tolerance in plants [8]. These effects suggest that MFs have the potential to act as a non-invasive tool for promoting growth and productivity in crops. Studies on the application of MFs to various plant species have demonstrated promising results, with positive effects observed on both growth parameters and crop yield [10], [11]. For example, MFs have been shown to improve seed germination rates, accelerate seedling growth, and enhance root and shoot development in crops, such as Ming aralia [12], soybean [13] and bean sprout [14]. These studies have demonstrated that an MF intensity of 150 mT is particularly effective in promoting the growth and development of various plant species [15]. Building on this evidence, we hypothesized that exposure to an MF of 150 mT could similarly enhance the growth and development of bitter gourd plants.

This study aimed to investigate the effects of a 150 mT MF on the growth and development of bitter gourd, focusing on key growth parameters at various stages, including germination, vegetative emergence, vegetative cotyledon, and V1 - V5 vegetative stages. By evaluating parameters such as germination rate, germination index, plant height, root length, fresh weight of roots and shoots, chlorophyll content, and leaf area, the study aimed to assess whether MF exposure could serve as a non-invasive approach to enhance the physiological and agronomic characteristics of bitter gourd.

2. Content

2.1. Materials and methods

2.1.1. Plant materials

In this study, the F1 hybrid bitter gourd variety Va.254 was used as the experimental material. This variety, a new-generation hybrid derived from the crossbreeding of local and wild bitter gourd, was sourced from Thailand and provided by Viet A Agricultural Development Co., Ltd. (Gia Lam District, Hanoi City). The Va.254 variety is recognized for its adaptability to year-round cultivation, strong resistance to pests and diseases, and vigorous branching capacity, contributing to its high yield potential. The fruits of this variety are characterized by their glossy green color, prominent ridges, and thick flesh, with lengths of 21 - 23 cm. Typically, the fruits are harvested 38 - 42 days after planting, making this variety suitable for research on growth and development under controlled conditions.

2.1.2. Methods

Growth condition: The bitter gourd plants were grown under controlled conditions to ensure optimal development and to minimize external variability, as previously described [16]. The plants were cultivated in a greenhouse environment with a temperature range of 25 - 30°C, and relative humidity maintained at approximately 70 - 80%. Sufficient light was provided through natural sunlight, supplemented with artificial light as needed to ensure a photoperiod of 12 - 14 hours daily.

Seed germination assay: To evaluate the effect of a 150 mT MF on bitter gourd germination, seeds of the F1 hybrid variety Va.254 were surface sterilized using 1% sodium hypochlorite for 5 minutes, then rinsed thoroughly with sterile water, and placed in Petri dishes lined with sterile filter paper. The setup included a treatment group exposed to 150 mT MF and a control group without MF exposure, with both groups maintained at 25°C in an incubator. Moisture levels were monitored daily to ensure optimal germination conditions. Germination parameters were recorded, including germination rate (the percentage of seeds that germinate over the total number of seeds tested during the experimental period), mean germination time (the average time, in hours, required for seeds to germinate], and germination index (the speed and uniformity of germination, giving greater weight to seeds that germinate earlier).

Growth parameter analysis during vegetative emergence and vegetative cotyledon stages: To analyze plant height, root length, and fresh weight during the vegetative emergence and vegetative cotyledon stages in bitter gourd, standardized methods commonly employed in recent studies were followed [17]. Plant height was measured from the base of the stem at the soil surface to the tip of the highest leaf using a digital caliper (Mitutoyo Corporation, Japan). For root length, plants were carefully removed from the growing medium, and roots were washed with distilled water. The longest root was measured using a ruler (Staedtler, Germany). Fresh weight was determined immediately after harvest by separating the shoot and root, gently blotting them with paper towels to remove surface moisture, and weighing each separately using an analytical balance (Sartorius, Germany).

