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The Effect of Wi-Fi Electromagnetic Waves on the Properties of *Camelina sativa*

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ABSTRACT

Electromagnetic waves are one of the tensions around agricultural plants, which have recently been widely used due to the development of telecommunication technology. Therefore, a field experiment was conducted during the years 2020-2021 at the Research Farm of Tarbiat Modares University to investigate the effect of WiFi electromagnetic wave (WEW) on the seed germination and growth characteristics of camelina. Seeds were exposed to Wi-Fi electromagnetic radiation at 15 cm (ER 15) and 25 cm (ER 25) cm from the modem for 24 hours (Pre-sowing treatment). The results showed that the germination percentage of seeds treated with WEW decreased by 24%. and this decrease was observed among growth factors such as hypocotyl length (20-43%), number of siliques per plant (56%), thousand seed weight (43%). Conversely, the root length, plant height, seed per silique and dry plant weight were increased by 24.6, 60.9, 10.5 and 56.3% under WEW treatment, respectively. Overall, this study showed that grain yield was greatly affected by electromagnetic waves and increased by about 23.45%. In general, among all the growth parameters, the correlation of the GY was positive and significant with DPW (r=0.735*), PH (r=0.669*) and SPS (r=0.659*). This result highlights the necessity for a better understanding of the mechanisms of electromagnetic waves in crops to help better seedling establishment.

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1. Introduction

Camelina (*Camelina sativa* L. Crantz) is known as an oilseed and dicotyledonous plant from the Brassicaceae family (Righini *et al*., 2019). It is a small bushy plant with a spreading root system (Gesch and Johnson, 2015) and It has two winter and spring growth types (Czarnik *et al*., 2018; Krzyżaniak *et al*., 2019). Camelina seeds contain about 33-47% fat (Günç Ergönül and Aksoylu Özbek, 2018). The nutritional value of camelina is well known from the past until today. Today, its oil is used to heal wounds, treat burns, stomach ulcers, and eye inflammation (Zanetti *et al*., 2021). Due to the high content of essential fatty acids (FAs) as well as natural antioxidants in camelina seeds, its oil has a unique nutritional value. These compounds include polyunsaturated fatty acids, Phenols, carotenoids, vitamins, phospholipids, tocopherols and phytosterols (Krzyżaniak *et al*., 2019).

With the advancement of wireless technology and the ever-increasing development of communication devices, the level of exposure of living organisms to electromagnetic waves has increased (Saleh *et al*., 2020). According to researchers, electromagnetic waves are one of the stress factors affecting plants. These abiotic environmental stressors with their negative effects induce the production of reactive oxygen species (ROS) in different living organisms (Stefi *et al*., 2018). Physiologically, electromagnetic waves are able to pass through the cell membrane by oscillating the free ions of the cell membrane. This movement behavior of ions causes the destruction of ion channels and biochemical changes in the membrane, and as a result, disrupt all cellular functions (Wust *et al*., 2020).

It has been reported that growth factors in several plants such as sunflower (Vashisth and Nagarajan,

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2010), wheat and beans (Cakmak *et al.*, 2010) are improved under the influence of electromagnetic waves. The response of the rooting process in oregano exposed to magnetic field waves is positive and significant (Bilalis *et al.*, 2012a). Some studies apply magnetic waves before seed germination increases subsequent plant growth (Efthimiadou *et al.*, 2014; Menegatti *et al.*, 2019), while other reports show growth inhibition (Teixeira da Silva and Dobránszki, 2016; Halgamuge, 2017). Also, research findings on the camelina family's plants, including watercress (*Lepidium sativum*) and broccoli (*Brassica oleracea*), showed that Wi-Fi radiation did not affect germination. So in the plants of Boraginaceae, Brassicaceae, and Caesalpinioideae families, the results showed a significant percentage of meiosis abnormalities and pollen sterility in the experiment compared to control samples. These abnormalities included chromosome adhesion, premature chromosomes, retardation, and multipolar division. Furthermore, the pollen germination percentage was remarkably higher in samples exposed to the field of electromagnetic waves (Zaidi *et al.*, 2018). In addition, plants that were exposed to Wi-Fi waves gained less height than control plants (Jimenez, 2019).

According to the mentioned, ER may have a positive or negative effect on the quality of seedlings. It is a critical point that should be considered because poor seed germination is one of the significant problems in agriculture and affects the yield and quality of the crop. The purpose of this study is to investigate the effect of Wi-Fi electromagnetic waves on seed germination and growth characteristics of *C. sativa*.

