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Pepermint (Mentha piperita L.) growth and biochemical properties affected by magnetized saline water

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ABSTRACT

Due to the limitation of suitable water for crop production in the world, recycling water is among the most proper methods enhancing water efficiency and availability. One modern method, which is of economic, health, and environmental significance, and may improve water properties for plant use is water magnetization. Medicinal plants are of nutritional, economic and medical values and their growth decreases under salinity stresses. This research was hypothesized and conducted because there is not any data, to our knowledge, on the use of magnetized salty water affecting the growth and biochemical properties of peppermint (*Mentha piperita* L.). The experiment was a split plot design with three replicates. The main plots consisted of magnetic fields at control (M1), 100 mT (M2), 200 mT (M3), and 300 mT (M4), the sub-plots consisted of salinity treatments (NaCl) at control (S1), 4 dS/m (S2), 8 dS/m (S3), and 12 dS/m (S4), and the growth media including cocopeat (X1), palm (X2), cocopeat + perlite (V/V = 50, X3) and palm + perlite (V/V = 50, X4) were located in the sub-sub-plots. Different plant growth and biochemical properties including plant fresh and dry weight, plant menthol, menthone, chlorophyll and proline contents were determined. Analysis of variance indicated the significant effects of experimental treatments and their interactions on the growth and biochemistry of peppermint. Different magnetic fields significantly increased plant growth, and interestingly with increasing the salinity level the alleviating effects of magnetic field on salinity stress became more clear (significant interaction between salinity and magnetic field treatments). Cocopeat was the most efficient growth medium. At the third level of salinity (8 dS/m) just the two levels of 100 and 200 mT increased plant menthol concentration. Treatments M3S2X4 and M1S1X1 resulted in the highest (38%) and the least menthol percentage (13%), respectively. Treatments S2 and M2 and M3 significantly increased plant menthone concentration, especially in the growth media of X1 and X3. However, at the third level of salinity, M3 and M4 were the most effective treatments. The highest (25.8%) and the least (1.2%) concentrations of menthone were related to treatments M3S2X4 and M2S4X1, respectively. The results indicated that it is possible to alleviate the stress of salinity on peppermint growth and improve its biochemical (medicinal) properties using magnetized salty water, although proline concentration was not much affected by the magnetic field.

1. Introduction

Plants, including the medicinal, are subjected to different types of stresses (Zamani et al., 2020) including salty water. Saline water negatively affects plant growth by increasing the cellular osmotic potential and the concentration of toxic ions such as sodium (Na+) and chloride (Cl-) in plant cells. It is accordingly important to find methods, which may alleviate such a stress (Daei et al., 2009; Miransari and Smith, 2019).

Research has indicated the positive effects of magnetic field on plant growth and crop production. Magnetic field is among the safe and modern techniques, which has been indicated to enhance seed germination and growth of different plant species including the medicinal sage (*Salvia officinalis*) (Abdani Nasiri et al., 2018) and wheat plants

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Fig. 1. Different stages of the experiment including the setup of the experiment, preparation of the growth medium, magnetizing salty water and measurements.

(Massah et al., 2019) under different conditions including stress. Magnetizing water is among the methods, which can improve water properties (Cai et al., 2009; Wang et al., 2018) and hence make the recycling of salty water possible (da Silva and Dobránszki, 2014; El-Zawily et al., 2019). Magnetized water may also be used for leaching the salty soil and increase the efficiency of soil water (Zlotopolski, 2017). Magnetic field may result in oxidative stress through the production of reactive oxygen species, which can also act as signal molecules affecting plant response under stress. At the enzymatic level, magnetic field can increase the activity of different enzymes including catalase, peroxidase and superoxide dismutase (Massah et al., 2019; Zareei et al., 2019).

There is little data on the use of magnetic field for the improvement of salty water properties affecting plant growth. For example, Aghamir et al. (2016) found that magnetized salty water can increase seed germination and seedling growth of bean (*Phaseolus vulgaris*) plants. The enhancing effects of magnetic field on the improvement of salty water properties are functions of: 1) exposure time, 2) the magnitude of magnetic field, 3) plant species, 4) environmental conditions, and 5) salt properties and concentration (Vashisth and Nagarajan, 2010; Jamil et al., 2012; Hasan et al., 2019).

