Research Article

Electromagnetic Field Improved Nanoparticle Impact on Antioxidant Activity and Secondary Metabolite Production in *Anthemis gilanica* Seedlings

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Electromagnetic field (EMF) causes fundamental alternations in biological systems. In this study, we studied the effects of EMF on physiological responses and secondary metabolites production in SiO_2 NP-treated *Anthemis gilanica* plants. The results indicated that EMF improved plant growth by inducing chlorophyll and carotenoid content, which led to enhanced biomass in SiO_2 NP-treated plants. EMF enhanced adventitious roots in SiO_2 NP-treated plants. EMF treatment improved the activity of antioxidative enzymes such as superoxide dismutase, catalase, and peroxidase in both control and SiO_2 NP-treated plants. EMF and SiO_2 NP treatments significantly declined hydrogen peroxide content in *A. gilanica* plants. Although protein content was reduced by SiO_2 NP treatment, combined application of EMF with SiO_2 NP caused a significant induction in protein content. Our results presented that EMF induced secondary metabolites accumulation such as flavonoid and phenol in SiO_2 NP-treated *A. gilanica* plants. This work can open prospects for the production of the pharmaceutically high-value secondary metabolites.

1. Introduction

The *Anthemis* genus belongs to the Asteraceae family and is distributed across Asia, Europe, Saudi Arabia, and Africa [1]. *Anthemis gilanica* grows spontaneously in the Eshkevar-e Sofla mountains of Rudsar, Gilan province of Iran [2]. It is a rich source of natural antioxidants and is used in folk medicine and various industrials of food, cosmetics, aromatherapy, perfumery, and pharmaceuticals [3, 4] and has an economical application in endemic areas. It is traditionally used for the treatment of spasms, stomachaches, earaches, gastrointestinal disorders, and deafness [3]. Anti-inflammatory, antispasmodic, and antibacterial properties of Anthemis extract have been reported due to the existence of main chemical constituents, including phenolic, flavonoid, and terpenoid compounds [3–6]. Therefore, access to the specific condition of *A. gilanica* culture with more growth,

antimicrobial activity, and secondary metabolites is so valuable.

Magnetic field (MF) is an unavoidable environmental agent affecting the growth and development processes of living organisms due to the usage of many manmade devices and the industrial revolution. MF may induce paramagnetic characteristics of some molecules in the cells [7] and affect electrical characteristics and permeability of cell membrane, the activity of free radicals, and ionic transports of the membrane [8, 9]. It has been reported that MF at suitable intensities can have an inductive effect on secondary metabolite production and antioxidant capacity [4, 7, 10], which may be related to MF impact on plant metabolism.

Silicon (Si) is a beneficial element that affects plant growth and development. It has been reported that Si can enhance the antioxidative defense system and improves resistance to environmental stress [4, 11]. Nanoparticles

(NPs) are very small particles with at least two dimensions in the size range of 1–100 nm. The small scale of these particles and a greater proportion of surface atoms produce specific behaviors in their physical properties compared to their bulk materials. Most of these changes are associated with the appearance of quantum effects when size is reduced and converted to the origin of an event like superparamagnetism [12]. The negative and positive impacts of NPs in agriculture associate significantly with physiochemical properties, concentration, exposure method of NPs, and/or plant species. For example, SiO_2 NPs application caused a significant increase in photosynthetic pigments in *Zea mays* [13]. Ag NPs are reported to have an inductive effect on the secondary metabolite content of *Bacopa monnieri* [14]. Moreover, SiO_2 NPs significantly changed antioxidant capacity and vascular tissues in *A. gilanica* [4]. Therefore, the goal of this article was to study the impact of SiO_2 NPs as a chemical elicitor, MF as a physical elicitor, and their combinations on the growth and bioactive compounds production metabolite in *A. gilanica* seedlings. Few studies have been conducted about the impact of SiO_2 NPs and EMF on antioxidative defense mechanisms in medicinal plants, and this is the first study in *A. gilanica*. Data from this research help us to gain biological knowledge about the response mechanisms to NPs, MF, and interaction between them, which may also help in getting more induction of valuable phenolic and flavonoid compounds that can be used in the pharmaceutical and food industries.