2. Materials and methods

2.1. Plant materials and treatments

Camelina seeds (Soheil cultivar) were obtained from Biston Shafa Co. (Kermanshah, Iran), and to treat with Wi-Fi electromagnetic waves, Mobin Net Modem HUAWEI B612s_25d was used. The frequency of Wi-Fi radiation was in the range of 4.2 to 8.5 GHz. One group of seeds was exposed to electromagnetic radiation (ER) at a distance of 15 cm (ER 15) and another group at a distance of 25 cm (ER 25) from the modem (the space is marked with a ruler) for 24 hours (Fig. 1).

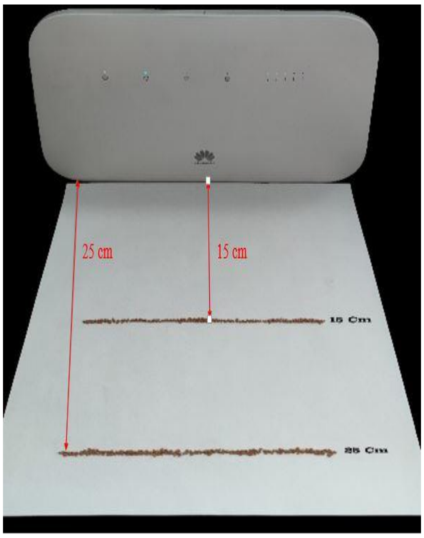

Figure 1. Camelina seed treatment at a distance of 15 and 25 cm from Mobin Net modem HUAWEI B612s_25d

2.2. Experimental setup

The irradiated seeds were cultivated in November 2020 in the research farm of the Faculty of Agriculture of Tarbiat Modares University, Iran, (35º 44' N, 51º 09' E and 1265 masl). Each experimental unit was considered 3.70 m long and 1.2 m wide with a row distance of 50 cm. Control and treated seeds (ER 15 and ER 25) were planted in three rows and 0.5 cm as a sowing depth. In the 2-4 leaf stage, excess seedlings were thinned. A round of irrigation was done immediately after planting, then in order to reach a uniform green surface, the second irrigation was done at an interval of 5 days. To control the weeds, the plots and the distance between them were manually weeded twice during the growing season.

2.3. Site characterization

To determine some physicochemical characteristics of the soil from the experimental site, a composite sample of the soil from a depth of 0-30 cm was prepared and sent to the soil laboratory. The results of the soil test are shown in Table 1. Weather parameters, including minimum and maximum air temperature (ºC) and rainfall (mm) are shown in Fig. 2.

Table 1. Soil physico-chemical properties (depth of 0-30 cm) before camelina planting during the 2020- 21 growing season.

soil texture	clay (%)	sand	loam	pH	EC† (dS/m)	O.C (%)	OM	TN	P (mgkg^{-1})	K
sandy loam	10	74	16	7.3	0.90	0.85	1.385	0.15	35	475

† EC: electrical conductivity; OC: organic carbon; OM: organic matter; TN: total nitrogen.

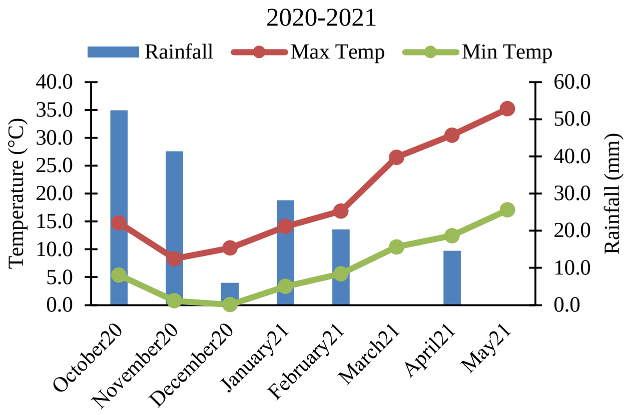

Figure 2. Accumulated monthly rainfall, and maximum and minimum temperatures during the 2020-21 growing season.

2.4. Measurement of germination characteristics

This test was done by planting germination paper on a plate. The papers were moistened with water before cultivation. Camelina seeds were placed in three rows in the middle of the paper. The seeds were placed in the light for 16 hours at 30 ºC and 8 h in the dark at 20 ºC. During the experimental period, daily visits were made, and the number of germinated seeds was recorded. The seed germination percentage started with the beginning of germination of the first seed and until the last day of seed germination. The daily germination was counted and finally, the germination percentage was calculated from Equation 1 (ISTA, 2008). Also, ten seedlings were randomly selected among normal seedlings, and the characteristics of radicle length and hypocotyl length were measured with a ruler with an accuracy of one millimeter (mm).

