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Examining the influence of electromagnetic fields on wheat (Triticum aestivum L.) plants under water stress (drought)

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ABSTRACT

Magnetic fields have garnered significant interest from the scientific community due to their potential to improve seed germination, seedling growth, and various physiological, biochemical, and yield-related traits in plants, including cereal crops and vegetables. Over the years, research has highlighted the magnetic field (MF) as a safe and effective alternative for enhancing agricultural productivity. This study aimed to evaluate the impact of magnetic field pre-treatment on wheat (Triticum aestivum), a major crop in Libya and globally, primarily used for human nutrition due to its high content of proteins, minerals, and carbohydrates. One of the most important applications of magnetic fields is the treatment of wet seeds. The study also explored the effects of magnetic fields applied at different durations (control, one day, two days). Growth parameters such as plant height, number of leaves per plant, root length, fresh weight, and dry matter were assessed, along with yield characteristics like number of seeds per spike, 100-grain weight, and total grain yield under drought stress. Additionally, physiological aspects such as mineral nutrient content, monosaccharides, disaccharides, total soluble sugars, crude protein, proline, auxin levels, and protein analysis using SDS-PAGE were measured. The results showed that magnetic field treatments significantly improved plant growth compared to untreated seeds under drought stress. The findings indicate that pre-sowing magnetic field treatment has the potential to enhance the development of wheat seeds, improving growth parameters, mineral nutrients, total soluble sugars, pigments, and proteins. Notably, exposing seeds to the magnetic field for two days produced the best results.

Keywords: *Magnetic fields (MF), Wheat (Triticum aestivum), Drought stress, Seed treatment, Growth parameters, Protein analysis.*

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Introduction

Wheat is one of the most essential cereal crops globally, serving as a major source of protein and calories in human diets **(Nyaupane et al., 2024).** However, drought stress significantly reduces wheat yield by approximately 50-60% **(Zhao et al., 2020)**, Temperature has a major effect on seed germination (**Aiad et al., 2024**), which could exacerbate food security challenges globally as water shortages and declining yields continue alongside rapid population growth **(El-Mouhamady et al., 2023).** Drought not only lowers crop production but also causes soil erosion and environmental degradation **(Fang and Xiong, 2015).**

Various studies have examined the detrimental effects of drought on wheat growth, including reduced plant height, tiller formation, and spike development, as well as lower seed weight and nutrient uptake **(Dalirie et al., 2010; Poudel et al., 2020).** The physiological stress from water scarcity leads to early senescence, reduced photosynthesis, and nutrient imbalances, ultimately diminishing plant health and yield **(Hajibarat and Saidi, 2022).** While, Food and Agriculture Organisation (FAO) reported that, agriculture is responsible for more 69% of the world's water consumption (**Aiad et al., 2022**).

To address these challenges, magnetic fields (MFs) have been explored as a potential tool for enhancing agricultural productivity. Magnetic field treatments, particularly in seed pre-sowing, have gained attention for their eco-friendly, noninvasive nature **(Teixeira da Silva and Dobránszki, 2015).** They have been reported to improve seed germination, seedling growth, and plant productivity without the use of harmful chemicals **(Vashisth and Joshi, 2017).** The magnetic field affects seed hydration, membrane integrity, and biochemical processes, leading to improved seed vigor, faster germination, and enhanced nutrient uptake **(Pang and Deng, 2008; Vashisth and Joshi, 2017).** Magnetic field exposure has been shown to positively impact seed hydration, membrane integrity, and biochemical processes, which are crucial for seed vigor and growth. Studies have demonstrated that magnetic fields can enhance water uptake in seeds, improving hydration and supporting cell membrane stability **(Mano et al., 2021).**

This, in turn, leads to faster germination and better overall seed performance. Furthermore, magnetic fields are believed to influence enzymatic activities and nutrient absorption, facilitating improved nutrient uptake and promoting stronger seedling development **(Amirov et al., 2022).** These findings suggest that magnetic field treatment can be an effective tool for enhancing seed quality and crop productivity under varying environmental conditions.

