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Mitigation salinity water stress using magnetic technology and humic acid on productivity of Barley (*Hordeum vulgare* L.) growing in Al-Maghrah region

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AL-MAGHRAH region, 280 000 feddan, like the most locations of million and half feddan project is mainly depended on the well water of various degrees of salinity stress (4000 – 8000 ppm) that may be prevents cultivated crops from realizing their full yield. Barley is considered to be one of the best crops that can withstand difficult environmental conditions, such as salinity, as in the Al-Maghrah region. A germination experiment was conducted at Laboratory of Seed Technology Research Department, Field Crops Research Institute, Agriculture Research Centre to study the impact of seed treatments (dry seeds, hydro-seeds, and magneto-primed seeds) on germination characteristics, seedling development, and vigour of barley. Results cleared that that magnetized barley grains treatment (soaking barley grains in magnetized water for 8 hours before sowing) surpassed dry grains or hydro-grains treatment (soaking barley grains in tap water for 8 hours before sowing) in germination traits at 14 days after sowing. The improvement ranged between 5.00 – 40.68% compared to dry grains treatment and 3.52 – 24.82% compared to hydro-grains treatment in tested germination parameters. Positive effects were observed in MGT, where it is faster by 19.84% compared dry grains treatment and 11.54% compared to hydro-grains treatment. Under field conditions. Four field experiments were conducted during winter seasons (2022-2025) to alleviate salinity irrigation water stress using the application of magnetic technology combined with foliar spraying of humic acid at 45 and 60 days after sowing on the productivity of barley crops. Results revealed that irrigation barley plants with magnetically treated brackish-water significantly surpassed irrigation with brackish-water treatment in barley yield and its components. Similar trends were recoded under spraying barley plants with 50 or 100-ppm humic acid at 45 and 60 days after sowing. In general, magnetically treated brackish water magnetic accompanied spraying with 100-ppm humic acid at 45 and 60 days of barley sowing gave the highest values in barley yield and its components compared to the control. The improvement rate ranged from 11.05 - 22.99% in barley yield components. As well as the percentage increases in grain, straw and biological yield (ton fed^{-1}) reached 39.65, 34.39 and 35.98%, respectively, compared to the control.

Keywords: Barley, Salinity water stress, Magnetic technology, Humic acid, Al-Maghrah region.

Introduction

Al-Maghrah region is located in the Western Desert in northwest Egypt. It is located in the space between latitudes 29° 500 and 30° 410 N and longitudes 28° 100 and 29° 100 E in the northeast expansion of the Qattara Depression. Its climate is described as short warm in the winter and hot in the summer, with high evaporation rates and little precipitation (Youssef *et al.*, 2012). The rainfall ranges between 25 to 50 mm every year, and the average ranges of temperature from 23 to 39 °C (Mohamaden *et al.*, 2017).

Eltarabily and Moghazy (2021) indicated the alkaline nature and elevated salinity levels of groundwater in the studied project area; their research suggests that highly salt-tolerant field crops such as barley, canola, jojoba and quinoa should be cultivated in this region. Salinity stress represents a major challenge to worldwide crop production, highlighting the necessity of grasping how crops such as barley (*Hordeum vulgare* L.) respond to stress (Abdelrady, *et al.*, 2024 and Abd El Lateef *et al*., 2025).

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Barley (*Hordeum vulgare* L.) is an ancient annual plant that has been domesticated (Badr *et al.*, 2000, Purugganan and Fuller, 2009, Mansour and Moustafa, 2016). At present, barley ranks as the fourth most widely grown cereal crop based on field production and yield (http://faostat.fao.org). Approximately 75% of worldwide production is utilized for livestock feed, while 25% is either malted or ingested as food by humans (Blake *et al.*, 2011). In less affluent nations, barley serve in marginal and difficult agricultural conditions as crucial food source (Grando and Macpherson, 2005), delivering harvestable yields in conditions that are marginal and difficult for agriculture. Recent studies have categorized barley as a genuine functional food in more advanced societies.

Magnetized water is a promising technique that has been employed in managing saline water for irrigation purposes. Magnetized water alters the chemical and physical characteristics of water. It creates a consistent structure with minor changes in key traits, including electrostatic polar force, surface adhesion, hardness, specific gravity, viscosity, salinity, water solubility, and water-surface contact angle (Hozayn *et al.*, 2014). The magnetic treatment of water neither adds nor removes any substances from the water, making it a safe and eco-friendly technology (Dastorani *et al.*, 2022). Additionally, a promising technique for reducing saltiness is magnetized water. It lowers soil alkalinity, decreases the amount of saltiness in irrigation water, and exhibits a significant leaching rate of excess soluble salts (Hilal and Hilal, 2000, and Hozayn 2015). Without having any negative or damaging effects, the application of the magnetic treatment in irrigation water improved crop growth, yield, and germination (Ben Hassen *et al.*, 2020, Hozayn *et al.*, 2020, and Hozayn *et al.*, 2021).

Seed germination is a complex physiological and biochemical modification phenomenon, which leads to the activation of the embryo. Seed germination is a critical stage, which affects total dry matter and grain yield output (Parihar *et al.*, 2015). Salt stress induced a delay in rice seed germination showing an adverse association between seed germination and salt stress (Shereen *et al.*, 2011).