Growth parameter analysis during V1 - V5 stages: To assess the growth parameters of bitter gourd across the V1 - V5 stages, plant height was recorded by measuring the vertical distance from the base of the stem at the soil surface to the highest leaf using a digital caliper (Mitutoyo Corporation, Japan). Root length was determined by carefully extracting the plants from the growing medium, rinsing the roots with distilled water to remove debris, and measuring the longest root using a precision measuring ruler (Staedtler, Germany). Fresh biomass of roots and shoots was evaluated immediately after harvesting to prevent moisture loss. The separated plant parts were gently blotted to remove excess water and then weighed using an analytical balance (Sartorius, Germany). Leaf area was quantified using a leaf area meter (LI-3100C, LI-COR Biosciences, USA). Chlorophyll (Chl) content was assessed non-destructively using a Chl meter (SPAD-502 Plus, Konica Minolta, Japan) to obtain Soil Plant Analysis Development (SPAD) values, which are indicative of relative chlorophyll concentration.

Data analysis: Statistical comparisons between the MF-treated and control groups were performed using an independent samples *t*-test for each growth parameter. For multiple-stage comparisons, one-way analysis of variance (ANOVA) was applied, followed by Tukey's post-hoc test to identify significant differences among vegetative stages. All statistical analyses were conducted using SPSS software (IBM SPSS Statistics 26, USA) [18].

2.2. Results and discussion

2.2.1. Evaluation of the effects of magnetic fields on bitter gourd during the germination stage

The evaluation of the effects of MF on bitter gourd during the germination stage demonstrated significant differences in germination performance between seeds exposed to a 150 mT MF and the control group. Germination rates were recorded at specific time intervals, and the germination index was calculated to compare the speed and efficiency of germination.

At 36 hours, the germination rate of seeds exposed to the 150 mT MF was 14.25%, compared to 10.56% in the control group, indicating a faster initial response under the influence of the MF. This trend continued, with MF-treated seeds achieving a germination rate of 42.22% at 48 hours, significantly higher than the 28.61% observed in the control. By 60 hours, the gap narrowed slightly, with the MF group reaching 57.5% germination compared to 55% in the control. At 72 hours, the MF-treated seeds maintained a higher germination rate of 89.45%, compared to 79.75% in the control. By the end of the observation period at 84 hours, the MF group achieved complete germination (100%), while the control group reached 90.25% (Figure 1A).

The germination index further highlighted the MF's positive effects on germination speed and uniformity. At 36 hours, the germination index for the MF group was 12.25, more than double the value of 5.33 recorded for the control group. This advantage persisted at subsequent time points, with the MF-treated seeds reaching a germination index of 15.86 at 48 hours, compared to 8.61 in the control group. At 60 hours, the germination index was 17.98 for the MF group and 12.49 for the control. By 72 and 84 hours, the MF-treated seeds had germination indices of 20.24 and 21.35, respectively, outperforming the control group, which achieved germination indices of 15.15 and 16.77 (Figure 1B). These results indicated that exposure to a 150 mT MF positively influenced both the rate and efficiency of bitter gourd seed germination (Figure 1C).

The positive effects of MF on seed germination observed in this study are consistent with findings from recent studies across various plant species. Numerous studies have shown that exposure to MFs can significantly enhance germination rates, reduce germination time, and improve seedling vigor by stimulating key physiological processes [10], [11]. For example, maize seeds exposed to 100 mT MF for 1 hour achieved a 95% germination rate, compared to only 80% in untreated seeds [19]. Similarly, another study demonstrated that rice seeds treated with a 125 mT MF for 2 hours increased germination percentage from 70% in the control to 85% in the treated group [20]. In addition to higher germination rates, MFs have been shown to reduce mean germination time, a critical indicator of seed germination efficiency. For example, chickpea seeds exposed to 200 mT MF for 1 hour had a reduced mean germination time of 4.5 days compared to 6 days in the control group [21]. Similarly, a study on sunflower seeds showed a 20% reduction in mean germination time when seeds were exposed to 150 mT MF for 24 hours [22]. The results of this study confirm previous findings, demonstrating that MFs can enhance germination rate, reduce germination time, and improve germination index in various plant species. Specific data from earlier studies, such as the 15% increase in rice seed germination rates [20] and the 20% reduction in mean germination time in sunflower seeds [22], highlighted the consistent benefits of MF treatment across different crops.