Pepermint (*Mentha piperita* L.) is an important medicinal plant, which can be used for the treatment of different diseases and can also be used as favorable drink with tea (Zheljazkov et al., 2010). The value of medicinal plants is determined by the amount and quality of their effective biochemicals (Mahdavi et al., 2020). Such properties are functions of plant species, environmental properties including water and soil (Mohammadi and Asadi-Gharneh, 2018a,b; Sabet and Mortazaeinezhad, 2018). Accordingly, if medicinal plants grow under proper conditions, their quantity and quality is improved although research has indicated stress may enhance the quantity and quality of effective biochemicals in medicinal plant (Gharibi et al., 2016; Pizzino et al., 2017). For example, Alhaithloul et al. (2020) found that if *Mentha piperita* and *Catharanthus roseus* grow under drought and temperature stress, their quality is enhanced, which is due to the enhanced production of secondary metabolites including tannins, alkaloids and terpenoids.

The most important reason for presenting this research is because: 1) the costs of increasing the level of magnetic field is not much, 2) they are certainly sustainable approaches, 3) they are safe, 3) they are economically and environmentally friendly, and 5) the costs of increasing the magnetic field is much less than the costs of yield reduction under salt stress.

With respect to the importance of finding a safe and environmentally friendly method to grow peppermint and improve its biochemical (medicinal) properties under salt stress conditions, this research was conducted. Although the effects of salinity on peppermint growth and physiology have been previously investigated (Li et al., 2016; Vatankhah et al., 2017), there is not any data, to our knowledge, on the effects of magnetized salty water affecting the growth and biochemical properties of peppermint.

2. Materials and methods

2.1. Experimental site

The experiment was conducted in the Research Greenhouse of Isfahan Islamic Azad University (51°77’ E and 32°63’ N), Iran in 2015 in a four-month period using hydroponic conditions. The experimental conditions including temperature, relative humidity, irrigation, nutrient solution, and fertigation (using Hoagland solution) were kept constant.

2.2. Experimental design

The experiment was a split plot design with three replicates. The main plots consisted of magnetic fields at control (M1), 100 mT (M2), 200 mT (M3), and 300 mT (M4). However, the sub-plots consisted of salinity treatments (NaCl) at control (S1) (Table S1), 40 mM (S2), 80 mM (S3), and 120 mM (S4), which were prepared by using tap water (EC = 0.356 dS/m, pH = 7.5, Ca = 60 mg/l, Mg = 12 mg/l, HCO_3 = 2.2 meq/l, SO_4 = 0.15 meq/l) and the 100-L tanks (Fig. 1). The growth medium was located in the sub-sub-plots including cocopeat (X1), palm (X2), cocopeat + perlite (V/V = 50, X3) and palm + perlite (V/V = 50, X4) (Fig. 1) (Table S1). The coco peat growth medium was obtained in the form of compacted blocks with 100% purity, and were inserted in water to increase their volume and make them homogenous. The other growth media were also used with the purity of 100%.

2.3. Planting peppermint

Peppermint cuttings were planted in seedling trays with cocopeat. The cocopeat medium, containing macro- and micro-nutrients, had been already treated with tap water to make them bulky and homogenous. The other type of medium was also prepared by mixing cocopeat with perlite (a natural medium lacking nutrients) at V/V: 50 using 3-L pots.

2.4. Irrigation

The salty water was prepared using 100-L tanks, which were then magnetized and treated with nutrient solution according to the following details. The seedlings were irrigated twice a day and when they grew they were irrigated four times a day.

2.5. Magnetizing water

The salty water was magnetized using a magnetizer consisting of: 1) AC to DC convertor, 2) amplifier, and 3) coil with iron core to produce magnetic field. The voltage rate determines the rate of magnetic field. For the production of magnetic field, around the water tubes, iron core coils were prepared and the rate of magnetic field was a function of the rate of electricity. Accordingly using an oscillator, the rate of the magnetic field was adjusted. The selectors of the instrument were used for controlling the rate of the magnetic field; when all the four switches were on, the maximum magnetic field of 300 mT was producible (Fig. 1).

2.6. Fertigation

The seedlings were initially fertilized with NPK (20-20-20), and two weeks after transplanting the seedlings to the pots, they were fertigated in the hydroponic conditions using Hoagland's solution (Hoagland and Arnold, 1950). with the pH of 5.5–6.5 and salinity (EC) of 1.5–2 dS/m.

2.7. Growth conditions

During the growth of the plants, the daily and nightly temperature of 35 and 17 °C were achieved, respectively. The plants were thinned and at the height of 20 cm were placed on a stool. Different pests including different flies were controlled four times during the seasons using evisect and avant, pesticides.