2. Materials and Methods

2.1. Plant Material and Culture Conditions. Seeds of *A. gilanica* Bornm. and Gauba with voucher number of 603_AUPF were gathered from Rahimabad of Rudsar mountains, Gilan providence of Iran. Seeds were sowed in distilled water and were put on a wet towel paper in dark condition. After one week, the germinated seeds were exposed to the different MF intensities (0 and 4 mT) for 1 hour during three days (Figure 1). A homogenous MF was applied in the middle of a polyethylene tube covered with the copper wire based on the method described by Hassanpour and Niknam [15]. Then, the seedlings were transferred in plastic pots with a 17 cm diameter filled with perlite and fed with ½ Hoagland nutrient solution (pH 7) once a week. SiO_2 NP (10–20 nm, CAS No. 7631-86-9) was commercially bought from Merck. The SiO_2 NP (6 gL^{-1}) suspension was prepared in deionized water and then was homogenized with a homogenizer (IKA, *T* 18 digital ULTRA-TURRAX) for 2 min, 21000 rpm to avoid aggregation. The SiO_2 NP solution (100 ml for each pot) was added to the roots once a week at the vegetative stage. The pots were put in a growth chamber with a temperature of 25/18°C (day/night), 56% humidity, and 16/8 (light/dark) photoperiod. The selection of EMF intensity and SiO_2 NP level was conducted according to the published works [4, 15]. After four weeks, the seedlings were harvested for physiological and anatomical analyses. Six plants per treatment were used for analyses in all the experiments.

2.2. Growth Parameters. For determination of fresh (FW) and dry weight (DW), five plants per treatment were dried in an oven at 45°C for three days. Relative water content (RWC) was determined based on the method of Weatherley [16] using the equation of RWC (%) = ((FW − DW)/(SW − DW)) × 100. Water-saturated weight (SW) was quantified by putting the leaves in deionized water for 24 h at 4°C.

2.3. Photosynthetic Pigments. The photosynthetic pigments were measured according to Lichtenthaler [17] using leaf extraction in 80% acetone. The absorptions were recorded at 480, 649, and 665 nm with a UV-Vis Double Beam Spectrophotometer (model SQ-4802, UNICO, USA).

2.4. Proline and Total Soluble Sugars. Proline content was evaluated through the procedure described by Bates et al. [18]. Total soluble sugars were estimated by the procedure of anthrone-sulphuric acid using the protocol of Fales [19], and the standard curve was drowned by different glucose concentrations.

2.5. H_2O_2 Content. The hydrogen peroxide (H_2O_2) content was estimated spectrophotometrically at 390 nm via the method described by Velikova et al. [20]. The standard curve was drawn with different H_2O_2 concentrations.

2.6. Protein and Enzyme Assays. The fresh leaves (0.5 g) were homogenized in 3 ml of cold extraction buffer containing Tris-HCl 1 M (pH 6.8), and then the homogenates were centrifuged at 13000 × *g* for 20 minutes at 4°C. The supernatants were separated and used for protein and enzymes analyses. Total protein was determined according to Bradford [21].

The superoxide dismutase (SOD) activity was quantified using an assay solution composed of sodium phosphate buffer (0.1 M, pH 7.8), EDTA (0.1 mM), methionine (13 mM), riboflavin (1.3 μM), NBT (63 μM), and plant extract (0.1 ml) [22]. The assay solution was put in front of the light for 20 minutes, and the enzyme activity was recorded at 560 nm.

The peroxidase (POX) activity was assayed based on Abeles and Biles [23] method with an assay solution of benzidine (0.1 ml), 0.2 ml H_2O_2 (3%), 2 ml acetate buffer (0.2 M, pH 4.8), and enzyme extract (60 μl). The changes in absorbance were read at 530 nm.

The catalase (CAT) activity was determined by the described method of Aebi [24]. The assay mixture was 0.075 ml H_2O_2 (3%), 0.625 ml potassium phosphate buffer (50 mM, pH 7.0), and enzyme extract (5 μl). The changes in absorbance were recorded at 240 nm.

2.7. DPPH Activity, Phenol, and Flavonoid Contents. Reducing the activity of the 2, 2-diphenyl-2-picryl hydrazyl (DPPH) was considered as the scavenging activity of enzyme extract and was assayed according to the method of Patro
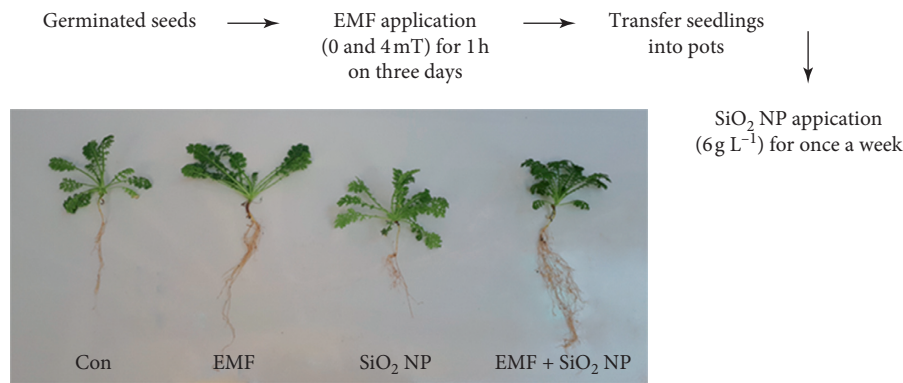
Germinated seeds → EMF application (0 and 4 mT) for 1 h on three days → Transfer seedlings into pots

SiO$_2$ NP appication (6 g L^{-1}) for once a week

Con   EMF   SiO$_2$ NP   EMF + SiO$_2$ NP

FIGURE 1: Depiction of EMF and SiO$_2$ NPs on *A. gilanica* plants.

et al. [25]. The 500 mg of leaf dry powder was homogenized in 10 ml of methanol (80%) and centrifuged at 4000 rpm for 5 min. The 150 μL extract was added to 2.5 mL of DPPH (0.5 mM in methanol). The absorbance was recorded using a UV–visible spectrophotometer at 517 nm at room temperature after 30 min darkness.