Humic acid is considered one of the most influential components of soil and constitutes a significant portion of organic matter and humus (Eissa, 2014 and Alsudays *et al.*, 2024). In rice cultivars that are sensitive to salinity, humic acid can effectively increase salt tolerance and has a promising potential for mitigating stress (Mohamed, 2020, Amer et al., 2018 and Shukry *et al.*, 2023). Compared to plants grown under salinity stress, plants treated with humic acid showed increased development, photosynthesis, activity of antioxidant enzymes, dry matter, productivity, and N, P, K, Ca, Mg, Na, Fe, Zn, Mn contents (Mart, 2007 and Abiven, *et al.*, 2009).

Materials and Methods

Laboratory and field experiments, respectively, were conducted at Seed Preservation Laboratory, Department of Seed Technology, Field Crops Research Institute, Agriculture Research Center, and at Agricultural Experimental and Production Farm for Academy of Scientific Research and Technology, Al-Maghrah Region, Matrouh Governorate, Egypt during winter seasons of 2022/23 and 2023/24 and 2024/25. The studies aim to select the best priming-seed treatment to apply under field conditions to alleviate salinity water stress on productivity of barley using application of magnetized seed under laboratory experiment and magnetized water and foliar spraying of humic acid at 45 and 60 days after sowing under field conditions.

Laboratory experiment

Laboratory experiment was carried out at the Seed Preservation Laboratory, Department of Seed Technology, Field Crops Research Institute, Agriculture Research Center, Giza, Egypt during winter season of 2022/23. The research intends to assess the impact of magneto-priming seed treatments (dry seeds, hydro-seeds, and magneto-primed seeds) on germination characteristics, seedling development, and vigour of barley. To choose the suitable treatment for implementation in field conditions. A completely randomized design (CRD) with four replications was used for the experiment. Barley seeds (variety Giza 123) were acquired from the Barley Research Department at the Agriculture Research Centre, located in Giza, Egypt).

Magneto and hydro-priming seeds: Magneto-priming was prepared by passing dry seeds through the magnetic device's funnel (2000-2500 Gauss; 0.5 inch and produced by NRC, Egypt), then magnetized seeds were soaked in magnetized water (Tap water after passing in magnetic unit, 2000-2500 Gauss; 0.5 inch and produced by NRC) then were left for 8 hours. While hydro-priming seeds was prepared by soaking dry seeds in tap water for 8 hours. Finally, treated seeds were exposed to surface-dried with paper towels to match their initial moisture content for 24h at 15°C in the incubator under dark conditions. For equal control, seeds from the identical batch were kept in a non-magnetic field setting for consistent control. The seeds were prepared for the germination process in the lab experiment.

Following ISTA (1999), a germination test was conducted in which 25 barley seeds were planted in sterile Petri dishes that were covered at the bottom with two sheets of Whitman filter paper. The dishes were then kept in an incubator set at 20±2°C. Every day, the total number of seeds that germinated was recorded and on the fourteenth day, the percentage was determined. Germination (G%), shoot, root and seedling length (cm), seedling fresh and dry weight (g), seed germination Index (GI), germination rate (GR), speed germination index (SGI), mean germination time (MGT), seedling vigor-I (SV1) and seedling vague-I (SVII) were calculated. Daily counts of the total number of seeds that germinated were made, and the following formula was used to get the percentage at day 14 according to Association of Official Seed Analysis (AOSA, 1983):

- **Germination (%):** (The number of germinated seeds/The total number) X 100
- **Germination Rate (GR):** It was defined according to the following formula: GR= a + (a +b) + (a + b + c) …….. (a + b + c + m)/ n (a + b + c + m), Where a, b, c are No. of seedlings in the first, second and third count, m is No. of seedlings in final count, n is the number of counts.
- **Mean Germination Time (MGT):** It was calculated based on the following equation: **MGT=** Σ Dn/ Σn, where (n) is the number of seeds, which were germinated on day, D is number of days counted from the beginning of germination.
- **Speed Germination Index (SGI):** It was calculated as described in following formula:

SGI= (No. of germinated seed/days of first count) + (……./…….) + (No. of germinated seed/days of final count). Seeds were considered germinated when the radical was at least 2 mm long.

- **Seedling root and shoot length (cm):** It was measured of ten normal seedlings at 14 days after planting.
- **Seedling fresh and dry weight (g):** Ten normal seedlings 14 days after planting were measured to determine fresh weight then the seedlings were dried in hot-air oven at 85^{o} C for 12 hours to obtain the seedlings dry weight (g).
- **Seedling vigour index I** = Germination (%) x Seedling length (Root +Shoot)
- **Seedling Vigour index II** = Germination (%) x Seedling dry weight (Root +Shoot)

Field experiments:

Four field Experiments using Barley (variety Giza-123) were conducted at Agricultural Experimental and Production Farm for Academy of Scientific Research and Technology, Al-Maghrah Region, Matrouh Governorate, Egypt during the winter seasons of 2022/23; 2023/24 and 2024/25. The experiment aims to alleviate salinity irrigation water stress using the application of magnetic technology combined with foliar spraying of humic acid at 45 and 60 days after sowing on productivity of barley crops in Al-Maghrah region.

Al-Maghrah Region is located on the northeastern border of the Qattara Depression in the Western Desert, 40 km south of the city of Al-Hammam, which is about 3 km east of the Petroleum Road and about 70 km west of the El-Alamein International Road. Al-Maghrah is about 40 km from the city of El-Alamein (100 km by road). Al-Maghrah Region lies between 28° 55' 59" E and 30° 13' 59" N. The experimental soil and irrigation water in the site of experiment were analyzed according to the method described by Chapman and Pratt (1978; Table 1). Table 1 shows that the experimental site's soil was sandy and deficient in organic matter and NPK. In addition, irrigation water was saline.