(1) $$GP = \frac{\text{Total number of germinated seeds}}{\text{Total number of seeds}} \times 100$$

2.5. Growth characteristics measurement

When the green color of the siliques changed, and 50% of the seeds turned brown, harvesting began, and the following plant traits were measured: In order to determine the plant height during physiological ripening, five randomly selected plants in each plot from the soil level to the highest point of the canopy. To determine the number of siliques per plant, five plants were randomly selected in each plot and used to measure this trait. The number of seeds per silique of the sub-branches of five plants was randomly counted and averaged to determine the number of seeds in the silique. Then, five samples of 100 seeds from each experimental plot were randomly selected and calculated by determining their mean weight using a sensitive digital scale with an accuracy of 0.001 grams and multiplying by 10 to determine thousand seed weight. In order to measure dry plant weight, first, five plants except for the roots (including stem, branch, leaf, silique, and seed) were dried using an oven for 48 hours at 75 °C, and then their mean was calculated using a digital scale with an accuracy of 0.001 grams as the final weight of the plant.

2.6. Grain yield

To investigate the camelina grain yield, at physiological maturity (BBCH: 89; Martinelli and Galasso, 2011), 2.0 m^2 area of each plot was harvested.

2.7. Statistical analysis

All data were analyzed using SAS software based on a one-way analysis of variance (ANOVA). The mean comparison was examined by the LSD test at $P<0.05$, and the correlation of traits was done by the Pearson correlation coefficient procedure. Graphs were drawn with Prism GraphPad. 9 software.

3. Results and discussion

3.1. Germination

The germination percentage of the treated (ER 15 and ER 25 cm) and untreated seeds (control) in the plate were calculated by counting the germinated seeds until the fifth day in 3 groups compared to the total number of cultivated seeds. According to the results, the germination percentage shows a significant difference between the treated and untreated samples ($P<0.01$) (Table 2). Therefore, Wi-Fi waves have been influential on camelina plant germination due to the same time and different treatment intervals. Based on the results, the highest percentage of germination in the plate was observed in the control sample with an average of 91.67% and the lowest was observed in ER 15 with an average of 68.67% and ER 25 with an average of 69.0% (Fig. 3).

3.2. Root length

Analysis of variances showed that the impact of wifi electromagnetic on root length was significant (Table 2). The highest root length was observed in the ER15 and increased by about 24.6% compared to the control and the lowest was observed in the 25 cm distance from the exposure source (ER 25) (Fig. 4).

Table 2. Analysis of variance for seed germination and growth characteristics affected by Wi-Fi electromagnetic waves on camelina.

S.O.V	df	Mean Square								
		GP†	RL	HL	PH	SPP	SPS	TSW	DPW	GY
Block	2	8.11	0.195	0.037	11.6	165.7	2.39	0.120	60.37	13992.2
Treatment	2	521.4**‡	0.135**	0.96*	362.7**	27858.7**	1.34*	0.367*	698.51*	31395.2**
Error	4	8.77	0.058	0.084	13.2	80.9	0.10	0.043	65.88	1497.7
Total	8									
CV (%)	-	3.87	5.34	15.82	7.66	4.50	3.50	17.91	11.60	4.02

† Germination percentage (GP), root length (RL), hypocotyl length (HL), plant height (PH), silique per plant (SPP), seed per silique (SPS), thousand seed weight (TSW), dry plant weight (DPW), grain yield (GY).
‡ ns, * and ** show not significant and significant differences at (P<0.05), and (P<0.01) levels of probability, respectively.

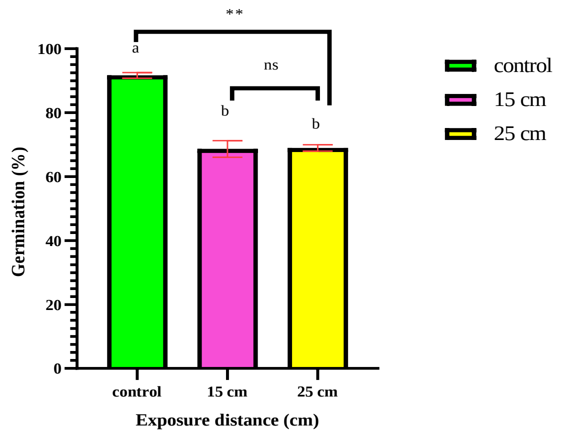

Figure 3. Effect of Wi-Fi electromagnetic waves (15 and 25 cm) on germination of camelina; Each column (mean ± SE) with common letters shows non-significantly differences (*P*<0.05) according to the LSD test.