Total phenolic content was determined spectrophotometrically at 725 nm using the Folin–Ciocalteu procedure [26]. The assay solution was 500 μl Folin–Ciocalteu reagent, 400 μl sodium carbonate 0.7 M, and 100 μl extract, which was kept at room temperature for 30 min in the dark. The total phenolic was monitored as mg of gallic acid in 1 g DW.

Total flavonoid content was quantified using the aluminum chloride method [27]. The assay solution was 500 μL leaf extract, 50 μL sodium nitrate solution (5%), 50 μL aluminum chloride solution (10%), and 250 μL sodium hydroxide solution (4%), which was kept at room temperature for 30 min. The absorbance was immediately recorded at 415 nm and expressed as mg of rutin equivalents in 1 g DW.

2.8. Statistical Analysis. The experiment was designed in a randomized complete block design, and the analysis of variance (ANOVA) and mean comparison (Duncan's multiple range test at $P \leq 0.05$) were done with SPSS software (version 18). All data were represented as mean ± standard errors (SE) of three or five independent replicates of each treatment.

3. Results

The results shown in Table 1 indicated that EMF significantly enhanced growth traits in terms of FW, DW, root length, and the number of the adventitious roots as compared to nonmagnetized plants. EMF treatment increased FW and DW by 66.6% and 46.2%, respectively, compared with the control. The increment of root length and the number of adventitious roots were significant under EMF treatments and an increase of 30.21% and 51.11% compared to control was observed at both parameters, respectively. In contrast to EMF, SiO$_2$ NP application did not change significantly fresh and dry weights, root length, and adventitious root compared to control. However, shoot length showed a 23.11%

enhancement under SiO$_2$ NP length in comparison to control plants. The interaction treatment of EMF/SiO$_2$ NP induced root length and number of the adventitious roots markedly compared to untreated plants.

Application of EMF, SiO$_2$ NP, and EMF/SiO$_2$ NP enhanced RWC compared to control condition, and the highest content (65.7%) was observed in plants treated to EMF (Table 1). EMF application resulted in a 31.85% increase in protein content as compared with the control plants. Treatment with SiO$_2$ NP showed no effect on protein content in plants grown under normal conditions. In plants treated to SiO$_2$ NP, EMF application induced protein content significantly compared with the control. EMF significantly enhanced photosynthetic pigment contents in *A. gilanica* plants, especially Chl a compared to Chl *b* and carotenoid. The contents of Chl a, Chl *b*, and carotenoid were reduced following SiO$_2$ NP exposure in control plants. EMF treatment caused a significant enhancement in Chl a and carotenoid in plants treated with SiO$_2$ NP, but this treatment had no significant effect on Chl *b* content (Figure 2).

Proline content increased significantly under SiO$_2$ NP and EMF compared to control; however, the highest level was observed in EMF and EMF/SiO$_2$ NP-treated plants. Proline content in EMF/SiO$_2$ NP treatment was 86.5% higher than control (Figure 3(a)). Total sugar content increased significantly under EMF and decreased under SiO$_2$ NP treatment. EMF treatment induced a 47.49% increase in total sugars compared to control. EMF also stimulated the soluble sugar accumulations in EMF/SiO$_2$ NP-treated plants (Figure 3(b)).

H$_2$O$_2$ content was approximately 44.44% lower in plants exposed to EMF than in control plants. H$_2$O$_2$ content was increased by exogenous SiO$_2$ NP application in control plants. The level of H$_2$O$_2$ in EMF-treated plants following SiO$_2$ NP application was reduced compared to control plants (Figure 4(a)). EMF treatment improved SOD activity in *A. gilanica* plants when compared with control. A significant increase was observed in SOD activity in both EMF- and SiO$_2$ NP-treated plants. There was no significant difference in SOD activity between EMF-treated plants and cotreated EMF/SiO$_2$ NP plants (Figure 4(b)). EMF and SiO$_2$ NP treatment significantly induced POX activity compared to control, and the effect of EMF was more pronounced in *A. gilanica* plants. In plants exposed to SiO$_2$ NP, POX

TABLE 1: Effect of EMF and SiO$_2$ NPs on some growth parameters and protein content in *A. gilanica* seedlings.