Treatment: The experiment in the first winter season of 2022/23 included two treatments (Control treatment was irrigated with Brackish water (BW), while the other treatment (Magnetized Brackish-water (M-BW) was irrigated with water after magnetization through passing a three-inch of magnetic unit (produced by NRC; 0.26-0.28 Tesla). The experiments in the second and third winter seasons (2023/24 and 2024/25) was included two factors: 1) water treatments: (irrigation with brackish water (BW) and Magnetized-BW (M-BW; brackish water after magnetization through passing a three-inch static-magnetic unit, 0.26 -.028 Tesla, produced by National Research Centre), and factor 2) Foliar spraying by 0.0, 50 and 100 ppm of humic acid at 45 and 60 days after sowing. The two factors quadrupled and were put in split plot design where water treatments were arraigned in main plots and levels of humic acid were arranged in sub-plot. The layout and design of experiment is shown in Fig. 1.

Table 1. Analysis of experimental site soil and irrigation water under irrigation with brackish (BW) and magnetized brackish water (M-BW) treatments.

Treatment	Soil analysis (00-30cm)		Irrigation water analysis	
Soil properties	**BW**	**M-BW**	**BW**	**M-BW**
Particle size distribution of soils				
Very coarse sand (1–2 mm)	3.58	3.58	..	..
Coarse sand (0.5–1 mm)	9.28	9.28	..	..
Medium sand (0.25–0.5 mm)	33.58	33.58	..	..
Fine sand (0.10–0.25 mm)	35.37	35.37	..	..
Very fine sand (0.05–0.10 mm)	17.19	17.19	..	..
Slit and clay (0.05-0.002 mm)	0.99	0.99	..	..
Texture	Sand	Sand	..	..
pH	8.28	8.55	6.33	6.34
EC (ds cm^{-1})	0.35	0.26	9.81	8.62
$CaCO_3$ (%)	1.87	1.67	…	..
Organic matter (%)	0.13	0.18	..	..
Soluble anions (meq 100g $soil^{-1}$)			**Soluble anions (meq L^{-1})**	
HCO^{-3}			2.80	2.92
CO^{-3}	0.27	0.43	..	..
Cl^{-}	1.95	1.32	86.50	83.00
SO^{-4}	1.08	0.85	8.82	7.46
Soluble cations (meq 100g soil $^{-1}$)			**Soluble cations (meq L^{-1})**	
Na^{+}	1.71	1.24	64.60	62.00
K^{+}	0.16	0.24	1.02	1.08
Ca^{++}	0.40	0.35	17.50	16.10
Mg^{++}	1.14	0.77	15.00	14.20