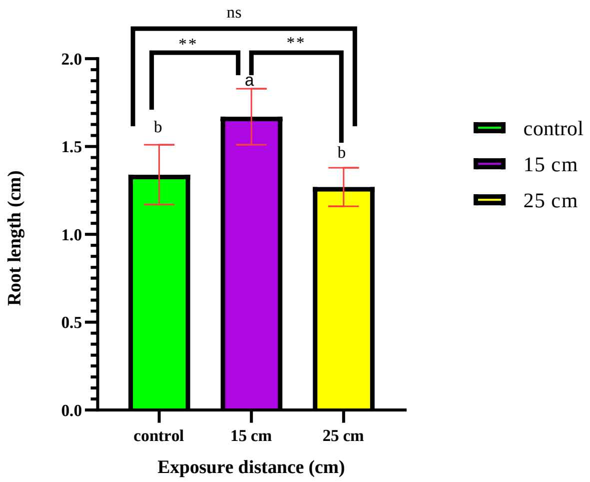

Figure 4. Effect of Wi-Fi electromagnetic waves (15 and 25 cm) on root length of camelina; Each column (mean ± SE) with common letters shows non-significantly differences (P<0.05) according to the LSD test.

3.3. Hypocotyl length and plant height

The results in Table 2 demonstrated that the impact of electromagnetic waves on the hypocotyl length trait is significant (P<0.01). A significant decrease in hypocotyl length was observed under exposure to the shortest distance of electromagnetic waves. So the lowest value of hypocotyl length with a 43.5% reduction was related to ER 25 (Fig. 5).

The analysis of variance showed that the electromagnetic waves had a significant (P<0.01) effect on the plant height in the maturity stage (Table 2). In the ER15, electromagnetic waves significantly increased the elongation of stem height and statistically, there was no significant difference with ER25 (Fig. 6).

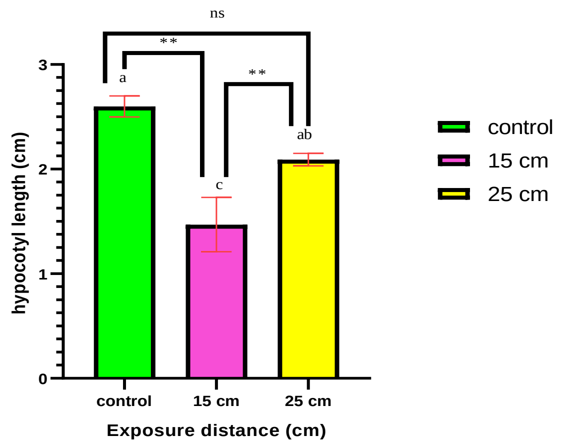

Figure 5. Effect of Wi-Fi electromagnetic waves (15 and 25 cm) on the hypocotyl length of camelina. Each column (mean ± SE) with common letters shows non-significantly differences (*P*<0.05) according to the LSD test.

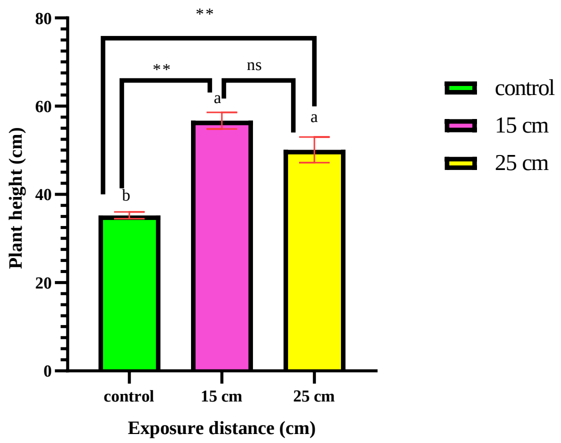

Figure 6. Effect of Wi-Fi electromagnetic waves (15 and 25 cm) on plant height of camelina. Each column (mean ± SE) with common letters shows non-significantly differences (*P*<0.05) according to the LSD test.

3.4. Siliques per plant

The data in Table 2 clearly show that the effect of WEW on silique numbers per plant was statistically significant (P<0.05). The number of siliques per plant of camelina significantly decreased in the ER 15 and it showed a decrease (approx. 56%) compared to the control (Fig. 7).