Parameters	Treatments			
	CON	EMF	SiO$_2$ NP	EMF + SiO$_2$ NP
FW (g plant^{-1})	0.72 ± 0.038[cd]	1.20 ± 0.065[a]	0.78 ± 0.033[c]	0.83 ± 0.046[b]
DW (g plant^{-1})	0.067 ± 0.0041[c]	0.098 ± 0.0039[a]	0.071 ± 0.0044[c]	0.069 ± 0.0032[b]
Shoot length (cm)	2.25 ± 0.091[b]	2.15 ± 0.083[b]	2.77 ± 0.064[a]	2.11 ± 0.085[b]
Root length (cm)	7.76 ± 1.091[bc]	11.12 ± 0.835[a]	8.85 ± 0.723[b]	11.50 ± 0.698[a]
No. of adventitious roots	5.5 ± 0.431[b]	11.25 ± 0.335[a]	5.85 ± 0.463[b]	12.5 ± 0.227[a]
RWC (%)	52.8 ± 1.956[c]	73.8 ± 3.982[a]	65.7 ± 2.173[b]	65.7 ± 2.361[b]
Protein (mg g^{-1} FW)	25.1 ± 1.723[c]	42.7 ± 2.791[a]	23.5 ± 1.380 [cd]	36.8 ± 2.297[b]

Bars indicate means ± SE (*n* = 5) in each group. Different letters indicate significant differences at *P* < 0.05.
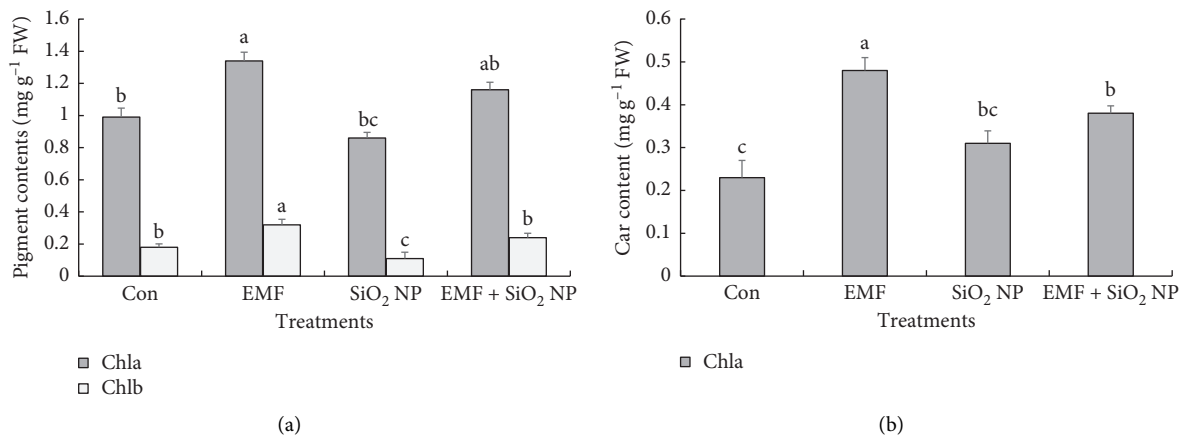

(a)

(b)

FIGURE 2: Effect of EMF and SiO$_2$ NP treatments on chlorophyll a and b (Chl) (a) and carotenoid (Car); (b) contents of *A. gilanica* plants. Bars indicate means ± SE (*n* = 5) in each group. Different letters indicate significant differences at *P* ≤ 0.05.
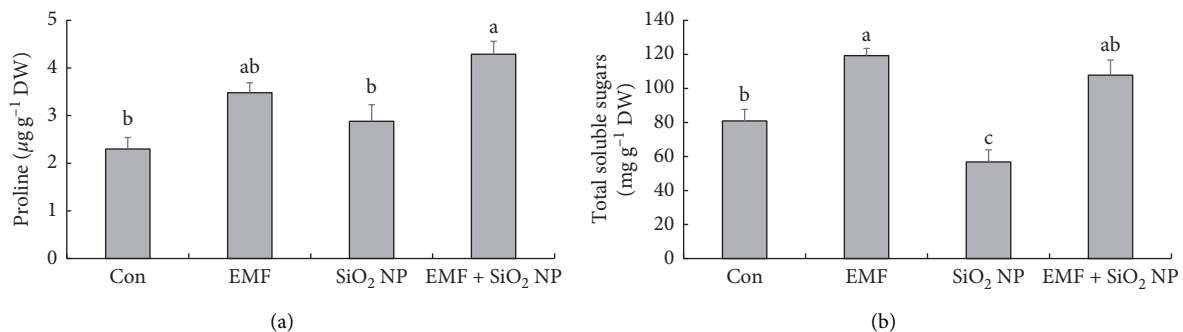

(a)

(b)

FIGURE 3: Effect of EMF and SiO$_2$ NP treatments on the content of proline (a) and total soluble sugars (b) of *A. gilanica* plants. Bars indicate means ± SE (*n* = 3) in each group. Different letters indicate significant differences at *P* ≤ 0.05.

activity was induced following EMF treatment (Figure 4(c)). EMF led to a significant rise in CAT activity compared to control. SiO$_2$ NP exposure elevated the CAT activity in plants grown in both control and EMF conditions. The highest CAT activity (37.5%) was observed in plants treated to EMF/SiO$_2$ NP (Figure 4(d)).