2.8. Harvesting

The fresh weight of the harvested plants was determined in the lab. The samples were then washed with distilled water, air dried for 48 h, dried in the oven at 70 °C, and milled using an Moulinex electric mill. The essential oils of the peppermint plants containing menthol and menthone were measured using gas chromatography (GC, Model Agilent 5975C-7890, USA) (Mostafavi et al., 2019). Chlorophyll was measured using chlorophyll meter (Model: CCM-200, USA) (Fig. 1). Proline was measured according to the method of Bates et al. (1973) in three replicates according to the following details. The plant sample at 0.2 g was homogenized and treated with liquid nitrogen using a crucible. The sample was then treated with 10 mL sulfosalicylic acid (3%). The prepared extract was mixed with 2 mL acetic acid and 2 mL ninhydrine (1.25 g ninhydrine + 30 mL glacial acetic acid + 20 mL phosphoric acid 6 M) and was placed in a bain-marie (100 °C). The test tubes were cool down and treated with 4 mL toluene. The samples were vigorously shaken and after the formation of the two different phases, the absorption of toluene was measured using spectrophotometer (Shimadzu, UB-120–02, Japan) at the wavelength of 518 nm (Daghaghian et al., 2017). The concentration of proline was determined (μM/g fresh sample weight) using the standard concentration of proline (Moshabaki Isfahani et al., 2019).

2.9. Statistical analysis

Data were subjected to analysis of variance using Minitab. Means were compared using Duncan multiple range test at P = 0.05.

Table 1
Pepermint fresh and dry weight (g/pot) affected by magnetic field, medium and salinity. Means followed by different letters are significantly different using Duncan's multiple range test at P = 0.05.

Magnetic field (mT)	Medium	S1 (2)	Fresh weight		
			Salinity (dS/m)		
			S2 (4)	S3 (8)	S4 (12)
M1 (0) Isfahan (Khorasgan) Branch	X1 (Coco peat)	470 ± 54ci	392 ± 20 hm	282 ± 25 mt	115 ± 44va′
	X2 (Coco peat + perlite)	451 ± 48di	219 ± 82gw	250 ± 19pv	125 ± 13va′
	X3 (Palm)	337 ± 60jg	265 ± 22nu	134 ± 24ua′	35 ± 8a′
	X4 (Palm + perlite)	312 ± 34ks	291 ± 15 mt	114 ± 16va′	41 ± 10za′
M2 (100)	X1 (Coco peat)	634 ± 44a	526 ± 43af	364 ± 35hp	207 ± 13gw
	X2 (Coco peat + perlite)	509 ± 35 ag	509 ± 70 ag	276 ± 22 mt	219 ± 82gw
	X3 (Palm)	382 ± 50jq	270 ± 51	189 ± 41sy	68 ± 3xa′
	X4 (Palm + perlite)	307 ± 22ks	279 ± 16 mt	123 ± 26va′	107 ± 24va′
M3 (200)	X1 (Coco peat)	578 ± 85ad	435 ± 63el	435 ± 97el	286 ± 50 mt
	X2 (Coco peat + perlite)	538 ± 85ae	358 ± 61ip	332 ± 34jg	165 ± 21ta′
	X3 (Palm)	321 ± 26jr	260 ± 23ou	214 ± 17gw	41 ± 5za′
	X4 (Palm + perlite)	395 ± 49ls	314 ± 43ks	218 ± 8gw	49 ± 23za′
M4 (300)	X1 (Coco peat)	617 ± 29 ab	493 ± 41bh	403 ± 14 fm	194 ± 39rx
	X2 (Coco peat + perlite)	587 ± 21ac	434 ± 14el	304 ± 43ls	259 ± 19pu
	X3 (Palm)	440 ± 63ek	168 ± 20tz	295 ± 26 mt	62 ± 10va′
	X4 (Palm + perlite)	406 ± 28 fm	209 ± 22gw	334 ± 24jg	95 ± 4va′
			Dry weight		
Magnetic field (mT)	Medium	S1 (2)	S2 (4)	S3 (8)	S4 (12)
M1 (0)	X1 (Coco peat)	74 ± 13bi	71 ± 4.0ci	46 ± 4.0jo	22 ± 8.0
	X2 (Coco peat + perlite)	76 ± 9.0bh	51 ± 1.0ho	37 ± 2.0lt	22 ± 2.0sw
	X3 (Palm)	55 ± 17fo	45 ± 4.0ks	21 ± 5.0sw	7.0 ± 2.0w
	X4 (Palm + perlite)	49 ± 8.0io	56 ± 1.0fo	22 ± 7.0sw	7.0 ± 2.0w
M2 (100)	X1 (Coco peat)	97 ± 12 ab	22.0 ± 1.0sw	52 ± 9.0go	34 ± 2.0mu
	X2 (Coco peat + perlite)	64 ± 6.0dk	95 ± 20ac	40 ± 2.0ks	22 ± 1.0sw
	X3 (Palm)	52 ± 10go	51 ± 1.0ho	32 ± 3.0ow	10 ± 1.0uw
	X4 (Palm + perlite)	42 ± 0.0ks	52 ± 6.0go	23 ± 3.0sw	31 ± 14pw
M3 (200)	X1 (Coco peat)	77 ± 8.0bg	87 ± 22ad	57 ± 9.0fo	40 ± 3.0ks
	X2 (Coco peat + perlite)	79 ± 9.0bf	63 ± 4.0dk	44 ± 8.0ks	22 ± 1.0vw
	X3 (Palm)	55 ± 7.5fo	33 ± 5.0nv	27 ± 0.0rw	8.0 ± 1.0vw
				30	
	X4 (Palm + perlite)	60 ± 12el	59 ± 4.0 fm	30 ± 2.0qw	11 ± 3.0uv
M4 (300)	X1 (Coco peat)	87 ± 8.0ad	77 ± 6.0bg	55 ± 2.0fo	87 ± 8.0ad
	X2 (Coco peat + perlite)	105 ± 5.0a	63 ± 4.0dk	35 ± 7.0lu	105 ± 5.0a
	X3 (Palm)	59 ± 14 fm	58 ± 15fn	34 ± 2.0mu	59 ± 14 fm
	X4 (Palm + perlite)	75 ± 7.0bh	44 ± 3.0ks	41 ± 2.0ks	75 ± 7.0bh