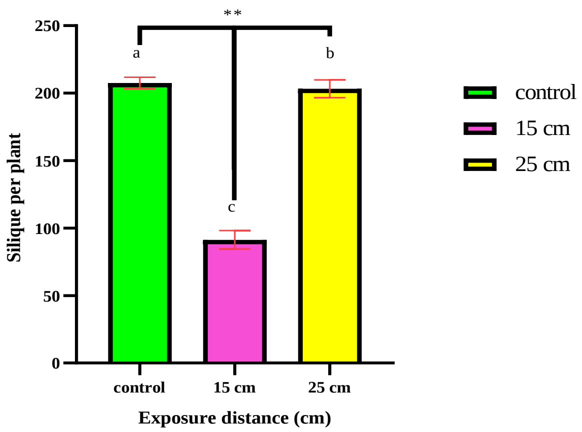

Figure 7. Effect of Wi-Fi electromagnetic waves (15 and 25 cm) on silique per plant of camelina. Each column (mean ± SE) with common letters shows non-significantly differences (*P*<0.05) according to the LSD test.

3.5. *Seed per silique*

Based on the results, WEW had a significant effect on the seed per silique (Table 2). However, it increased sharply (about 60.9%) in the plants exposed to WEW. Furthermore, ER 25 had no significant effect on seed per silique compared to the control plants (Fig. 8).

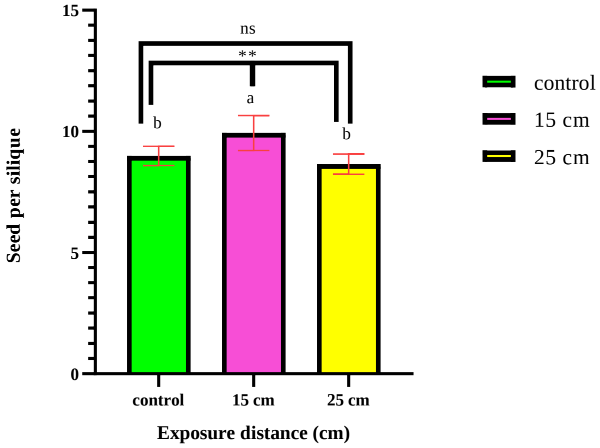

Figure 8. Effect of Wi-Fi electromagnetic waves (15 and 25 cm) on seed per silique of camelina. Each column (mean ± SE) with common letters shows non-significantly differences (*P*<0.05) according to the LSD test.

3.6. Thousand seed weight

According to the analysis of variance, it can be stated that the treatment interval with WEW affects the mean seed weight, and the mean seed weight shows a statistically significant difference between the treated and control plants (P<0.01) (Table 2). At a distance of ER 15, the radiation of electromagnetic waves caused a 43% decrease in the weight of a thousand seeds compared to the control (Fig. 9).

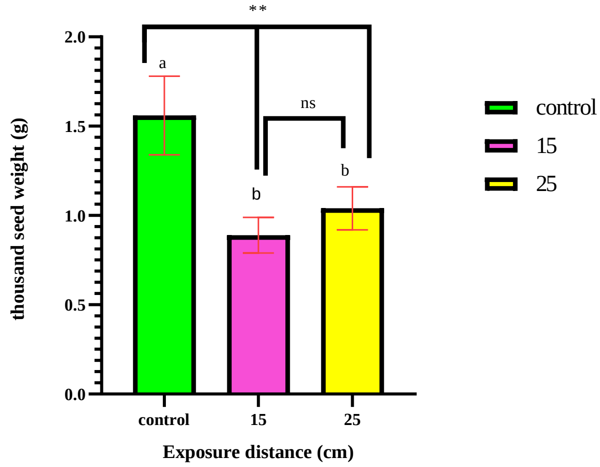

Figure 9. Effect of Wi-Fi electromagnetic waves (15 and 25 cm) on thousand seed weight of camelina. Each column (mean ± SE) with common letters shows non-significantly differences (*P*<0.05) according to the LSD test.

3.7. Dry plant weight

The results reported in Table 2 demonstrate a significant difference in the dry plant weight of camelina at (P<0.05) (Table 2). Electromagnetic waves in the 15 cm treatment caused a significant increase (about 56.3%) in dry weight compared to the control plants (Fig. 10).