Total phenolic and flavonoid contents were more eminent in leaves than those in roots. EMF caused a considerable increase (43.51%) in total phenol content in the leaf compared to control plants. Treatment with SiO$_2$ NP and

EMF/SiO$_2$ NP resulted in the induction of total phenol content in the leaf of *A. gilanica* plants (Figure 5(b)). In roots, all treatments enhanced the total phenol content compared to control, and the maximum increase was detected in plants cotreated with EMF and SiO$_2$ NP. Flavonoid content of leaf was induced in the plants exposed to EMF compared to control. Enhancement of flavonoid content in leaf was detected in both EMF- and EMF/SiO$_2$ NP-treated plants (Figure 5(a)). No significant change in flavonoid content was identified following EMF and SiO$_2$ NP
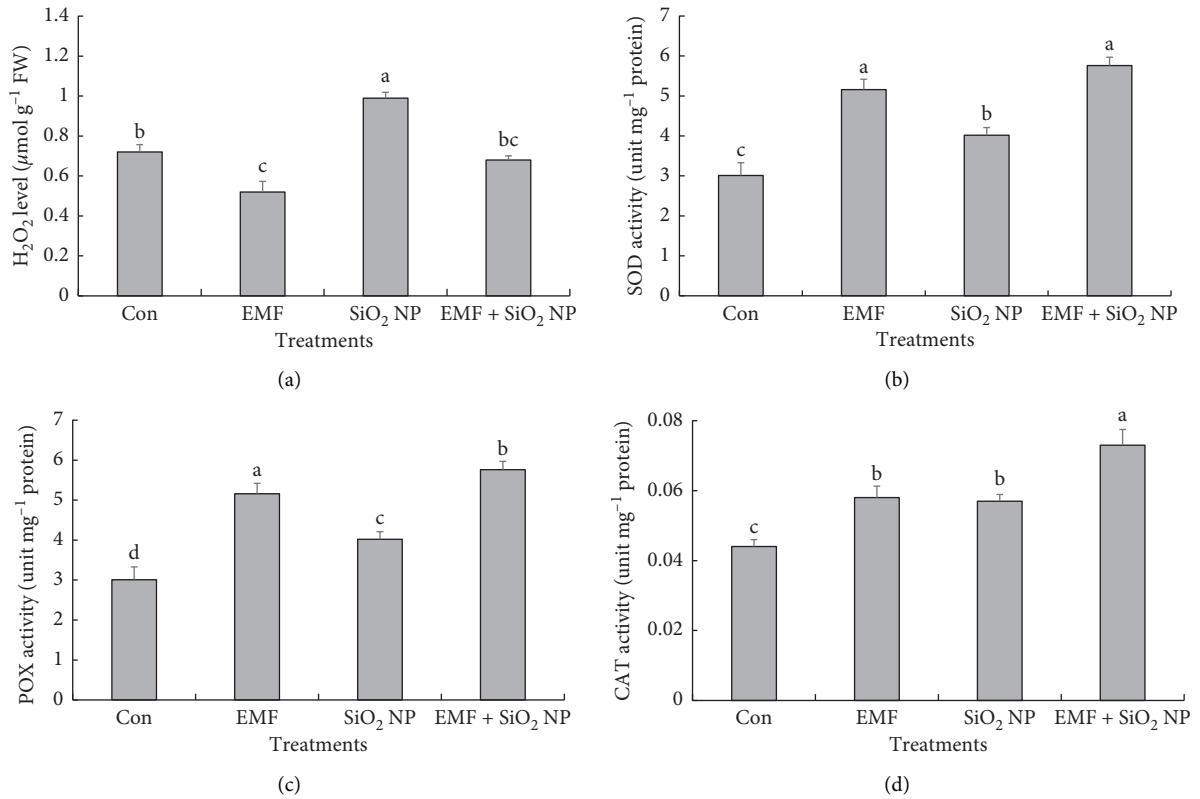
FIGURE 4: Impact of EMF and SiO$_2$ NP treatments on H$_2$O$_2$ content (a), SOD activity (b), POX activity (c), and CAT activity (d) in *A. gilanica* plants. Bars indicate means ± SE ($n = 3$) in each group. Different letters indicate significant differences at $P \leq 0.05$.
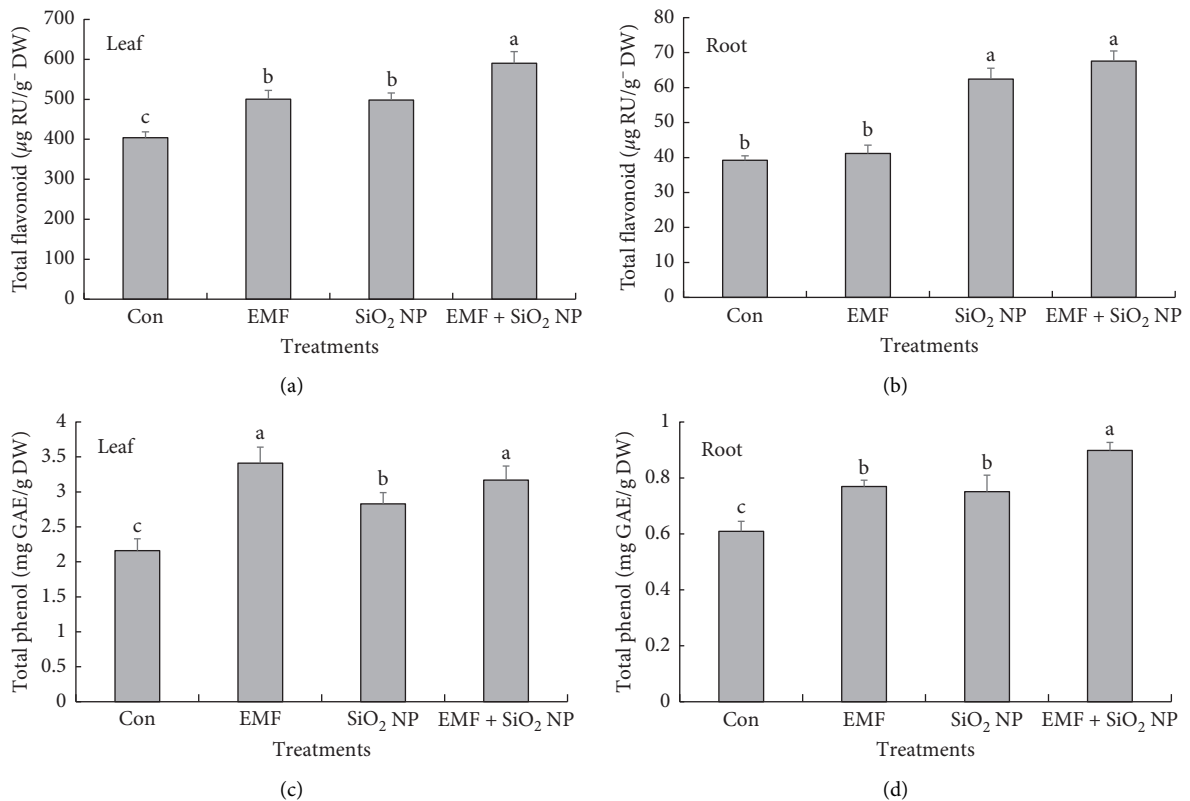