3. Results

3.1. Plant fresh and dry weight

With increasing the salinity level (Tables 1 and 2), peppermint fresh and dry weight significantly decreased. Although at S1, the magnetic range of M2-M4 was the most effective, S2M2, resulted in the highest and significantly different rate of plant fresh and dry weight (Tables 1 and 2). The highest plant fresh (634 g) and dry (97 g) weights, significantly different from the other treatments, were resulted by

Table 2
Pepermint menthol percentage affected by magnetic field, medium and salinity.

Magnetic field (mT)	Medium	S1 (2)	Salinity (dS/m)	S3 (8)	S4 (12)
			S2 (4)		
M1 (0)	X1 (Coco peat)	13 ± 3.0k′	25 ± 0.3mn	22 ± 0.3sv	27 ± 0.3hk
	X2 (Coco peat + perlite)	32 ± 2.0de	18 ± 0.20a'h'	22 ± 0.3sv	25 ± 0.4no
	X3 (Palm)	16 ± 0.3i'j'	18 ± 0.3f′	17 ± 0.1g'h'	16 ± 0.1i'j'
	X4 (Palm + perlite)	18 ± 0.3e'g'	22 ± 0.3tw	19 ± 0.3b'e'	16.8 ± 0.2h'I'
M2 (100)	X1 (Coco peat)	20 ± 0.3zc′	27 ± 0.3hi	33 ± 0.1d	19.0 ± 0.2c'e'
	X2 (Coco peat + perlite)	21 ± 0.3uy	34 ± 0.3c	31 ± 0.3ef	27.0 ± 0.15hk
	X3 (Palm)	19 ± 0.3c'f'	25 ± 0.3np	14 ± 0.3k′	21.0 ± 0.25
	X4 (Palm + perlite)	14 ± 0.3k′	26 ± 0.3il	27 ± 0.3hj	21.0 ± 0.28
M3 (200)	X1 (Coco peat)	24 ± 0.3oq	15 ± 0.3aj	31 ± 0.4 fg	22 ± 0.3sv
	X2 (Coco peat + perlite)	35 ± 0.4c	21 ± 0.4vy	26 ± 0.3ik	36 ± 0.3b
	X3 (Palm)	12 ± 0.2I′	27 ± 0.2hj	14 ± 0.5k′	20 ± 0.3 yb′
	X4 (Palm + perlite)	28 ± 0.2h	38 ± 0.2a	23 ± 0.3qs	14 ± 0.3k′
M4 (300)	X1 (Coco peat)	34 ± 0.3c	18.6 ± 0.4d'f'	20.2 ± 0.3 yb′	13.8 ± 0.3k′
	X2 (Coco peat + perlite)	24 ± 0.5np	27.2 ± 0.3hj	26.1 ± 0.1jl	22.2 ± 0.3sv
	X3 (Palm)	23 ± 0.3pr	32.4 ± 0.4d	20.5 ± 0.3xa′	19.6 ± 0.2a'd'
	X4 (Palm + perlite)	22 ± 0.2ru	22.8 ± 0.3qt	25.8 ± 0.3 km	20.5 ± 0.3xa′

Means followed by different letters are significantly different using Duncan's multiple range test at P = 0.05.

treatment M2S1X1. However, the least and significantly different plant fresh (35 g) and dry (7 g) weights were related to treatment M1S4X2 (Table 1).