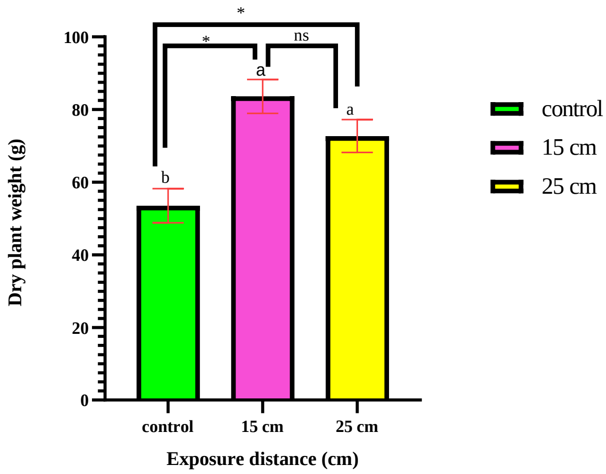

Figure 10. Effect of Wi-Fi electromagnetic waves (15 and 25 cm) on dry plant weight of camelina. Each column (mean ± SE) with common letters shows non-significantly differences (*P*<0.05) according to the LSD test.

3.8. Grain yield

Grain yield has significantly increased at Wi-Fi electromagnetic exposure as compared to the control (Table 2). The maximum grain yield was observed under ER15 and ER25 at 23.45 and 9.59% as compared to the control plants, respectively (Fig. 11).

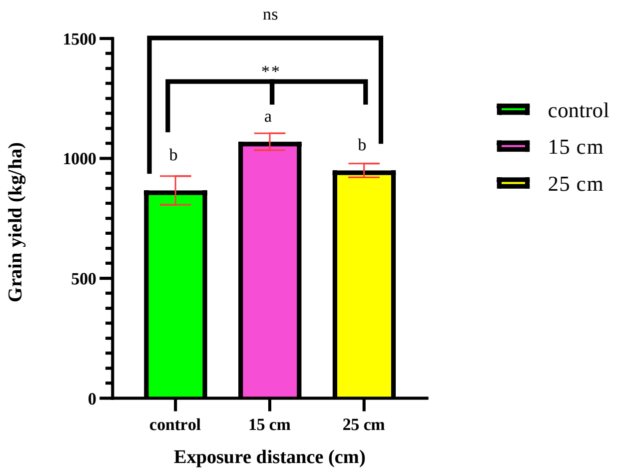

Figure 11. Effect of Wi-Fi electromagnetic waves (15 and 25 cm) on grain yield of camelina. Each column (mean ± SE) with common letters shows non-significantly differences (*P*<0.05) according to the LSD test.

3.9. Correlation coefficients of germination and growth characteristics

According to the results in Table 3, among the growth parameters of camelina, the highest correlation was reported between the HL and SPP (r=0.861**). This indicates an increase in the height of the plant, and as a result, an increase in the number of sub-branches, followed by an increase in siliques in the plant. Also, considering the high negative and significant correlation between GP and PH (r=0.933**). Conversely, the correlation between GP and HL was positive and significant (r=0.803**). Furthermore, among all the growth parameters, the correlation of the GY was positive and significant with DPW (r=0.735*), PH (r=0.669*) and SPS (r=0.659*) but the correlation between GY with HL (r= -0.778*) and SPP (r= -0.769*) was negative and significant. Moreover, in this study, TSW had a positive and significant correlation with GP (r=0.772*), HL (r=0.704*), and SPP (r=0.682*), which shows the importance of these traits in increasing the TSW of camelina plant.

Table 3. Pearson correlation coefficients among germination percentage and growth indices in camelina affected by Wi-Fi electromagnetic waves.

	GP	RL	HL	PH	SPP	SPS	TSW	DPW	GY
GP	1								
RL	-0.339^{ns}	1							
HL	0.803**	-0.539^{ns}	1						
PH	-0.933**	0.490^{ns}	-0.847**	1					
SPP	0.662*	-0.542^{ns}	0.861**	-0.816**	1				
SPS	-0.204^{ns}	0.551^{ns}	-0.566^{ns}	0.287^{ns}	-0.452^{ns}	1			
TSW	0.772*	0.015^{ns}	0.704*	-0.788*	0.682*	0.017^{ns}	1		
DPW	-0.779**	0.529^{ns}	-0.896**	0.763*	-0.766*	0.659*	-0.591^{ns}	1	
GY	-0.601^{ns}	0.190^{ns}	-0.778*	0.669*	-0.769*	0.659*	-0.632^{ns}	0.735*	1

Germination percentage (GP), root length (RL), hypocotyl length (HL), plant height (PH), silique per plant (SPP), seed per silique (SPS), thousand seed weight (TSW), dry plant weight (DPW), grain yield (GY).
ns, * and ** show no-significant and significant differences at (*P*<0.05), and (*P*<0.01) levels of probability, respectively.