Magnetic fields can alter water properties, such as surface tension and viscosity, which improves water absorption and ion uptake, enhancing plant growth **(Cai et al., 2009; Szczes et al., 2011).** Moreover, the influence of MF on plant cells affects membrane permeability and biochemical pathways, potentially increasing the uptake of essential nutrients like calcium, nitrogen, and magnesium, which are crucial for plant development **(Belyavskaya, 2004; Dhawi, 2014).**

Increased chlorophyll content, a key factor for photosynthesis, has also been observed in plants exposed to magnetic fields, improving their growth and stress resilience **(Asghar et al., 2016; Shine et al., 2021).** Studies have shown that exposure to magnetic fields enhances seedling growth, root development, and biomass production in various crops, including wheat, maize, and soybean **(De Souza et al., 2006; Atak et al., 2003).**

The use of magnetic fields as a pre-sowing seed treatment, known as magnetopriming, is recognized as a safe, cost-effective method for enhancing plant performance. This approach positively influences germination rates, seedling vigor, and crop productivity without adverse environmental impacts. Recent studies have reported that magnetic treatment significantly improved germination percentage, growth parameters, and yield attributes in crops such as wheat and soybean, highlighting its practicality and sustainability **(Selim et al., 2019; Bilalis et al., 2021).** It provides an environmentally friendly alternative to chemical treatments, offering benefits like increased germination rates, better nutrient uptake, and enhanced resistance to stress **(Pietruszewski and Martínez, 2015; Vashisth and Joshi, 2017).**

This study aimed to assess the impact of pre-sowing magnetic field treatment on wheat **(Triticum aestivum L.)**, focusing on its effects on the growth, development, and physiology of the wheat plants under drought stress, as well as its influence on grain yield.

Materials and Methods

Experiment Setup

The experiment was designed to assess the effect of magnetic field treatment on wheat (Triticum aestivum L.) under three different drought conditions: well-watered (80% field capacity), moderate drought (50-70% field capacity), and severe drought (30% field capacity). The wheat seeds were soaked in water and then exposed to a magnetic field for 2 days. Following the magnetic field exposure, the seeds were planted in pots containing a uniform soil mix, and the soil moisture was maintained according to the assigned drought conditions. The plants were grown in a controlled environment at 25°C with a 12-hour light/dark cycle.

Plant Growth

Growth parameters, such as plant height, root length, number of leaves, dry weight, and grain yield, were recorded. At harvest time, which occurred when 57% of the spikes had reached emergence and maturity, a random sample of plants from each treatment was collected. The following morphological and yield components were recorded: plant height (from the root tip to the ear lip), root length, number of leaves per plant, dry weight per plant (measured two weeks after harvest, using plants dried in the sun), number of seeds per spike, 100-grain weight (average weight of 100 seeds), grain yield per plant (average yield from ten plants), and seed setting (number of spikelets per spike).

To study the physiological effects of magnetic field treatment under drought stress, measurements of carbohydrates, minerals (Na, Mg, Fe, Ca, K, Zn), nitrogen, crude protein, proline, and amino acid contents were taken from the wheat seeds. The magnetic field treatment with the highest grain yield and physiological analysis was selected for further screening using SDS-Polyacrylamide gel electrophoresis (SDS-PAGE) and auxin content analysis.

Estimation of carbohydrates (Said and Naguib, 1964).

1 gram of dried wheat seeds was mixed with phenol solution and trichloroacetic acid, left overnight, filtered, and then neutralized **(Said and Naguib, 1964).** The residue was dried at 80°C for polysaccharide estimation. Reducing sugars were determined by a method involving the Nelson test Nelson **(1944)** as modified by Naguib **(1964)** and total reducing value and polysaccharides were measured using the modified Nelson's method Nelson, (1944).

Extraction and determination of mineral elements

Determination of sodium, magnesium, calcium and potassium ions **Jackson (1967).** To analyze mineral content, the wheat seeds were dried, ground, and digested with a mixture of sulfuric and perchloric acids. The resulting digest was used to measure sodium, magnesium, calcium, and potassium ions using flame photometry, while iron and zinc ions were determined with atomic absorption spectrophotometry **(AOAC, 2003).** Nitrogen content was assessed using the Macro-Kjeldahl method **(Chapman and Pratt,1982).,** and crude protein was calculated by multiplying nitrogen concentration by 6.25. **(A.O.A.C.1970)**.