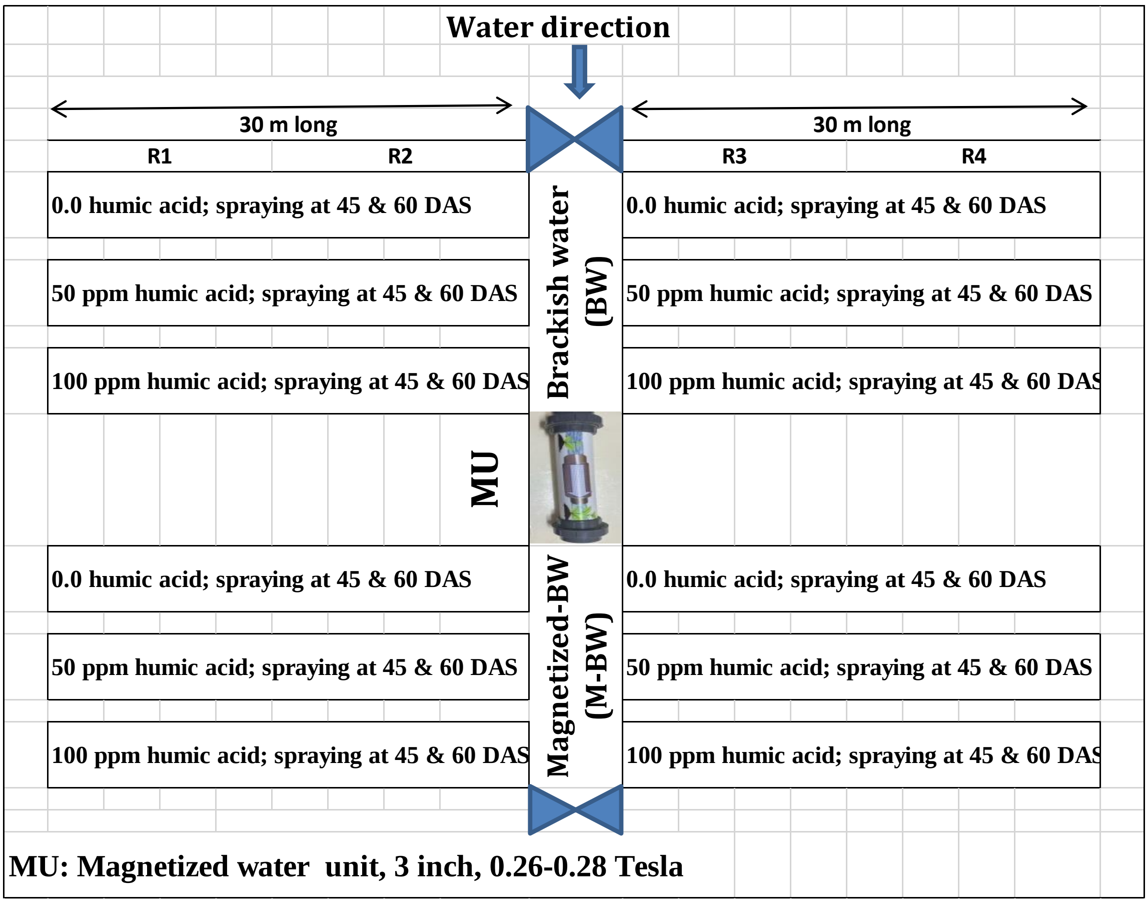

Fig. 1. Layout of experiment design under drip irrigation system.

Cultivation method: The soil was ploughed twice, settled and divided into terraces (1 m width x 30 long). During seedbed preparation, 150 kg fed^{-1} calcium superphosphate (15.5% P_2O_5) was applied. Recommended rates of barley grains (60 Kg fed^{-1}; Var., Giza-123; obtained from Barley Research Department, Field Crop Research Institute, Agriculture Research Centre, Giza, Egypt) were sown by manually planter in rows (20 cm apart) at the second week of November at winter seasons of 2022/23; 2023/24 and 2024/25 years. The drip irrigation system was implemented right after sowing and adjusted according to the plants' needs throughout the experimental period. Nitrogen fertilizer in the form of ammonium sulfate (20.60 N%) was applied at a total rate of 120 kg N per fed, divided into four equal portions starting 15 days post-sowing and continuing until flowering. Potassium fertilizer was applied at a rate of 50 kg per fed as potassium sulfate (48% K_2O), one month after sowing. According to the leaflet Agriculture Research Center, other recommended practices for barley planting were carried out in this province conditions.

Seasonal irrigation scheduling estimation

Drip irrigation system was set up according to the treatments and hydraulically tested prior to use in the pilot site. The system consisted of a pump, pressure gauges, a filter, an injection unit. The emitters were built-in with an average discharge of 4.0 l h^{-1} at 1.0 bar pressure and a 0.3-meter emitter spacing.

To estimate the water requirements of the barley crop, meteorological data were collected for the three seasons at the Al-Maghrah Experimental Station. Table (2) shows the monthly averages of the meteorological data.

Table 2. Average of three seasons (from sowing to harvesting) meteorological data at the experimental station of Al-Maghrah.

Month	Min Temp °C	Max Temp °C	Precipitation mm day^{-1}	Relative Humidity %	Wind Km day^{-1}	Sun Hours	Radiation MJ m^{-2} day^{-1}	ETo mm day^{-1}
				2022/2023				
November	13.2	24.5	0.3	61	200	8.5	14.5	3.2
December	11.5	22.2	1.1	67	220	7.5	12.3	2.56
January	8.6	19.6	0.7	69	229	7.5	13	2.42
February	7.1	18.5	1.8	69	230	7	14.6	2.55
March	10.4	24.2	0.3	58	266	8.5	19.2	4.23
April	12.5	28	0.5	51	272	9	22.2	5.58
May	16.5	32.5	0	48	320	9.7	24.3	7.18
				2023/2024				
November	15.1	26	0.3	60	214	8.5	14.5	3.47
December	11.2	21.8	0.2	69	230	7.5	12.3	2.53
January	7.5	19.2	0.9	60	238	7.5	13	2.68
February	7.9	21	1.8	66	214	7	14.6	2.8
March	10.1	24.1	0.3	60	250	8.5	19.2	4.06
April	13.7	30.3	0	54	295	9	22.2	5.93
May	17.5	34	0	40	271	9.7	24.3	7.42
				2024/2025				
November	13.5	24.2	0.2	62	240	8.5	14.5	3.38
December	8.9	20	0.3	66	234	7.5	12.3	2.45
January	9.2	20.2	0.2	71	197	7.5	13	2.26
February	7.7	18.7	0.3	64	244	7	14.6	2.77
March	11.1	25.9	0.5	54	265	8.5	19.2	4.6
April	13.5	28.8	0	50	288	9	22.2	5.87
May	17.4	33.1	0.3	41	290	9.7	24.3	7.45

Irrigation scheduling values, as shown in Table 3, resulted from the CROPWAT 2012 version 8.0.1.1 computer program (calculated using the "FAO-Penman-Moteith equation") Allen et al. (1998)

using local meteorological data and the characteristics of the experimental plants.

$$ET_c = ET_o \times K_c \quad (1)$$

Where:

ETc = crop evapotranspiration in mm / day.

ETo = reference evapotranspiration in mm / day.

Kc = crop coefficient.

The daily irrigation water was calculated using the following equation (2) for three seasons under a drip irrigation system (Allen et al. 1998):

$$IR_g = \frac{(ET_o \times k_c \times K_r)}{E_i} - R + LR \quad (2)$$

Where: IR_g is the crop irrigation requirements, (mm day^{-1}), ET_o is the reference evapotranspiration, (mm day^{-1}), k_c is the crop coefficient (Allen et al. 2005), K_r is the ground cover reduction factor, E_i is the irrigation efficiency, (%), R is the precipitation, (mm), LR is the leaching requirements, (mm). crop irrigation requirements were converted from mm ha^{-1} day^{-1} to m3 ha^{-1} day^{-1} (Savva, Frenken, 2002).