Electromagnetic waves at different frequencies can cause changes in growth indicators, germination, and plant genetic and molecular characteristics (Mildažienė *et al*., 2019; Sukhov *et al*., 2021; Upadhyaya *et al*., 2022; Schmidtpott *et al*., 2022). Also, these waves can effectively increase the growth and performance of many products (Hafeez *et al*., 2023). According to Ramezani Vishki et al. (2012), the inducing function of electromagnetic waves can affect the genes inside the nucleus and increase metabolism. On the other hand, increasing enzyme activity and absorbing water in the seed accelerates germination. However, with these interpretations, the results of previous findings prove well that electromagnetic waves may positively or negatively affect the germination and growth characteristics of different plants. The findings of the present study showed that the effect of WEW on the germination characteristics of camelina was reported to be negative, and these waves caused a 24% decrease in germination. Overall, several studies that have examined the effect of EW on the reduction of germination in rapeseed (Farid *et al*., 2017), watercress (Cammaerts and Johansson, 2015) and horse chestnut has been reported (Havas and Sheena Symington, 2016).

Our study clearly shows that WEW significantly increased root length in camelina seedlings. It seems that the effect of electromagnetic waves on hydrolytic and proteolytic enzymes in seeds increases the speed of root growth at the beginning of the germination stages (Poghosyan *et al*., 2023). Our results confirm with Morozov et al. (2013) who reported that in winter wheat the EMF treatment (72 *GHz* for 20 *min*) enhanced seedling height and root length by 2.6- and 1.5-fold, compared to the control. Similar to our study, under electromagnetic irradiation, the root length of wheat was enhanced significantly (by 12%) at the seedling stage compared with the control (Poghosyan *et al*., 2023). Talei et al. (2013) have revealed that 1-10 hours of microwave irradiation (2450 MHz) before planting rice seeds can significantly improve root length.

Our study showed that WEW in the 15 and 25 treatments caused a 43% and 20% decrease in camelina hypocotyl length compared to the control (Fig. 5). According to Shabrangi et al. (2015) in rapeseed and corn, electromagnetic waves are related to cell metabolism and protein induction, and it seems that the negative effect of these waves on the hypocotyl of camelina is more pronounced, and it has reduced hypocotyl length. In general, germination and seedling growth is the most sensitive stage of plant growth, which is affected by environmental factors (Farooq *et al*., 2021). Also, our study revealed that the plant height in ER 15 and ER 25 showed a decrease of 37.8% and 11.6%, respectively, compared to the control (Fig. 6). Similar to our study, the stem growth in mustard was reduced in the 60 and 120-minute treatments of electromagnetic waves compared to the control (Begum *et al*., 2021). Also, rapeseed plants treated with microwaves showed a significant decrease in stem height, which was in agreement with the results of our study (Farid *et al*., 2017).

Exposure of camelina seeds to WiFi electromagnetic waves at a distance of 15 cm caused a decrease (by approx. 56%) in the SPP (Fig. 7). The SPP is considered one of the most critical components of camelina yield and affects its final performance. The effect of electromagnetic waves on pollination, pollen germination, and the flower's initial formation causes the flower system's sterility. Finally, it reduces the production of siliques in camelina. According to our findings, pine trees near the masts emitting electromagnetic waves significantly reduced the number of flowers (Ozel *et al*., 2021).

The number of seeds per silique is one of the important components in the final yield of camelina, which can change under the influence of various environmental factors. In the present study, the SPS was significantly affected by WEW (Fig. 8). Our finding is confirmed by the results of Hameed et al. (2022) who revealed the highest productivity indicators, including the pods and seeds number in bean (*Vicia faba*) plants that were exposed to Wi-Fi waves for 60 days.

Based on the results, the effect of WEW on the Thousand seed weight in the treatment of 15 cm distance caused a remarkable decrease in this trait (43%) compared to the control (Fig. 9). Seed growth and development is controlled by genetic factors and results from three developmental stages: embryo, endosperm and maternal egg (Guo *et al*., 2022). Moreover, the size and quantity of seeds are evolutionarily important for the continuation of plant species. In contrast to our results, the magnetic field significantly increased the seed weight of *Glycine max* (Asghar *et al*., 2017). Also, Magnetic field and gibberellic acid treatments in safflower increased the thousand seed weight and finally, increased the final yield (Faqenabi *et al*., 2009).