Estimation of free amino acids

For amino acid analysis, wheat seeds were extracted with 75% ethanol and analyzed using HPLC with UV detection at 254 nm. Shad et al., **(2002).** Two grams of wheat grains were separately soaked in 75% ethanol (100 ml) for 24 hours. After this period, the sample was ground and filtered. The residue was rinsed with a small amount of 75% ethanol, and the volume was adjusted to 100 ml. The analysis of various amino acids was conducted using an HPLC system (HP1050) with a UV detector set to 254 nm. Separation was performed using an ODS C18 (5µm, 4 x 250 mm) column. The mobile phase consisted of 32% acetanol: tetrahydrofuran (90:10 v/v) and 64%

tetrahydrofuran: water (5/59 v/v), with 0.3 ml of acetic acid and the pH adjusted to 5.15 using 1M NaOH. The flow rate was set at 1.5 ml/min, the column temperature was maintained at 60°C, and the injection volume was 10 µl, following the method described by **Christian (1990).**

Estimation of proline

Proline content was determined by a colorimetric method involving ninhydrin reaction. The amount of proline was found using the method described by **Bates et al. (1973).** To do this, 0.1 g of fresh leaf tissue was mixed with 3% sulfosalicylic acid, filtered, and then mixed with acid ninhydrin solution. At 520 nm, absorption was measured with a UV spectrophotometer.

Protein analysis Bradford (1976).

For protein analysis, protein profiles were analyzed using SDS-PAGE, with the samples subjected to freeze-drying and protein content measured by Bradford's method**. Laemmli (1970).**

Determination of auxin

Finally, auxin content was measured using HPLC with a UV detector. This comprehensive analysis aimed to assess the impact of magnetic field treatment on wheat under drought stress, focusing on both morphological and physiological traits. Baydar and Ulger,(1998).

Statistical analysis

The data was subjected to one-way ANOVA and the differences between means at the 5% probability level were determined using Duncan's new multiple range test. The software SPSS, version 10 **(SPSS, Richmond, USA) was used as described by Dytham (1999)**. The mean values were statistically analyzed and compared by using New L.S.D value at 0.05 level **(Snedecor and Cochran, 1972).**

Results

Effect of magnetic field on the morphological characters

Data presented in table (Table 1) showed that the treatment of wheat (Triticum aestivum L.) seeds treated with magnetic field and grown under drought increased significantly the growth parameters (grain yield, 100 grain-weight (gm), number of seeds/spikes, dry weight/plant (gm), number of leaves/plant) as compared to control. Exposure for 2 days to magnetic field gives higher results than 1day.

Table 1. Growth parameters (grain yield, 100 grain-weight (gm), number of seeds/spikes, dry weight/plant (gm), number of leaves/plant) of wheat seeds with magnetic field and grown under drought.

Exposure Time	Drought Level	Plant Height (cm)	Number of Leaves/Seedling	Root Length (cm)	Fresh Weight/ Seedling (g)	Plant Height (cm)_2	Root Length (cm)_2	Number of Leaves/ Plant	Dry Weight/Plant (g)	Number of Seeds/Spike	100 Grain Weight (g)	Grain Yield (g)
Control	MD	31.00 Â±	9.70 Â± 0.57	3.60 Â±	0.90 Â± 0.14	83.50 Â±	3.90 Â±	4.70 Â± 0.57	0.60 Â±	58.70 Â± 1.52	4.40 Â±	0.40 Â±