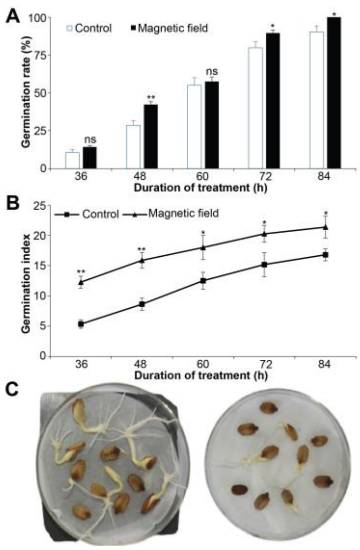

Figure 1. Effects of magnetic field exposure on bitter gourd seed germination (A); Germination rate (%) of seeds subjected to magnetic field treatment (black bars) compared to the control (white bars) over different durations (36 - 84 hours); (B) Germination index of seeds exposed to a magnetic field (triangles) and control conditions (squares), showing a consistent increase over time; (C) Representative images of germinated seeds under magnetic field treatment (left) and control conditions (right) after 84 hours.

Data are presented as mean ± standard error. Statistically significant differences between control and MF-treated groups are indicated by asterisks: $^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$ *(independent samples t-test).*

2.2.2. Assessment of the effects of magnetic fields on vegetative emergence and vegetative cotyledon stages of bitter gourd

Our evaluation of bitter gourd growth under an MF at the vegetative emergence and vegetative cotyledon stages revealed non-significant differences in plant height, root length, and fresh weights of roots and plants compared to the control group.

At the vegetative emergence stage, plants exposed to a 150 mT MF exhibited superior growth parameters compared to the control group. The plant height in the MF-treated group was 5.85 cm, slightly higher than the 5.45 cm observed in the control. Root development also benefited from MF exposure, with a root length of 5.50 cm compared to 4.82 cm in the control group (Figure 2A). Additionally, the fresh weight of plants in the MF-treated group reached 0.84 g, exceeding the control group's weight of 0.77 g. The fresh weight of roots also slightly improved, with the MF-treated group recording 0.32 g compared to 0.28 g in the control group (Figure 2B). These results suggest that MF exposure slightly affects both above-ground and root development during the early vegetative emergence stage.