Table 3. Irrigation water requirements (m^3 fed^{-1}) for barley crop (2022/23, 2023/24 and 2024/25 seasons).

Stage	Number of days			Kc	ET_c (mm)			Total of IR (m^3 fed^{-1})		
	1st	2nd	3rd		1st	2nd	3rd	1st	2nd	3rd
Initial	25	25	25	0.3	2.97	2.23	3.1	86.94	101.64	99.12
Development	40	40	40	1.15	7.21	6.78	6.87	321.72	322.56	301.14
Mid-season	60	62	62		19.21	19.39	20.03	805.14	900.48	873.6
Late-season	47	50	50	0.25	17.05	20.03	21.74	647.22	722.82	782.46
Total	**172**	**177**	**177**					**1861.02**	**2047.5**	**2056.32**

*ETc = crop evapotranspiration **IR = crop irrigation requirements

Data recorded:

Barley yield and yield components: At harvest time, one square meter of each plot was counted to measure the number of tillers/m^2, as well as plant height, number of spikelet's per spike, spike length and weight, spike grain weight, and 100-grain weight from randomly selected 20 tillers from each plot. The ten square meters from each treatment were manually threshed to determine grains, straw, and biological yield per 10 m^2, which were then converted to tons per feddan. The harvest and crop indexes were determined by dividing seed yield by biological yield and straw yield, respectively.

Statistical analysis: Data obtained from brackish and magnetized brackish-water under field conditions were statically analyzed using independent *t*-test (SPSS program version 16). While data obtained under water and humic spring factors were statically analyzed using an analysis of variance (ANOVA) in split plot design using (MSTAT-C v. 3.1. Program; Freedman 1988). Least Significant Difference (LSD $_{5\%}$) was applied to compare mean values.

Results:

Laboratory experiment:

Germination and seedling traits:

Results presented in Table 4 and plate 1 cleared that magnetized barley grains treatment (soaking barley grains in magnetized water for 8 hours before sowing) surpassed dry grains or hydro-grains treatment (soaking barley grains in tap water for 8 hours before sowing) in germination traits [Germination (%), Germination Index (GI), Speed Germination Index (SGI), Germination Energy (EG; %), Germination Rate GR (day) and Mean Germination Time MGT (day)] and seedling traits [seedling length (cm), ten seedling dry weight (g), seedling vigour-1 and vigour-2] of barley at 14 days after sowing. The improvement ranged between 5.00 – 40.68% compared to dry grains treatment and 3.52 – 24.82% compared to hydro-grains treatment in the above-mentioned parameters. Positive effects were observed in MGT, where it is faster by 19.84% compared dry grains treatment and 11.54 compared to hydro-grains treatment.

Table 4. Comparison among dry, hydro and magneto-priming grain treatments in Germination (G; %), Germination Index (GI), Speed Germination Index (SGI), Germination Energy (GE), Germination Rate (GR; day) and Mean Germination Time (MGT; day), seedling length (cm) and weight (g) and seedling vigor's of barely at 14 days after sowing.

	Character / Treatment	Means: Dry grains	Means: Hydro-grains	Means: Magneto-priming grains	$LSD_{5\%}$	Increase (+) or decrease (%): over dry grains	Increase (+) or decrease (%): over Hydro-grains
Germination traits	**Germination (%)**	93.33	94.67	98.00	**2.20**	**5.00**	**3.52**
	Germination Index (GI; %)	3.73	3.78	3.93	**ns**	**5.36**	**4.06**
	Speed Germination Index (SGI; %)	14.39	16.00	18.08	**1.18**	**25.68**	**13.02**
	Germination Energy (GE; %)	93.33	93.33	98.33	**1.99**	**5.36**	**5.36**
	Germination Rate (GR; day)	0.90	0.93	0.96	**0.04**	**6.49**	**3.32**
	Mean Germination Time (MGT)	1.48	1.34	1.19	**0.08**	**-19.84**	**-11.54**
Seedling traits	**Seedling length (cm)**	10.14	11.23	11.65	**0.28**	**14.94**	**3.82**
	Seedling dry wt. (g 10 seedling^{-1})	0.59	0.66	0.80	**0.77**	**34.47**	**20.16**
	Seedling vigore-1 (SV-1)	946.41	1061.98	1141.85	**42.39**	**20.65**	**7.52**
	Seedling vigore-2 (SV-2)	5.55	6.26	7.81	**0.58**	**40.68**	**24.82**