		2.64		1.15		1.53	0.11		0.05		0.36	0.02
Day 1	MD	35.00 Â± 0.57	9.00 Â± 1.00	3.70 Â± 2.08	0.97 Â± 0.06	83.60 Â± 1.70	5.10 Â± 0.20	5.00 Â± 1.00	0.72 Â± 0.03	62.60 Â± 2.51	4.70 Â± 0.50	0.41 Â± 0.03
Day 2	MD	38.00 Â± 1.53	11.60 Â± 0.57	5.00 Â± 1.15	1.83 Â± 0.11	104.00 Â± 2.00	5.60 Â± 0.23	8.30 Â± 0.57	0.86 Â± 0.03	105.00 Â± 3.00	4.77 Â± 0.30	0.57 Â± 0.02
Control	WW	29.00 Â± 5.19	9.00 Â± 1.00	3.50 Â± 0.86	0.91 Â± 0.23	83.00 Â± 1.00	3.00 Â± 0.76	4.00 Â± 0.57	0.70 Â± 0.01	53.80 Â± 3.21	4.10 Â± 0.15	0.37 Â± 0.04
Day 1	WW	32.00 Â± 3.60	9.80 Â± 0.57	3.83 Â± 1.04	0.93 Â± 0.23	89.00 Â± 2.51	5.00 Â± 1.32	4.67 Â± 1.15	0.88 Â± 0.04	61.60 Â± 2.08	4.90 Â± 0.10	0.45 Â± 0.03
Day 2	WW	39.00 Â± 0.57	11.80 Â± 0.57	5.63 Â± 0.41	1.90 Â± 0.26	122.00 Â± 2.51	6.23 Â± 0.30	8.70 Â± 1.52	0.90 Â± 0.02	119.00 Â± 1.15	5.57 Â± 0.41	0.59 Â± 0.01
Control	SD	28.00 Â± 1.00	9.60 Â± 0.57	3.18 Â± 0.28	0.89 Â± 0.03	89.00 Â± 6.08	3.10 Â± 0.61	5.00 Â± 0.57	0.67 Â± 0.05	55.00 Â± 2.51	4.40 Â± 0.45	0.40 Â± 0.01
Day 1	SD	31.00 Â± 3.21	9.85 Â± 0.57	3.50 Â± 0.50	0.97 Â± 0.20	90.00 Â± 0.57	5.00 Â± 0.20	5.30 Â± 0.57	0.87 Â± 0.03	59.30 Â± 0.57	4.93 Â± 0.15	0.45 Â± 0.01
Day 2	SD	34.00 Â± 3.78	11.00 Â± 1.00	5.17 Â± 0.28	1.43 Â± 0.20	94.90 Â± 1.55	5.13 Â± 0.32	8.00 Â± 0.01	0.88 Â± 0.03	84.30 Â± 4.04	5.46 Â± 0.45	0.48 Â± 0.01

Each listed value is a mean of 3 replicates. SD. Significantly different from control at P<0.01.

Changes of total soluble sugar of wheat (Triticum aestivum) affected by magnetic field:

It is appeared from in table 2 that monosaccharide, disaccharide, polysaccharide and total soluble sugar content of wheat (Triticum aestivum) seeds increased during exposure to magnetic field compared to control.

Table 2. Monosaccharide, disaccharide, polysaccharide and total soluble sugar content of wheat seeds.

Exposure Time	**Drought Level**	**Plant Height (cm)**	**Number of Leaves/Seedling**	**Root Length (cm)**	**Fresh Weight/ Seedling (g)**	**Plant Height (cm)_2**	**Root Length (cm)_2**	**Number of Leaves/ Plant**	**Dry Weight/Plant (g)**	**Number of Seeds/Spike**	**100 Grain Weight (g)**	**Grain Yield (g)**
Control	MD	31.00 Â± 2.64	9.70 Â± 0.57	3.60 Â± 1.15	0.90 Â± 0.14	83.50 Â± 1.53	3.90 Â± 0.11	4.70 Â± 0.57	0.60 Â± 0.05	58.70 Â± 1.52	4.40 Â± 0.36	0.40 Â± 0.02
Day 1	MD	35.00 Â± 0.57	9.00 Â± 1.00	3.70 Â± 2.08	0.97 Â± 0.06	83.60 Â± 1.70	5.10 Â± 0.20	5.00 Â± 1.00	0.72 Â± 0.03	62.60 Â± 2.51	4.70 Â± 0.50	0.41 Â± 0.03
Day 2	MD	38.00 Â± 1.53	11.60 Â± 0.57	5.00 Â± 1.15	1.83 Â± 0.11	104.00 Â± 2.00	5.60 Â± 0.23	8.30 Â± 0.57	0.86 Â± 0.03	105.00 Â± 3.00	4.77 Â± 0.30	0.57 Â± 0.02
Control	WW	29.00 Â± 5.19	9.00 Â± 1.00	3.50 Â± 0.86	0.91 Â± 0.23	83.00 Â± 1.00	3.00 Â± 0.76	4.00 Â± 0.57	0.70 Â± 0.01	53.80 Â± 3.21	4.10 Â± 0.15	0.37 Â± 0.04
Day 1	WW	32.00 Â± 3.60	9.80 Â± 0.57	3.83 Â± 1.04	0.93 Â± 0.23	89.00 Â± 2.51	5.00 Â± 1.32	4.67 Â± 1.15	0.88 Â± 0.04	61.60 Â± 2.08	4.90 Â± 0.10	0.45 Â± 0.03
Day 2	WW	39.00 Â± 0.57	11.80 Â± 0.57	5.63 Â± 0.41	1.90 Â± 0.26	122.00 Â± 2.51	6.23 Â± 0.30	8.70 Â± 1.52	0.90 Â± 0.02	119.00 Â± 1.15	5.57 Â± 0.41	0.59 Â± 0.01