At S3 (8 dS/m) (Table 1), the significantly highest fresh and dry weights were obtained by M3 and M4, and at S4, the three levels of magnetic field including 100, 200 and 300 mT resulted in the significantly highest fresh and dry weights. The growth media of cocopeat and cocopeat + perlite were the most efficient ones resulting in the highest rate of plant growth at different levels of salinity and magnetic field (Table 1).

3.2. Plant menthol concentration

The concentration of plant menthol significantly increased from S1 to S3 (Table 2), and there was not a clear trend of growth medium affecting menthol concentration. However, in the treatment S4 just M2 and M3 significantly increased plant menthol concentration (Table 2). Treatments M3S2X4 (38%) and M1S1X1 (13%) resulted in the significantly highest and least percentage of menthol, respectively. However, the highest menthol increase (15%) was resulted by treatment M3S2X3 (27%) compared with M3S1X3 (12%) (Table 2).

3.3. Plant menthone concentration

At the control level of salinity M2 and M3 (Table 3) significantly increased plant menthone concentration, especially in the growth media of cocopeat and cocopeat + perlite. This was also the case at the second level of salinity; however, there was not a clear difference among the different growth media. At the third level of salinity, M3 and M4 were the most effective treatments, and there were not clear differences among the different growth media. The significantly highest (25.8%) and the least (1.2%) concentrations of menthone were related to M3S2X4 and M2S4X1 treatments, respectively (Table 3).

3.4. Plant chlorophyll concentration

Treatment S1M2 (Table 4) significantly increased plant chlorophyll concentration compared with the control level of magnetic field. However, with increasing the level of salinity to S2 and S3, M3 was the most effective treatment on the alleviation of salinity stress, though there was not a clear trend among the different growth medium. At the highest level of salinity, the three levels of magnetic field were equally effective on the alleviation of stress significantly affecting chlorophyll concentration, compared with control (Table 4).

3.5. Plant proline concentration

Although the results indicated the effectiveness of different levels of magnetic field on proline counteraction at different levels of salinity stress (Table 5), there was not a clear effect of magnetic field on the enhancement of proline concentration. It is because high and comparable concentrations of proline were resulted at the control level of salinity and at different levels of magnetic field. Interestingly, at the highest levels of salinity (8 and 12 dS/m) and the highest level of magnetic field (300 mT), the least concentrations of proline were resulted. There was not a clear trend of growth medium on the concentration of proline at different levels of salinity and magnetic field (Table 5).

The analysis of variance (Table 6) indicated the significant effects of different experimental treatments and their interactions on the measured parameters including plant fresh and dry weight, menthol, menthone, chlorophyll and proline contents (Table 6).

4. Discussion

Due to the restriction of water in the world, using salty water may be suitable method for crop production. However, salty water negatively affects plant growth, which is due to the presence of salt ions and the high osmotic potential. Different methods have been so far used to alleviate the stress of salty water on plant growth and crop production, among which the use of magnetic field is the newest one. There is some data on the use of magnetized water affecting plant growth and crop production under salinity stress, however, to our knowledge, there is not any data on the use of salty magnetized water affecting peppermint growth and biochemical properties using different plant growth medium.

Although there were some effects of cocopeat on plant growth and its biochemical properties, there was not a clear trend of growth medium on plant growth under different treatments. With increasing the rate of magnetic field and using the proper growth medium (cocopeat + perlite) the negative effects of salinity stress on plant growth was alleviated. Accordingly, at the higher levels of salinity, the alleviating effects of magnetic field on plant growth became clearer, which was also evident from the significant interaction of salinity stress and

Table 3

Pepermint menthone percentage affected by magnetic field, medium and salinity.