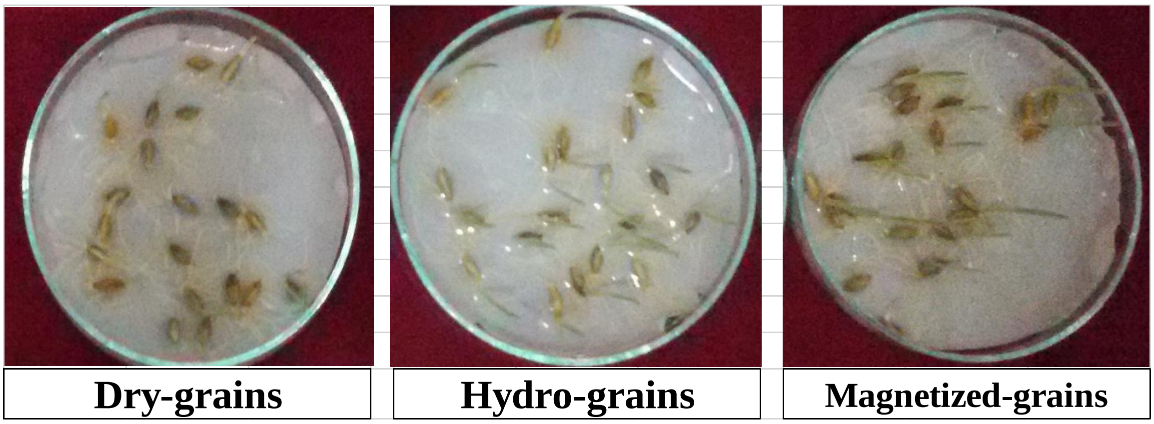

Plate 1. Comparison among dry, hydro and magneto-priming grain treatments on germination of barley.

Filed experiment:

Brackish water (BW) vs Magnetized Brackish water (M-BW); (winter seasons of 2022/23 and 2023/24)

Barley yield and yield components

Data presented in table 5 and plate 2 revealed that irrigation of barley plants with magnetically treated brackish-water significantly surpassed irrigation with brackish-water treatment in tillers (no m2) by 16.51%, plant height (cm) by 10.28%, spike length (cm) by 13.19%, spike weight (g) by 19.72%, and grains no. per spike by 11.27%, Spikelet's (no spike-1) by 11.27%. These improvements reflected for improving yield (ton fed-1) where biological, straw and grains yield increased by 23.23, 23.08 and 23.77%, respectively under irrigation with magnetized brackish water (M-BW) compared to brackish water (BW). Similar trends were recorded in harvest and crop indexes (%) where the improvement was 0.47 and 0.69% in the above-mentioned parameters, respectively under treatment M-BW compared to BW. Similar trends were recorded in winter seasons of 2023/24 (Table 6), where irrigation Barley plants with magnetically treated brackish-water significantly surpassed irrigation with brackish-water treatment in tillers (no 0.5 m2) by 16.12%, plant height (cm) by 13.58%, spike length (cm) by 11.34%, spike weight (g) by 15.57%, grains weight per spike (g) by 14.44%, Spikelet's (no spike-1) by 8.21%. These improvements reflected for improving yield (kg/fed) where biological, straw and grains yield increased by 21.14, 19.16 and 27.12%, respectively under irrigation with magnetized brackish water (M-BW) compared to brackish water (BW). Similar trends were recorded in harvest and crop indexes (%) where the improvements were 4.32% and 5.07% in the above both mentioned parameters, respectively under treatment M-BW compared to BW.

Table 5. Comparison between irrigation with brackish water (BW) and magnetized brackish water (M-BW) on barley yield and yield components at harvest (winter season of 2022/23).

Treatment / Character		Mean: Brackish water (BW)	Mean: Magnetized-BW (M-BW)	*t*-sig.	Increase (%) over control
Tillers (no 0.5 m^2)		137.50	160.20	**	**16.51**
Plant height (cm)		63.20	69.70	**	**10.28**
Spike Character (s)	**Length (cm)**	9.10	10.30	*	**13.19**
	weight (g spike^{-1})	3.82	4.58	*	**19.72**
	Grains (no spike^{-1})	49.70	55.30	**	**11.27**
	Spikelet's (no spike^{-1})	16.57	18.43	**	**11.27**
Yield (ton fed^{-1})	**Biological**	2.73	3.36	**	**23.23**
	Straw	2.14	2.64	**	**23.08**
	Grains	0.59	0.73	**	**23.77**
Harvest index (%)		21.50	21.60	ns	**0.47**
Crop index (%)		27.41	27.60	ns	**0.69**

Table 6. Comparison between irrigation with brackish water (BW) and magnetized brackish water (M-BW) on barley yield and yield components at harvest (winter season of 2023/24).

Treatment / Character		Mean: Brackish water (BW)	Mean: Magnetized-BW (M-BW)	*t*-sig.	Increase (%) over control
Tillers (no 0.5 m^2)		158.80	184.40	**	**16.12**
Plant height (cm)		74.40	84.50	**	**13.58**
Spike Character (s)	**Length (cm)**	19.40	21.60	*	**11.34**
	weight (g spike^{-1})	2.52	2.91	*	**15.57**
	Grain wt. (g spike^{-1})	2.20	2.52	*	**14.44**
	Spikelet's (no spike^{-1})	19.50	21.10	*	**8.21**
Yield (ton fed^{-1})	**Biological**	3.02	3.65	**	**21.14**
	Straw	2.27	2.70	**	**19.16**
	Grains	5.75	0.95	**	**27.12**
Harvest index (%)		24.91	25.99	ns	**4.32**
Crop index (%)		33.49	35.18	ns	**5.07**


Irrigation with Brackish water (BW) | Irrigation with Magnetized-BW (M-BW)

Plate 2. Comparison between irrigation with Brackish water (BW) and Magnetized Brackish water (M-BW) on expected productivity of barley (winter season of 2023/24).

Impact of magnetic technology and foliar application of humic acid on yield and yield components of Barley growing in Al-Maghrah region:

Significant and positive effects of magnetized irrigation water [Brackish water (BW) and Magnetized-BW (M-BW)], spraying with different concentration of humic acids (0.0, 50 and 100 ppm at 45 and 60 days after sowing) and its interactions were recorded on barley yield and its components at harvest (Table 7 and 8).