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Day 1	SD	31.00 Â± 3.21	9.85 Â± 0.57	3.50 Â± 0.50	0.97 Â± 0.20	90.00 Â± 0.57	5.00 Â± 0.20	5.30 Â± 0.57	0.87 Â± 0.03	59.30 Â± 0.57	4.93 Â± 0.15	0.45 Â± 0.01
Day 2	SD	34.00 Â± 3.78	11.00 Â± 1.00	5.17 Â± 0.28	1.43 Â± 0.20	94.90 Â± 1.55	5.13 Â± 0.32	8.00 Â± 0.01	0.88 Â± 0.03	84.30 Â± 4.04	5.46 Â± 0.45	0.48 Â± 0.01

Each listed value is a mean of 3 replicates. SD. Significantly different from control at $P<0.01$.

Metal Elements (Zn, Mg, Na, K):

It is appeared from figs. (1,2,3), that the Na, Mg, Fe, Ca, K, Zn and N contents in wheat (Triticum aestivum) seeds increased after exposure to MF compared to control. Exposure for 2 days to MF gives higher results than 1day.Also, the results presented in fig (3) indicated that the magnetic field exhibited marked significant increase in crude protein of wheat (Triticum aestivum) seeds compared with untreated plants.

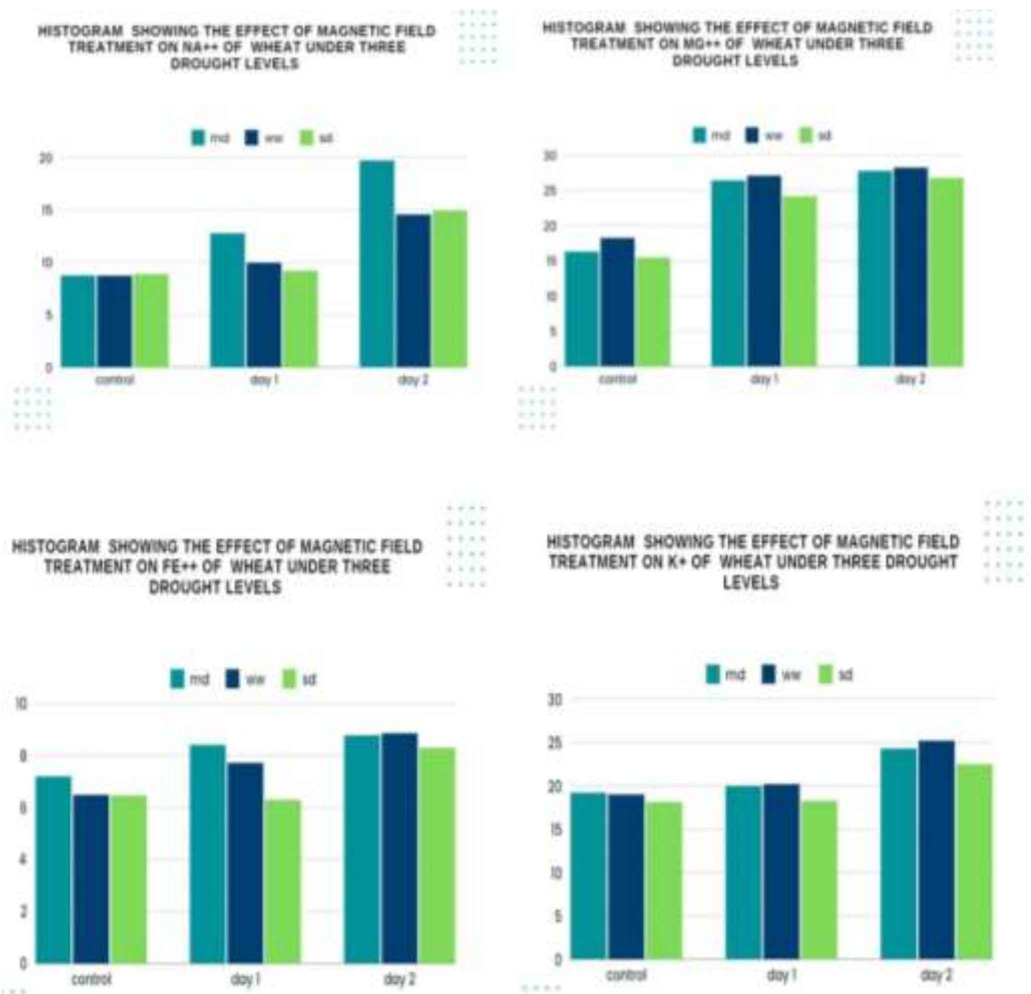


Fig.1. Histogram showing the effect of magnetic field treatment (20 G) on Na, Mg, Fe, Ca, K, Zn of wheat under three drought levels.

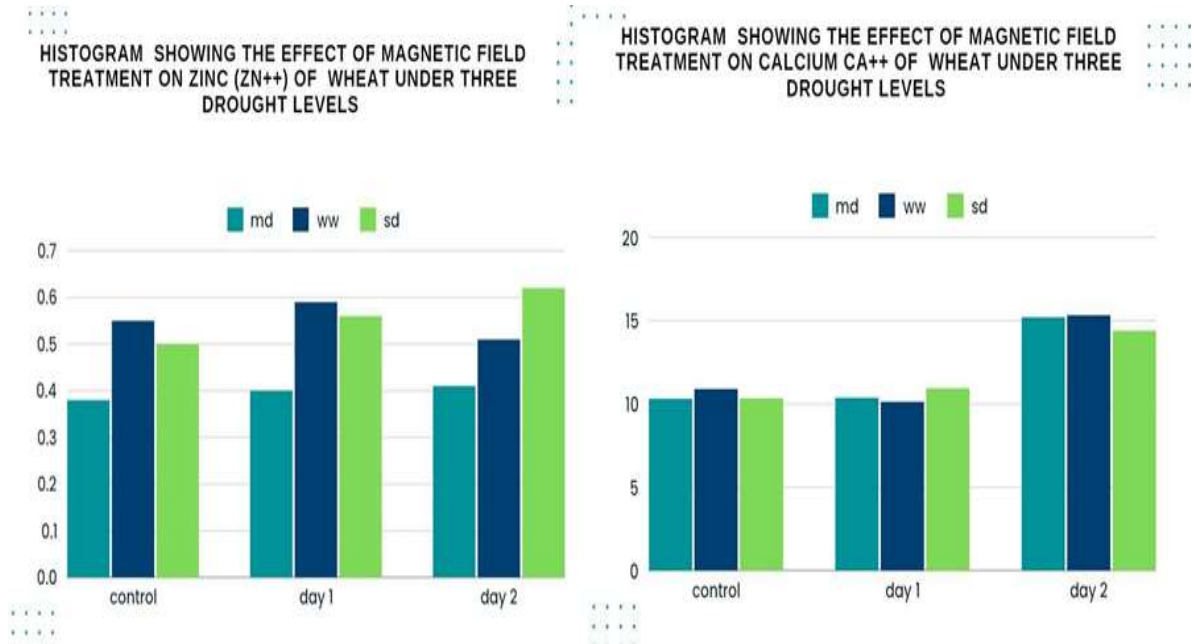


Fig.2. Histogram showing the effect of magnetic field treatment (20 G) on Ca, and Zn of wheat under three drought levels