Magnetic field (mT)	Medium	S1 (2)	Salinity (dS/m)	S3 (8)	S4 (12)
			S2 (4)		
M1 (0)	X1 (Coco peat)	6.8 ± 0.3gv	3.4 ± 0.2 e′g′ 6.07 ± (.11) vx 6.056 ± (.05) vx 3.75 ± (.25) c′f′	8.3 ± 0.3pq	7.8 ± 0.3qr
	X2 (Coco peat + perlite)	1.8 ± 0.2i'f'	6.1 ± 0.1vx	4.3 ± 0.2a'd'	9.9 ± 0.2kn
	X3 (Palm)	1.8 ± 0.25i'j'	6.1 ± 0.1vx	10.3 ± 0.3jm	5.0 ± 0.2 yb′
	X4 (Palm + perlite)	10.743 ± 0.3ik	3.8 ± 0.3c'f'	4.8 ± 0.3 yb'	10.6 ± 0.4il
M2 (100)	X1 (Coco peat)	12.2 ± 0.3h	10.8 ± 0.2	4.2 ± 0.3b'e'	1.2 ± 0.2j′
	X2 (Coco peat + perlite)	13.2 ± 0.3 fg	9.3 ± 0.17no	2.5 ± 0.3g'i'	3.8 ± 0.3c'f'
	X3 (Palm)	19.7 ± 0.3c	15.8 ± 0.27e	8.9 ± 0.3op	10.2 ± 0.2jn
	X4 (Palm + perlite)	5.2 ± 0.3xa′	11.1 ± 0.1ij	6.8 ± 0.3tv	2.9 ± 0.1f'h'
M3 (200)	X1 (Coco peat)	17.7 ± 0.3	24.6 ± 0.4b	10.23 ± 0.3jm	10.23 ± 0.3jm
	X2 (Coco peat + perlite)	13.5 ± 0.4f	11.2 ± 0.3i	5.5 ± 0.4zc′	4.4 ± 0.1zc′
	X3 (Palm)	6.2 ± 0.3uw	1.8 ± 0.2i'j'	9.5 ± 0.5mo	13.5 ± 0.5 fg
	X4 (Palm + perlite)	7.2 ± 0.3rt	25.8 ± 0.3a	18.2 ± 0.3d	8.8 ± 0.3op
M4 (300)	X1 (Coco peat)	3.6 ± 0.4c'f'	8.3 ± 0.3 pg	8.2 ± 0.3pq	9.7 ± 0.2ln
	X2 (Coco peat + perlite)	4.2 ± 0.3b'e'	8.8 ± 0.3op	7.2 ± 0.3	7.7 ± 0.2qs
	X3 (Palm)	3.4 ± 0.3d'g'	4.3 ± 0.2a'd'	2.4 ± 0.4h'i'	3.9 ± 0.2c'e'
	X4 (Palm + perlite)	5.4 ± 0.4vz	12.6 ± 4gh	18.2 ± 0.3	7.0 ± 0.2ru

Means followed by different letters are significantly different using Duncan's multiple range test at P = 0.05.

Table 4
Pepermint chlorophyll percentage affected by magnetic field, medium and salinity.

Magnetic field (mT)	Medium	S1 (2)	Salinity (dS/m)	S3 (8)	S4 (12)
			S2 (4)		
M1 (0)	X1 (Coco peat)	35.8 ± 8.9bh	34.6 ± 6.7bi	37.6 ± 7.4ah	26.1 ± 7.2ci
	X2 (Coco peat + perlite)	33.3 ± 10.6bi	29.4 ± .3.2bi	41.9 ± 3.9af	15.8 ± 1.8fi
	X3 (Palm)	40.5 ± 14.5 ag	22.9 ± 7.6ci	19.6 ± 8.2ei	8.7 ± 5.6i
	X4 (Palm + perlite)	36.2 ± 3.4bh	30.1 ± 8.4bi	27.6 ± 12.7ci	32.4 ± 4.6bi
M2 (100)	X1 (Coco peat)	35.6 ± 7.8bh	30.7 ± 3.4bi	36.3 ± 3.7ci	35.6 ± 7.8bh
	X2 (Coco peat + perlite)	41.5 ± 11.0af	40.13 ± 11.5 ag	37.6 ± 7.5	41.5 ± 11.0af
	X3 (Palm)	55.4 ± 6.2 ab	20.63 ± 4.7ei	29.7 ± 3.3bi	55.4 ± 6.2 ab
			31		
	X4 (Palm + perlite)	38.0 ± 22.3ah	31.3 ± 2.9bi	31 ± 4.3bi	38.0 ± 22.3ah
M3 (200)	X1 (Coco peat)	28.8 ± 3.9bi	47.6 ± 9.0ad	38.2 ± 8.3ah	41.0 ± 7.4 ag
	X2 (Coco peat + perlite)	31.2 ± 5.4 ag	63.3 ± 6.0a	28.7 ± 4.2bi	26.4 ± 4.6ci
	X3 (Palm)	39.93 ± 5.4 ag	22.5 ± 7.3ci	27.3 ± 5.3ci	14.3 ± 2.1gi
	X4 (Palm + perlite)	29.2 ± 9.9bi	29.4 ± 10.2bi	49.2 ± 8.4ac	35.3 ± 1.6bi
M4 (300)	X1 (Coco peat)	32.1 ± 5.8bi	36.1 ± 10.6bh	34.4 ± 4.4bi	29.3 ± 6.6bi
	X2 (Coco peat + perlite)	23.1 ± 6.4ci	32.9 ± 8.4bi	19.7 ± 5.2ei	35.9 ± 14.4bh
	X3 (Palm)	31.6 ± 6.1bi	23.5 ± 4ci	21.5 ± 4.9di	14.5 ± 17.1gi
	X4 (Palm + perlite)	26.9 ± 3.8ci	43.9 ± 8.5ae	33 ± 5.3bi	40.6 ± 2.0 ag

Means followed by different letters are significantly different using Duncan's multiple range test at P = 0.05.