Barley yield components:

Table 7 reveals that irrigation Barley plants with magnetically treated brackish-water surpassed irrigation with brackish water in tillers (no 0.5 m2) by 14.17%, plant height (cm) by 14.98%, spike length (cm) by 6.40%, spike weight (g) by 11.40%, grains weight (g spike-1) by 10.73%, and Spikelet's (no spike-1) by 6.28%. Same table also show that spraying barley plants with 50 ppm or 100 ppm humic acid at 45 and 60 days after sowing caused an improvement of barley yield components ranging 3.02 and 9.78% under 50 ppm humic and ranged from 4.98 to 11.75% under 100 ppm humic compared to 0.0 humic treatment. Regarding the interaction between magnetized irrigation water and spraying of humic acid treatments. Table 5 also show that irrigation barley plants with magnetized brackish water and spraying with 50 or 100 ppm humic acids at 45 and 60 days after sowing caused positive effects on all barley yield components compared to untreated treatment. The best treatment was irrigation with magnetized brackish water and spraying with 100 ppm humic acids at 45 and 60 days compared all treatments. Where cased an improvement by 11.05 – 23.84% compared untreated treatment.

Table 7. Impact of irrigation with magnetized brackish-water, foliar application with different concentrations of humic acid and their interactions on tillers (no m-2), plant height (cm) and spike characters of barley at harvest (Average of winter seasons 2023/24 and 2024/25).

Character / Treatment		Tillers (no. m^{-2})	Plant ht. (cm)	Spike character (s)			
				Length (cm)	Weight (g)	Grain wt. (g)	Spikelet's (no $spike^{-1}$)
Brackish water (BW)	Control (0.0)	286.67	67.00	19.00	8.01	2.29	16.57
	Humic acid (50 ppm)	298.60	69.65	19.70	8.34	2.48	18.20
	Humic acid (100 ppm)	316.00	73.60	19.85	8.60	2.46	18.30
Magnetized-BW (M-BW)	Control	313.60	78.80	19.80	8.63	2.64	18.93
	Humic acid (50 ppm)	356.80	80.55	21.40	8.85	2.65	18.50
	Humic acid (100 ppm)	355.00	82.40	21.10	9.16	2.76	18.97
LSD at 5%		**9.07**	**1.62**	**0.29**	**ns**	**ns**	**0.33**
Mean of Mains effects							
Water treatment	Brackish water (BW)	300.42	70.08	19.52	8.32	2.41	17.69
	Magnetized-BW (M-BW)	341.80	80.58	20.77	8.88	2.68	18.80
F test		**	**	*	*	*	**
Humic acid treatment	Control	300.13	72.90	19.40	8.32	2.47	17.75
	Humic acid (50 ppm)	327.70	75.10	20.55	8.60	2.56	18.35
	Humic acid (100 ppm)	335.50	78.00	20.48	8.88	2.61	18.63
LSD at 5%		**6.41**	**1.15**	**0.20**	**0.21**	**0.10**	**0.23**

Barley yield (ton fed^{-1}):

Table 8 reveals that irrigation barley plants with magnetically treated brackish-water surpassed irrigation with brackish water by 20.63, 19.25 and 25.03% in biological, straw and grains yield (kg fed-1). Similar trends were recorded in harvest and crop indexes (%) where the improvements were

3.52% and 4.70% in the above both mentioned parameters, respectively under treatment M-BW compared BW. Table 8 also show that spraying barley plants with 50-ppm or 100-ppm humic acid at 45 and 60 days after sowing caused an improvement of biological, straw and grains yield (kg fed-1) by 9.31, 10.37 and 10.72%, respectively under 50-ppm humic and 13.91, 14.42 and 12.32% under 100-ppm humic compared to 0.0 humic traetment. Regarding the interaction between magnetized irrigation water and spraying of humic acid treatments, table 8 also show that irrigation barley plants with magnetized brackish water and spraying with 50 or 100 ppm humic acids at 45 and 60 days after sowing caused positive effects on biological, straw and grains yield (kg/fed) compared to untreated treatment. The best treatment was irrigation with magnetized brackish water and spraying with 100 ppm humic acids at 45 and 60 days compared all treatments. Where the improvement were 35.98, 34.98 and 40.34 in biological, straw and grains yields (kg/fed), respectively compared untreated treatment.

Table 8. Impact of irrigation with magnetized brackish-water, spraying with different concentration of humic acid and their interactions on biological, straw and grains yield (kg/fed), harvest and crop index (%) of barley at harvest (Average of winter seasons 2023/24 and 2024/25).

Character / Treatment		Yield (ton fed^{-1}) Biological	Straw	Grains	Harvest index (%)	Crop index (%)
Brackish water (BW)	Control (0.0)	2.53	1.91	0.62	24.82	32.86
	Humic acid (50 ppm)	2.80	2.12	0.68	23.73	32.29
	Humic acid (100 ppm)	3.07	2.38	0.69	22.90	29.15
Magnetized-BW (M-BW)	Control	3.19	1.60	0.78	24.46	32.45
	Humic acid (50 ppm)	3.51	2.66	0.85	24.17	31.92
	Humic acid (100 ppm)	3.44	2.56	0.87	25.57	34.36
LSD at 5%		**0.06**	**0.06**	**0.03**	**1.28**	**0.68**
Mean of Mains effects						
Water treatment	Brackish water (BW)	2.80	2.13	0.67	23.81	31.43
	Magnetized-BW (M-BW)	3.38	2.27	0.83	24.73	32.91
F test		**	**	**	*	*
Humic acid treatment	Control	2.86	1.75	0.70	24.64	32.65
	Humic acid (50 ppm)	3.16	2.39	0.77	23.95	32.11
	Humic acid (100 ppm)	3.26	2.47	0.78	24.24	31.75
LSD at 5%		**0.04**	**0.04**	**0.02**	**ns**	**0.48**