The accumulation of biomass depends on how the plant grows, and it should be noted that the performance of a product is achieved through the ability to accumulate biomass in the form of wet and dry biomass in the organs in which they are located. Therefore, the production and accumulation of biomass in these organs can determine the final yield (Suarez-Rivero *et al*., 2021). Our results showed that treatment of ER 15, caused an increase of 56.3% in dry plant weight compared to control (Fig. 10). Similar to our study, the pulsed electromagnetic fields increased the shoot fresh and dry weight of corn in all treatments compared to the untreated plants (Bilalis *et al*., 2012b). Vashisth and Joshi (2017), revealed that the seed corn treatment with the magnetic field (200 mT for 1 h) increased dry weight/ plant (24-70%) compared to the control seeds. In cauliflower (*Brassica oleracea*) seeds treated with higher-intensity electromagnetic fields had a higher biomass index and dry weight than the control, which was contrary to our results (Suarez-Rivero *et al*., 2021). Also in soybean, electromagnetic waves, improved grain yield compared to the version without radiation (Dukić *et al*., 2015).

The magnetic field can affect the germination and growth characteristics of the plant and thereby increase productivity and yield. In general, increases the income of farmers and creates sustainable and environmentally friendly agriculture. Previous research showed that the magnetic field can enhance grain yield (Chanioti *et al*., 2021). The result of our study showed that grain yield has significantly increased under Wi-Fi electromagnetic waves. Similar to our study, using a microwave device as a pre-sowing treatment before planting, increases the yield of rapeseed, camelina and mustard by 10 to 15% (Bastron *et al*., 2020). Also, When maize seeds with low germination ability were exposed to electromagnetic waves, they showed a yield of about 18-25% compared to the control plants (Chanioti *et al*., 2021). In another study, a magnetic field improved grain yield in two varieties of maize (Bilalis *et al*., 2012b). Also, the effect of these waves on the final yield of spring wheat has been reported to be 12.5-14.5% compared to control conditions (Pietruszewski and Kania, 2010).

Data in Table 3 presents positive relationships between GY and growth characteristics such as DPW (r=0.735*), PH (r=0.669*) and SPS (r=0.659*) of camelina (Table 3). It is possible to highlight that the Plants with higher height and dry weight can produce more seeds in silique with a consequence of having more grain yield. The correlation between PH and GY of camelina has been confirmed in other studies (Neupane *et al*., 2018, Neupane *et al*., 2019). Soorni et al. (2022) suggested that the positive relationships of the main characteristics suggest the feasibility of developing new higher-yielding camelina cultivars with high seed oil content. In this regard, Bakhshandeh et al. (2023) reported that The final grain yield of camelina has a positive and significant relationship with the main yield components, including the number of siliques, sub-branches and the number of seeds.

4. Conclusion

Pre-sowing treatment in electromagnetic fields is an inexpensive and environmentally friendly way to improve the quality of crop seeds. Most studies conducted on the effect of Wi-Fi electromagnetic waves emphasize that these waves have harmful or beneficial effects on the health of living beings. Our study showed that electromagnetic waves reduce camelina seed germination. But grain yield significantly increased under such conditions. This is the main objective of sustainable agriculture, especially in organic agriculture. Because it is an inexpensive and environmentally friendly technique that can be used easily. Currently, the use of these waves on seeds is used as a priming method among researchers. Therefore, exposure of camelina seed to the electromagnetic field at pre-sowing can be considered as a method to increase camelina grain yield.

Abbreviations

WiFi electromagnetic wave (WEW), Wi-Fi electromagnetic radiation at 15 cm (ER 15), Wi-Fi electromagnetic radiation at 25 cm (ER 25), Germination percentage (GP), root length (RL), hypocotyl length (HL), plant height (PH), silique per plant (SPP), seed per silique (SPS), thousand seed weight (TSW), dry plant weight (DPW).

Conflict of interests

All authors declare no conflict of interest.

Ethics approval and consent to participate

No human or animals were used in the present research.

Consent for publications

The authors declare that they have read the manuscript and approved it for publication.

Availability of data and material

Data will be made available on request.

Authors' contributions

Maryam Khashayarfard: Investigation, project administration, writing original draft, visualization; Danial Kahrizi: Conceptualization, methodology, validation, writing, review and editing, supervision; Sedigheh Arbabian: Methodology, Formal analysis; Fariba Sharifnia: Resources, review and editing. All authors reviewed the manuscript.

Informed consent

The authors declare not to use any patients in this research.

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