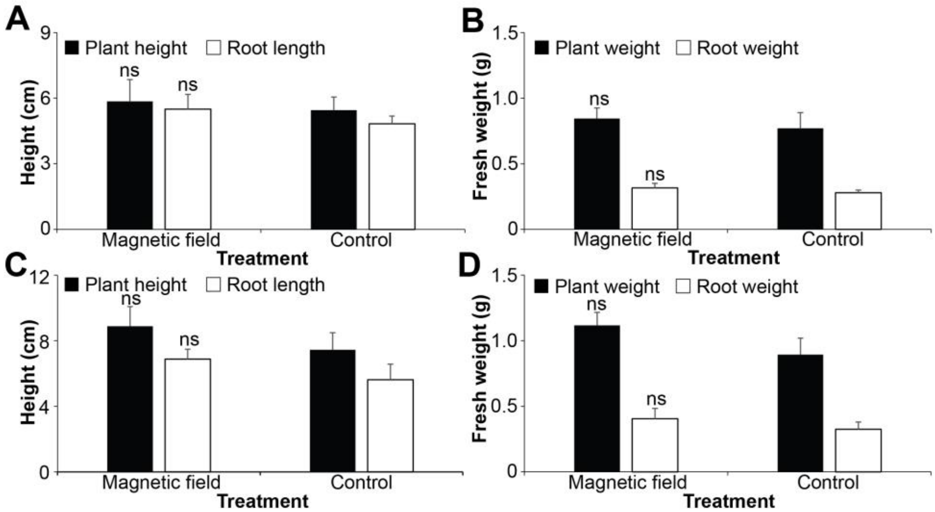

Figure 2. Effects of magnetic field exposure on plant growth parameters in the vegetative emergence and cotyledon stages in bitter gourd. (A, C) Plant height (black bars) and root length (white bars) under magnetic field and control conditions at the vegetative emergence stage (A) and cotyledon stage (C). (B, D) Fresh weight of the whole plant (black bars) and fresh weight of roots (white bars) under magnetic field and control conditions at the vegetative emergence stage(B) and cotyledon stage (D).
Data are presented as mean ± standard error. All differences between the magnetic field and control groups are not statistically significant ($p > 0.05$)

At the cotyledon stage, the positive effects of the MF on plant growth became more obvious. The plant height in the MF-treated group increased to 8.88 cm, higher than the 7.44 cm observed in the control group ($p > 0.05$). Root length also showed slight improvement under MF treatment, reaching 6.88 cm compared to 5.62 cm in the control (Figure 2C). Additionally, the fresh weight of roots and plants was higher in the MF-treated group (Figure 2D). The root fresh weight was 0.40 g under MF exposure, compared to 0.32 g in the control group. Similarly, the fresh weight of plants was 1.12 g in the MF-treated group, exceeding the 0.89 g recorded in the control (Figure 3). These results suggest that MF exposure slightly affects the growth parameters of bitter gourd, particularly at the vegetative cotyledon stage. The observed growth promotion may be attributed to MF-induced modulation of ion transport, membrane permeability, and enzymatic activity, which can enhance nutrient uptake and cellular metabolism. [23]. Recent molecular studies have demonstrated that MFs can alter gene expression patterns associated with stress responses, cell elongation, and hormonal signaling in plants. [24]. For example, proteomic analysis in barley exposed to MFs revealed significant protein changes related to redox regulation and energy metabolism [10]. This supports the hypothesis that MFs impact physiological functions at the cellular and molecular levels. These findings indicate that the biological effects of MFs may involve complex regulatory pathways that warrant further investigation in bitter gourd and related crops.

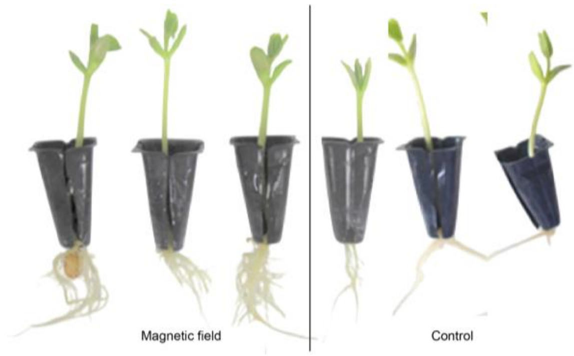

Figure 3. Representative comparison between magnetic field-treated and control bitter gourd plants at the cotyledon stage. MF-treated plants (left) appear taller and more developed than control plants (right), reflecting the observed increases in plant height, root length, and fresh weight during this stage.

2.2.3. Evaluation of growth parameters in bitter gourd from V1 to V5 stages under magnetic field exposure

The evaluation of root length, plant height, fresh weight of roots and plants, Chl content, and leaf area in bitter gourd across the V1 to V5 stages showed that plants exposed to a 150 mT MF exhibited slightly higher values than the control group, though the differences were not statistically significant. Figure 4 describes the changes in these parameters during vegetative stages.

Root length initially showed a slight increase in MF-treated plants compared to the control group (Figure 4A). At stage V1, the root length under MF exposure was 10.54 cm, while the control recorded 9.04 cm. This trend continued with MF-treated plants reaching 12.62 cm at V2, 14.88 cm at V3, 17.91 cm at V4, and 22.64 cm at V5, compared to 11.04 cm, 12.9 cm, 14.66 cm, and 21.6 cm in the control, respectively. Although the MF-treated plants exhibited slightly longer roots at each stage, the differences were not statistically significant.