FIGURE 5: Changes in flavonoid (a, b) and phenol (c, d) contents in *A. gilanica* plants under EMF and SiO$_2$ NP treatments. Bars indicate means ± SE ($n = 3$) in each group. Different letters indicate significant differences at $P \leq 0.05$.

treatments in leaves, but SiO_2 NP showed a considerable effect in both conditions on flavonoid content in the root of *A. gilanica* (Figure 5(b)). EMF caused a sharp induction (1.78-fold) in DPPH scavenging activity as compared to control plants. EMF treatment also induced DPPH scavenging activity in SiO_2 NP-treated plants compared to control (Figure 6).

4. Discussion

This study was conducted to investigate the impact of the EMF, SiO_2 NPs, and their interactions on stimulating the growth and production of phenolic and flavonoid compounds in *A. gilanica* seedlings. Our results showed that fresh and dry weights, root growth, and number did not significantly change in SiO_2 NP-treated plants in roots as compared to control, but EMF application markedly promoted effect of SiO_2 NP on the growth (Table 1 and Figure 1). The small NPs size and high surface area make them very active [12] and move into the roots through the apoplastic and symplastic pathways. At special concentrations, NPs may reduce the absorption of macro- and microelements and affect vital parts of plant cells such as photosynthetic apparatus, resulting in the decline of growth and yield [28, 29]. On the other hand, the primary response of plant cells to MF is the alteration of electrical properties and permeability of membranes, which can be due to changes in the spine of paramagnetic molecules and the related-physiochemical reactions. Following MF, ionic flows in cell membranes are changed and can result in increasing ion and organic molecule transports and finally growth induction [8]. Moreover, MF may play an important role in cation uptake capacity and has a positive effect on immobile plant nutrient uptake [30].