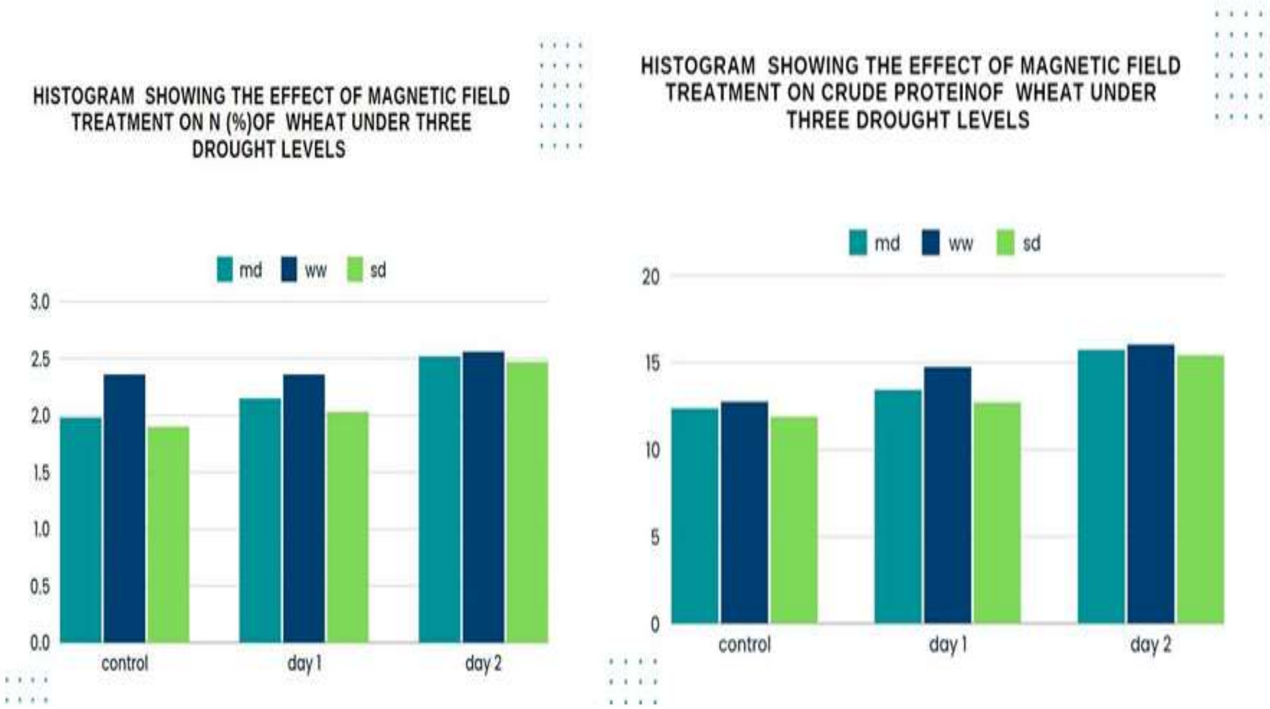
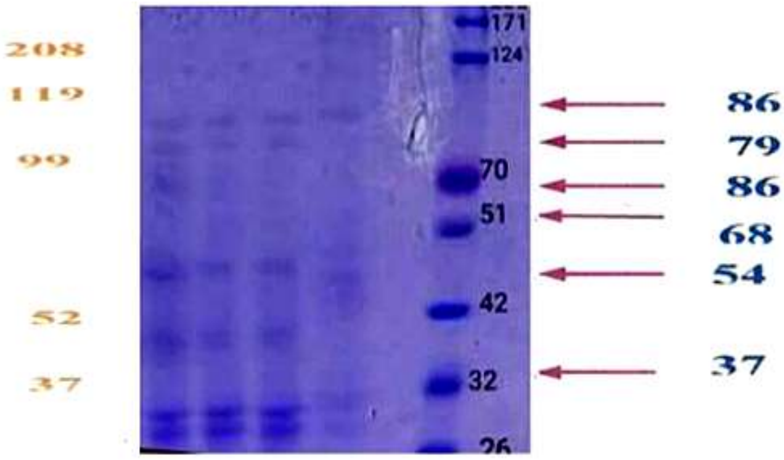


Fig.3. Histogram showing the effect of magnetic field treatment (20 G) on N (%) and Crude protein of wheat under three drought levels.

The SDS-PAGE analysis of wheat (Triticum aestivum) seeds irradiated by a magnetic field revealed significant changes in the protein profile, indicating a positive impact on protein content. The magnetic field exposure resulted in an increase in the number of polypeptide bands (14 bands in irradiated seeds compared to 11 in the control).

Six new bands with molecular weights of 85, 79, 70, 68, 62, and 37 KD appeared in the irradiated seeds, while three bands (86, 69, and 53 KD) disappeared. Additionally, eight common bands were present in both irradiated and control seeds, but the optical density (protein amount) of these bands was higher in the irradiated seeds, suggesting that the magnetic field treatment enhanced protein accumulation, benefiting the overall protein content in the wheat seeds.



Analysis of IAA concentration in the two days magnetic field treated wheat seeds:
The results in table (3) showed that, treatment of wheat seeds with magnetic field (20 G) resulted in a slight increase in its IAA content, therefore from this result we can indicate irradiation with magnetic field (20 G) stimulated IAA synthesis.