Similarly, plant height was slightly higher in the MF-treated group, though the variation was not significant (Figure 4B). At V1, plant height in the MF-treated group was 12.44 cm, compared to 10.85 cm in the control. This pattern continued at V2 (16.39 cm vs. 13.92 cm), V3 (24.64 cm vs. 22.30 cm), V4 (41.44 cm vs. 33.52 cm), and V5

(63.8 cm vs. 63.18 cm). The most notable difference was observed at V4, where the MF-treated plants were approximately 8 cm taller than the control group. However, by the final stage (V5), the difference between the two groups narrowed considerably.

The fresh weight of roots followed a similar pattern, with slightly higher values in the MF-treated group (Figure 4C). At V1, root fresh weight under MF exposure was 0.41 g, compared to 0.271 g in the control. At later stages, fresh root weight reached 0.93 g (V2), 1.14 g (V3), 1.38 g (V4), and 1.84 g (V5), while the control group recorded 0.653 g, 1.01 g, 1.15 g, and 1.65 g, respectively. Likewise, the fresh weight of plants was marginally higher in the MF-treated group, with values of 1.13 g (V1), 2.66 g (V2), 4.45 g (V3), 7.50 g (V4), and 10.68 g (V5), compared to 1.05 g, 2.62 g, 4.19 g, 6.12 g, and 10.55 g in the control (Figure 4D).

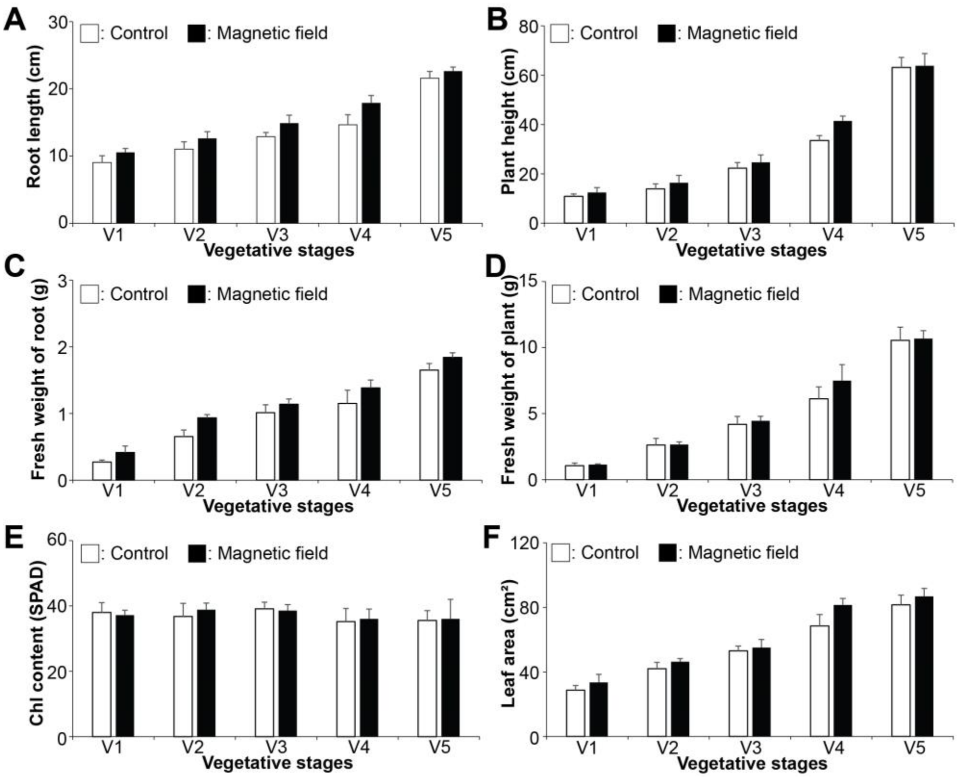

Figure 4. Effects of magnetic field exposure on the growth parameters of bitter gourd at different vegetative stages V1 - V5. (A) Root length (cm), (B) Plant height (cm), (C) Fresh weight of root (g), (D) Fresh weight of plant (g), (E) Chlorophyll content (SPAD value), and (F) Leaf area (cm²) are shown for both control (white bars) and magnetic field-treated (black bars) plants. MF-treated plants generally exhibited slightly higher values across parameters; however, most differences were not statistically significant.