RWC is a physiological parameter to evaluate the water status of plants. In our study, an enhanced level of RWC was perceived in EMF and SiO_2 NP-treated plants. The rise of RWC in plants could be associated with the impact of EMF and SiO_2 NP on osmolyte accumulation and induction of membrane permeability [4, 31]. The compatible solutions, proline, and total soluble sugars are effective compounds in cell protection under stress situations. These compounds can decrease the osmotic potential of cells by sustaining high turgor level and storage reserves to improve cell metabolism and maintaining plant growth. Increased proline content may be associated with protein destruction and generation of amino acids like proline [32], activation of the proline biosynthesis enzyme, and/or decrease of proline oxidation under stress conditions [33]. On the other hand, soluble sugars and proline may also act as protective osmolytes for ROS scavenging and prevention of lipid peroxidation and protein denaturation [6, 29]. In this research, SiO_2 NP application against EMF did not change proline content significantly and decreased total soluble sugars in *A. gilanica*. These results confirmed the data obtained from ZnO NPs impact on okra (*Abelmoschus esculentus*) [34]. Lower accumulation of osmotic adjustments in *A. gilanica* plants exposed to SiO_2 NP may cause less water sustaining and
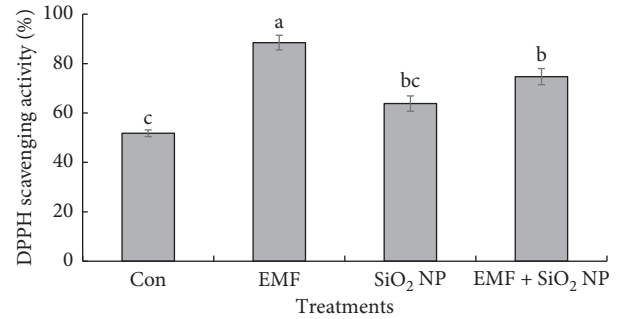
FIGURE 6: Impact of EMF and SiO_2 NP treatments on DPPH scavenging activity in *A. gilanica* plants. Bars indicate means ± SE ($n = 3$) in each group. Different letters indicate significant differences at $P \leq 0.05$.

protection against oxidative damage, which affect growth parameters.

Photosynthetic pigments are highly sensitive to stress conditions and can be an indicator to investigate the impact of stress on growth parameters. Our results stated that SiO_2 NP adversely influenced photosynthetic pigments and protein content. Zarafshar et al. [35] showed that SiO_2 NP reduced chlorophyll and carotenoid contents in pear seedlings. The decline in chlorophyll pigments and protein may be due to oxidative injuries through the ROS accumulation on stroma-lamellar proteins and other proteins under stress conditions [36, 37]. EMF and its interaction with SiO_2 NP showed a positive effect on protein and photosynthetic pigment in *A. gilanica* plants. Similarly, seeds exposed to MF displayed a significant rise in chlorophyll content and photosynthesis in Indian maize [38]. MF also increased significantly Chl *a* and Chl *b* and carotenoid in *Phoenix dactylifera L.* [39] and protein content maize [40]. Increased photosynthetic pigment may be associated with the þreduction of oxidative injury by improving antioxidant capacity, which is in agreement with the stimulation of enzymatic antioxidant activities in *A. gilanica*.

Antioxidative enzymes such as SOD, CAT, and POX deactivate or scavenge free radicals before they attack cellular components [41, 42]. SOD scavenges the superoxide anions and generates hydrogen peroxide, and CAT and POX convert hydrogen peroxide to water and O_2 [43]. Results obtained from our experiments showed that antioxidant enzyme and DPPH scavenging activities were induced with the SiO_2 NP application compared to control, but the increased levels improved markedly after EMF treatment (Figure 4). H_2O_2 content was also induced in SiO_2 NP-treated plants compared to control and EMF-treated plants indicating the toxicity impact of SiO_2 NP on the *A. gilanica* growth (Figure 4(a)). Disruption in ROS homeostasis by NPs may lead to impaired organelle function, membrane damage, and eventually phytotoxicity [44]. It can be proposed that the rise of antioxidant enzymes in SiO_2 NP-treated plants could not regulate ROS levels, resulting in the reduction of pigment and growth parameters. On the other hand, ROS suppression is triggered after plant exposure to EMF. Enzymatic activities such as CAT, POX, and SOD had

a twofold to a fourfold rise in MF-treated seedlings [45, 46]. Induction of antioxidant enzyme activities under EMF suggests that these enzymes may act as a magnetoreceptor. Magnetic characteristics of molecules define their capability of absorbing and then altering the energy into other forms and transferring them to other molecules in cells, thus making them more active [7].