Discussion

Germination and seedling traits:

Germination is a crucial phase in the establishment of seedlings and has a major impact on crop yield (Shreen et al., 2011). This study demonstrated that magnetized water has beneficial effects on the germination and seedling traits of barley plants when compared to the control treatment. The data align with the treatment of magnetized grains and concurrently with the results acquired by Hilal and Hilal (2003). (Hozayn et al., 2015) demonstrated that the presence of a magnetic field improved seed germination and seedling growth metrics in comparison to untreated seeds. Additionally, Belyavskaya (2001) noted that magnetic water notably stimulates cell metabolism and mitosis in the meristematic cells of peas, lentils, and flax. Aladjadjiyan (2002) demonstrated that treatment of maize seeds with magnetic water positively influences the growth of shoots during the initial phase. Electromagnetic fields can encourage seed germination and promote the growth of certain crops. This area positively influences the sprouting and development of grains (Luben et al., 2000).

Barley yield components:

In general, the data show greater tillering, plant height, spike length, spike weight, grains no. per spike, grains weight per spike as irrigating with magnetized brackish-water, while reversal magnitude of these attributes was evident for irrigating with brackish-water. These results align closely with those of Ben Hassen et al. (2020), who indicated that the majority of growth parameters increased with irrigation using magnetized saline solutions in comparison to their control. At every salinity level (320, 3000, and 6000 mg/L), using magnetized saline solutions for irrigation improved yield components in comparison to the control group. For the matching salinities of 320, 3000, and 6000 mg/L, the increase rates were 13.58%, 5.76%, and 18.67% for spike weight and 33.72%, 7.52%, and 9.14% for grain yield/tiller.

Applying humic acid topically considerably reduced the detrimental effects of salinity on barley growth and yield. Humic acid's beneficial effects on biomass accumulation and the K+/Na+ ratio are responsible for this increase in salt tolerance. These results coincide with humic acid's beneficial effects on maize growth (Kaya et al., 2018).

The best treatment was irrigation with magnetized brackish water and spraying with 100 ppm humic acids at 45 and 60 days compared all treatments. Where cased an improvement by 11.05 – 23.84% compared untreated treatment. In this respect, according to certain researchers, foliar application of humic acid and irrigation with magnetized water improved vegetative characteristics, photosynthetic pigments, and yield components (Imryed, et al., (2024).

Barley yield (ton fed^{-1}):

Generally, biological, straw and grains yield of barley plants showed better trend in irrigation plants with magnetically treated brackish-water compared to irrigation with brackish water. Magnetic treatment has altered the physical and chemical properties of water, particularly influencing hydrogen bonding, surface tension, polarity, pH, conductivity, and salt solubility. These modifications in water properties could influence plant growth and impact the yield of cultivated plants (Grewal and Maheshwari, 2011).

Likewise, spraying barley plants with 50-ppm or 100-ppm humic acid at 45 and 60 days after sowing caused an improvement of biological, straw and grain yield compared to 0.0 humic treatment. These findings align with the beneficial effects of humic acid, which has been shown to induce biochemical changes in cytoplasmic components and membranes that support plant development and salt resistance (Ouni et al., 2014). Furthermore, humic acid promoted maize growth by boosting cell division linked to the activation of antioxidant enzyme activity and ATPase expression (Morozesk et al., 2017).

The best treatment was irrigation with magnetized brackish water and spraying with 100 ppm humic acids at 45 and 60 days compared to all treatments. Where the improvements were 35.98, 34.98 and 40.34 in biological, straw and grains yields (ton fed-1), respectively compared untreated treatment. This aligns with previous studies indicating that the use of humic acid during salinity stress enhanced total chlorophyll levels in maize (Soltabayeva, et al., 2021). Moreover, irrigating with magnetized water can enhance photosynthetic processes and growth by altering nutrient absorption and boosting the paramagnetic characteristics of chloroplasts. This leads to enhanced ion movement and uptake, enhancing photosynthesis. Magnetized water has demonstrated an elevation in chlorophyll and carotenoid concentrations in leaves, probably because of proline and GA3, which are stimulated by the accumulation of Mg+2 for chlorophyll production (Radhakrishnan 2019), and K+ for boosting chloroplast quantities. These outcomes align with discoveries in cotton, wheat, soybean, and cowpeas (Yi et al., 2023).

Conclusion

In this study, application of magnetic technology in water or seeds and improving the nutritional status through spraying of humic acid (HA) at 45 and 60 days after sowing alleviated salinity stress in irrigation water which resulted in improving germination, growth and productivity of barley. It is unlikely that a single factor (magnetic water) was responsible for this but is more likely to be due to the improvements of barely establishment through mitigation of seed irrigation with the magnetic water as well as the HA treatment which improved the nutritional condition in such poor sandy soil which reflected on barley yields under serve marginal and difficult agricultural conditions.

Consent for publication:
All authors declare their consent for publication.

Author contribution:
The manuscript was edited and revised by all authors.

Conflicts of Interest:
The author declares no conflict of interest.

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