Table 5
Pepermint proline concentration (μM/g fresh sample weight) affected by magnetic field, medium and salinity.

Magnetic field (mT)	Medium	S1 (2)	Salinity (dS/m)	S3 (8)	S4 (12)
			S2 (4)		
M1 (0)	X1 (Coco peat)	0.19 ± 0.04np	0.36 ± 0.06lp	1.3 ± 0.93ae	0.66 ± 0.05hn
	X2 (Coco peat + perlite)	0.56 ± 0.10ip	1.55 ± 0.93 ab	1.7a	1.42 ± 0.54ad
	X3 (Palm)	0.51 ± 0.1ip	1.3ae	0.48 ± 0.03kp	1.5ac
	X4 (Palm + perlite)	0.54 ± 0.06ip	0.21 ± 0.04np	1.05 ± 0.93ci	0.74 ± 0.05gl
M2 (100)	X1 (Coco peat)	0.55 ± 0.04jp	1.2 ± bg	0.31 ± 0.05lp	0.73 ± 0.03 gm
	X2 (Coco peat + perlite)	0.93 ± 0.04dk	1.51 ± 0.54ac	1.32 ± 0.47ae	1.23af
	X3 (Palm)	1.1bh	1.55 ± 0.93 ab	1.2 ± bg	1.23af
	X4 (Palm + perlite)	0.30 ± 0.05lp	0.75 ± 0.04 fl	1.5ac	1.4ad
M3 (200)	X1 (Coco peat)	0.62 ± 0.03ho	1.5ac	1.27ae	1.3ae
	X2 (Coco peat + perlite)	0.23 ± 0.05mp	0.28 ± 0.05lp	1.3ae	0.11 ± 0.05p
	X3 (Palm)	0.45kp	1.2bg	1.17bg	0.17np
	X4 (Palm + perlite)	0.87 ± 0.03ek	1.2bg	0.17np	1.41ad
M4 (300)	X1 (Coco peat)	1.1 ± bh	1.5ac	0.52 ± 0.05gp	0.23 ± 0.05np
			0.62		
	X2 (Coco peat + perlite)	0.27 ± 0.05lp	0.62 ± 0.03ho	0.52 ± 0.05gp	0.15 ± 0.05op
	X3 (Palm)	0.98 ± 0.05dj	0.38 ± 0.04lp	0.61 ± 0.06hp	0.26 ± 0.02lp
	X4 (Palm + perlite)	0.18 ± 0.02np	0.32 ± 0.04lp	0.63 ± 0.08ho	0.28 ± 0.05lp

Means followed by different letters are significantly different using Duncan's multiple range test at P = 0.05.

Table 6
Analysis of variance indicating the effects of different experimental treatments on the determined parameters.

S.V.	d.f.	Fresh weight	Dry weight	Menthol	Menthone	Chlorophyll	Proline
Rep.	1	17372523.5**	432630.2**	106183.39**	13790.5**	194.15**	43052.93*
Magnetic field	3	54399.06**	654.35**	109.9**	38.03**	289.29**	768.02**
Salinity (S)	3	912971.81**	24722.7**	43.4**	39.84**	1132.45**	88.28**
Medium (X)	3	421531.58**	8195.48**	484.93**	43.17**	890.23**	82.03**
M x S	9	15366.11**	316.99**	90.68**	144.27**	95.15**	302.1**
X x S	9	7379.94**	195.77**	106.14**	68.96**	214.23**	183.41**
X x M	9	6908.47**	133.65*	74.14**	89.97**	120.95**	399.53**
X x M x S	27	5322.66**	257.45**	106.98**	81.78**	253.38**	171.86**
Error	128	1457.68	54.54	0.111	0.071	60.51	7.14

S.V.: source of variation, d.f.: degree of freedom, Rep.: replicates, n.s., *, **; not significant, significant at 5 and 1% of probability, respectively.

magnetic field. El-Zawily et al. (2019) indicated that such an interaction effect is due to the positive effects of magnetic field on the reduction of Na toxicity at the cellular level by reducing the absorption of Na + by plant cells. Accordingly, it is speculated that magnetic field can alleviate the stress of salinity on pepper mint growth and biochemical properties by regulating the concentration of cellular Na+. The other positive effects of magnetic field on the alleviation of salinity stress may be due to affecting water chemical and electrical properties. The effects of magnetic field on water properties have been indicated by different research. Due to the production of magnetic field by an electrical field, the treatment can also affect the electrical properties of water including the electrical properties of the ions affecting water properties and its utilization by plant. For example, Kadhim and Al-Rufaye (2018) found that the higher levels of magnetic field resulted in the less increase of water pH and electrical conductivity, indicating they may be more suitable for the treatment of ground water. Aghamir et al. (2016) found that the use of magnetized salty water increased seed germination and seedling growth, which can be due to its effects on the enhancement of seed and seedling biochemical processes.