Antioxidant compounds are molecules that quench free radical reactions and inhibit cellular injuries. These compounds neutralize the ROS in a process called radical scavenging and carry them away [47]. Flavonoids are known for their scavenging ability of H_2O_2 and are considered to play a vital function in the phenolic/ascorbate-peroxidase cycle [48]. Our results showed that EMF had a positive effect on nonenzymatic antioxidants. These findings illuminate the EMF-improved capability of scavenging free radicals, leading to growth enhancement in *A. gilanica* plants. Induction in the content of nonenzymatic antioxidants such as phenol and flavonoid has been described in other plants [49, 50]. The results of our study showed that nonenzymatic antioxidants are enhanced with the addition of SiO_2 NP (Figure 5). Suriyaprapha et al. [51] reported that SiO_2 NP increased nonenzymatic antioxidants. EMF treatment induced more accumulation of nonenzymatic antioxidants in SiO_2 NP-treated plants. It was shown that EMF enhanced the growth of *A. gilanica* plants by inducing organic combinations such as phenol and flavonoid.

5. Conclusions

This study demonstrated some beneficial impacts of germinated seeds exposed to EMF on growth parameters, antioxidative enzymes, and bioactive compounds (phenols and flavonoids) in control and SiO_2 NP-treated plants. EMF also declined the toxicity of SiO_2 NP on photosynthetic pigments, ROS accumulation, and growth in *A. gilanica*. It can be proposed that EMF with the stimulation of antioxidative capacity may be used as a tool for enhancing stress resistance under environmental stress. The mechanism of antioxidant enzyme activities as a magnetoreceptor is not clear under EMF and needs to be more investigated in the future.

Data Availability

All data are means ± SE with three or five replications of treatment parameters: CON EMF SiO_2 NP EMF + SiO_2 NP FW (g plant-1): 0.72 ± 0.038 cd, 1.20 ± 0.065 a, 0.78 ± 0.033 *c*, 0.83 ± 0.046 b; DW (g plant-1): 0.067 ± 0.0041 c, 0.098 ± 0.0039 a, 0.071 ± 0.0044 c, 0.069 ± 0.0032 b; shoot length (cm): 2.25 ± 0.091 b, 2.15 ± 0.083 b, 2.77 ± 0.064 a, 2.11 ± 0.085 b; root length (cm): 7.76 ± 1.091 bc, 11.12 ± 0.835 a, 8.85 ± 0.723 b, 11.50 ± 0.698 a; no. of adventitious roots: 5.5 ± 0.431 b, 11.25 ± 0.335 a, 5.85 ± 0.463 b, 12.5 ± 0.227 a; RWC (%): 52.8 ± 1.956 *c*, 73.8 ± 3.982 a, 65.7 ± 2.173 b, 65.7 ± 2.361 b; protein (mg g-1 FW): 29.1 ± 1.723 *c*, 42.7 ± 2.791 a, 23.5 ± 1.380 cd, 33.8 ± 2.297 b; Chl a: 0.99 ± 0.056 b, 1.34 ± 0.054 a, 0.86 ± 0.035 bc, 1.16 ± 0.047 ab; Chl b: 0.18 ± 0.021 b, 0.32 ± 0.034 a,

0.11 ± 0.039 *c*, 0.24 ± 0.027 d; Car: 0.23 ± 0.041 *c*, 0.48 ± 0.032 a, 0.31 ± 0.029 bc, 0.38 ± 0.017 b; H2o2: 0.93 ± 0.037 a, 0.52 ± 0.053 *c*, 0.78 ± 0.029 bc, 0.68 ± 0.021 b; SOD: 3.01 ± 0.32 *c*, 5.16 ± 0.26 a, 4.02 ± 0.19 b, 5.76 ± 0.21 a; POX: 2.82 ± 0.22 d, 4.35 ± 0.24 a, 3.31 ± 0.27 *c*, 3.98 ± 0.19 b; CAT: 0.044 ± 0.0026 c, 0.058 ± 0.0035 b, 0.057 ± 0.0014 b, 0.073 ± 0.0044 a; phenol (leaf): 2.16 ± 0.17 *c*, 3.41 ± 0.23 a, 2.83 ± 0.16 b, 3.17 ± 0.20 a; phenol (root): 0.609 ± 0.036 *c*, 0.769 ± 0.023 b, 0.751 ± 0.059 b, 0.898 ± 0.029 a; flavonoid (leaf): 404.01 ± 14.7 *c*, 500.5 ± 21.9 a, 498.26 ± 17.7 b, 590.18 ± 29.3 a; flavonoid (root): 39.19 ± 1.3 b, 41.14 ± 2.4 b, 62.44 ± 3.1 a, 67.57 ± 2.9 a; DPPH: 51.8 ± 1.36 d, 88.5 ± 2.97 a, 63.8 ± 3.17 *c*, 74.81 ± 3.27 b.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

A. E. took part in the bench experiments. H. H. and M. H. have designed and analyzed the data. All authors read and approved the final version of the article.

Acknowledgments

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