Data are presented as mean ± standard error.

In this study, Chl content remained relatively stable between the two groups (Figure 4E). At stage V1, Chl content was slightly lower in the MF-treated group (37.18) compared to the control (38.02). However, at V2, the MF-treated plants exhibited a slight increase (38.86 vs. 36.8). At V3 (38.58 vs. 39.12), V4 (36.04 vs. 35.22), and V5 (36.02 vs. 35.56), no significant differences were observed, indicating that MF exposure did not markedly affect chlorophyll content during the vegetative stages. Additionally, leaf area was consistently larger in the MF-treated group, though the increase was not statistically significant (Figure 4F). At V1, leaf area in the MF group was 33.462 cm^2, compared to 28.629 cm^2 in the control. The difference remained consistent throughout the growth stages, with MF-treated plants reaching 46.317 cm^2 (V2), 55.117 cm^2 (V3), 81.491 cm^2 (V4), and 86.783 cm^2 (V5), while the control recorded 41.946 cm^2, 53.081 cm^2, 68.514 cm^2, and 81.535 cm^2, respectively.

The findings of this study indicate that MF exposure had a slight but statistically nonsignificant effect on the growth parameters of bitter gourd during the V1 to V5 vegetative stages. While the differences were relatively small, root length, plant height, fresh weight of roots and shoots, leaf area, and Chl content tended to be higher in MF-treated plants compared to the control. Studies specifically examining the V1 to V5 stages in bitter gourd research are limited; however, comparisons can be drawn from related cucurbit crops. For example, in cucumber seedlings, exposure to a 125 mT MF resulted in a moderate increase in plant height and root biomass, but no significant effect on Chl content [25]. This aligns with the current study, in which minor variations in Chl content were observed between the control and MF-treated groups, but no consistent pattern suggested a meaningful impact of MF exposure. Overall, the findings of this study support previous reports suggesting that MFs can influence early plant growth, though the magnitude of the effect varies depending on species and experimental conditions. In bitter gourd, MF treatment during the V1 - V5 stages resulted in slight increases in root length, plant height, and biomass accumulation; however, these changes were not statistically significant.

3. Conclusions

This study assessed the effects of a 150 mT magnetic field (MF) on the growth and development of bitter gourd during germination and vegetative stages. The results demonstrated slight improvements in key parameters under MF exposure compared to the control. At the germination stage, seeds exposed to the MF achieved a 100% germination rate at 84 hours, compared to 90.25% in the control group, with higher germination indices recorded at all time points. During the vegetative emergence stage, MF treatment resulted in increased plant height (5.85 cm vs. 5.45 cm) and root length (5.5 cm vs. 4.82 cm) compared to the control. Similarly, at the vegetative cotyledon stage, MF-treated plants exhibited higher plant height (8.88 cm vs. 7.44 cm) and root length (6.88 cm vs. 5.62 cm). Across the V1-V5 stages, MF-treated plants showed consistent but statistically non-significant increases in root length (e.g., 22.64 cm vs. 21.6 cm at V5), plant height (e.g., 63.8 cm vs. 63.18 cm at V5), and leaf area (e.g., 86.783 cm^2 vs. 81.535 cm^2 at V5). The fresh weight of roots and whole plants was also slightly higher in the MF-treated group. These findings suggested that MF exposure may positively influence early growth and development in bitter gourd. Future studies are recommended to explore the underlying mechanisms and to optimize treatment conditions.

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