The effects of magnetic field on water properties are functions of exposure time, magnet type, intensity and polarity of the magnetic source. When water is subjected to a magnetic field the alterations in the molecular arrangement of water may change the following: 1) water boiling point, 2) viscosity, 3) dielectric constant, 4) the cluster structure of hydrogen bonds and their magnetic interactions, 5) the polarity of water molecules, 6) the amount of evaporation, 7) specific heat, 8) the entropy of water molecules, 9) more stability of water, and 10) less molecular energy and higher activation energy (Cai et al., 2009; da Silva and Dobránszki, 2014; Wang et al., 2018). Such alterations in water properties may affect plant water behavior and its subsequent growth and yield production. For example, easier and more efficient water and nutrient uptake, in magnetized salty water may increase plant growth and yield production (El-Zawily et al., 2019). One interesting effect of magnetized water on the properties of salty water may be by reducing the EC of the water, which is mainly due to the decreased concentrations of Na+ and Cl- (Hachicha et al., 2018) increasing the efficiency of salty water.

Hasan et al. (2019) investigated the effects of magnetic field on the growth of *Moringa* species under drought stress. similar to our results they found while drought stress decreased plant growth, chlorophyll content and nutrient uptake, the use of magnetized water alleviated the stress by enhancing such parameters including the reduction of plant Na+ and hence Na+/K+. The authors indicated that the increased cell division and cell expansion may be the main reasons for the improved plant growth irrigated with magnetized water. Another reason can also be the increased rate of photosynthesis, due to the increased rate of chlorophyll similar to our results. They also found that plant relative water content decreased under drought stress, however, magnetized water increased it and alleviated the stress. Magnetized water also increased plant water efficiency, stomatal conductance, rate of transpiration, and water vapor deficit under drought stress.

Our results indicated that with increasing the level of salinity the increased level of magnetic field was more effective on the alleviation of stress and the 300 mT treatment was the optimal one, which is similar to the results by Wang et al. (2018). The increased concentration of menthol and menthone by the magnetic field under saline conditions can greatly enhance the medicinal values of peppermint. This can be, as mentioned earlier, due to the higher uptake of water and nutrients, which can for example improve the enzymatic pathways resulting in the biosynthesis of such biochemicals, by peppermint subjected to the magnetic field.

However, another interesting result related to this research is that the use of magnetic field did not increase proline concentration compared with the control level. Although research has indicated that magnetic field may increase the rate of protein in plant (da Silva and Dobránszki, 2014), the amount of this specific amino acid was not increased by the magnetic field under salt stress. This may be because roots are the center of salt balance in plants and under saline conditions the salt ions are first absorbed by the roots, resulting in the movement of proline to the roots to adjust the osmotic potential.

5. Conclusion

The use of modern techniques, which may enhance the efficiency of salty water for plant use and crop production, is of utmost importance, mainly due to the restriction of water sources. The effects of magnetized salty water on peppermint growth and biochemical properties indicated that it is possible to enhance peppermint growth and biochemical properties under salinity stress using magnetic field. Although there was some effect of growth medium on plant growth and biochemical properties under salt stress, more investigation in this respect is required. Some interesting results of this experiment indicated that it is possible to enhance the medicinal value of peppermint under salinity using magnetic field as the concentration of menthol and menthone significantly increased under salinity stress by the magnetic field treatment. With increasing the level of salinity, the optimum rate of magnetic field (300 mT) was required to alleviate the stress. One of the main reasons for the increased plant growth using magnetized salty water is the increased concentration of chlorophyll, which can enhance the process of photosynthesis. Because of the role of the roots, which adjust the osmotic potential of plant during the uptake of slat ions, more proline may be directed to the roots, and accordingly less proline may be directed to the leaves, and the magnetic field may not increase proline concentration. The costs of increasing the level of magnetic field is not much, and they are certainly sustainable approaches, because they are safe and economically and environmentally friendly, and the costs of increasing the magnetic field is much less than the costs of yield reduction under salt stress. It is possible to increase peppermint growth and enhance its biochemical properties under salinity stress using magnetic field.

Authors statement

All authors contributed equally to the manuscript.

Declaration of competing interest

The authors declare they do not have any conflict of interest.

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Appendix A. Supplementary data

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