Table (3):

Wheat-seeds:	IAA conc. (ppm).
Control seeds	1.15
two days magnetic field treated wheat seeds	1.99

Discussion
In this study, the impact of magnetic field stimulation on wheat *(Triticum aestivum L.)* seeds was assessed, focusing on their yield, morphological, and physiological traits. The magnetic field treatment led to improvements in these parameters, aligning with findings from previous studies on other species **(Soliman and Harith, 2010).** Wheat is a globally significant and highly nutritious cereal, cultivated on 220 million hectares, contributing significantly to agricultural output **(Arzani and Ashraf, 2017).** However, Abiotic stresses, particularly drought, pose significant limitations to wheat yields, especially in arid regions where water scarcity is prevalent. Drought stress drastically reduces soil moisture availability, negatively impacting wheat growth by limiting photosynthesis, reducing leaf area, and accelerating leaf senescence, leading to substantial yield reductions **(Alghabari et al., 2024).** A recent meta-analysis indicated that drought conditions could decrease wheat grain yield by approximately 57%, highlighting the severity of drought-induced productivity losses **(Bhandari et al., 2021; Zhang et al., 2022)**. These findings underline the critical need for sustainable agricultural strategies to mitigate drought effects in vulnerable regions. Our research showed that drought stress negatively affects various aspects of wheat growth, including seed germination, plant height, and yield, a finding supported by earlier studies **(Anjum et al., 2017).** Drought stress negatively affects plant development and growth by reducing photosynthesis, slowing cell division, and disrupting nutrient uptake. Limited water availability prompts stomatal closure, significantly decreasing CO_2 absorption and impairing the photosynthetic capacity of plants **(Kapoor et al., 2020).** Additionally, drought reduces cellular turgor pressure, hindering cell division and expansion, ultimately resulting in stunted growth and lower biomass production **(Çakir, 2004; Farooq et al., 2022).** Nutrient uptake is also compromised under drought conditions due to limited nutrient mobility and reduced root functionality, leading to nutrient deficiencies that further impair plant health and productivity (Seleiman et al., 2021). On the other hand, magnetic field exposure enhanced wheat growth, increased protein biosynthesis, and improved several growth parameters like plant height, root length, and grain yield under drought stress. This effect is attributed to magnetic fields stimulating biochemical processes and enzyme activity, which help plants resist drought stress **(Govindaraj et al., 2017; De Souza et al., 2014).** Our results showed that magnetic field treatment increased the accumulation of essential elements such as Na^+, Mg^{++}, Fe^+, K^+, Zn^+, and Ca^{++} in wheat seeds compared to untreated seeds. Furthermore, the magnetic field treatment promoted higher protein content, soluble sugars, and proline accumulation, contributing to the plant's drought tolerance. These findings align with studies suggesting that Magnetic field **(MF)** treatment has been recognized as a promising strategy for improving drought tolerance in crops by enhancing nutrient uptake and regulating critical biochemical responses. Exposure to magnetic fields increases the efficiency of nutrient absorption, leading to improved plant nutrition and enhanced physiological functions under drought stress **(Kataria et al., 2020).** Additionally, MF treatment has been found to activate antioxidant enzymes and modulate stress-responsive biochemical pathways, ultimately boosting plant resilience and sustaining growth in water-limited environments **(Aladjadjiyan, 2007; Martínez et al., 2017; Alattar et al., 2022).** Ultimately, magnetic field treatment shows potential for producing drought-tolerant wheat mutants, thus improving yield and stress resistance in agricultural crops.

Conclusion

The present study provides strong evidence that magnetic field exposure significantly enhances the yield, morphological, physiological, and biophysical properties of wheat (Triticum aestivum L.), especially under drought stress. Seeds treated with the magnetic field showed a higher weight compared to untreated seeds. The study also found that exposure to the magnetic field for two days resulted in greater improvements than one-day exposure. Drought stress is a major challenge for wheat production globally, causing substantial yield losses, and understanding the mechanisms of drought tolerance is crucial. Developing drought-resistant wheat varieties is essential to ensure food security in the face of climate change. The use of magnetic field treatment on wheat seeds has shown significant potential in improving wheat growth and resilience to drought, making it a promising strategy for cultivation in water-stressed environments.

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